1290048

**Atlantic Richfield Company**

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December 13, 2013

***VIA EMAIL AND HAND DELIVERY***

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
US EPA Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

**Subject: Solids Repository Engineering Design and Operations Plan**
**Rico-Argentine Mine Site – Rico Tunnels**
**Operable Unit OU01 Rico, Colorado**

Dear Mr. Way,

A digital file in PDF format of the Solids Repository Engineering Design and Operations Plan (EDOP), Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01 Rico, Colorado, dated December 13, 2013, is being submitted to you today via email. Three (3) hard copies of the report will also be hand-delivered to your office no later than December 16, 2013.

Atlantic Richfield Company (AR) is submitting this report responsive to requirements in Task C of the Removal Action Work Plan accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, Colorado, U.S. EPA Region 8, Docket No. CERCLA-08-2011-0005.

If you have any questions, please feel free to contact me at (951) 265-4277.

Sincerely,

Anthony R. Brown
Project Manager
Atlantic Richfield Company

cc: Ronald Halsey, Atlantic Richfield Company (via e-mail)
Terry Moore, Atlantic Richfield Company (via e-mail)
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Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
AECOM
Denver, CO
60306858.020
December 2013

# Solids Repository Engineering Design and Operations Plan

# Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU1
# Rico, Colorado

Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
AECOM
Denver, CO
60306858.020
December 2013

# Solids Repository Engineering Design and Operations Plan

# Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01
# Rico, Colorado


Prepared By Elliott D. Drumright, PE
Senior Geotechnical Engineer

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Released By Thomas M. Kreutz, PE
Project Manager

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# List of Acronyms

| | |
|---|---|
| AECI | Anderson Engineering Company, Inc. |
| AECOM | AECOM Technical Services, Inc. |
| amsl | above mean sea level |
| AR | Atlantic Richfield Company |
| ASTM | American Society for Testing and Materials |
| bgs | below ground surface |
| CD | Certificate of Designation |
| CDPHE | Colorado Department of Public Health and Environment |
| CERCLA | Comprehensive Environmental Response Compensation and Liability Act |
| CHDPE | corrugated high density polyethylene |
| cm/sec | centimeters per second |
| CPT | Cone Penetrometer Test |
| CQAPP | Construction Quality Assurance Project Plan |
| cy | cubic yard |
| EDOP | Engineering Design and Operations Plan |
| HDPE | high density polyethylene |
| HELP | Hydrological Evaluation of Landfill Performance |
| HMWMD | Hazardous Materials and Waste Management Division |
| HPGA | horizontal peak ground acceleration |
| IDF | Interim Drying Facility |
| NCRS | Natural Resources Conservation Services |
| pcf | pounds per cubic foot |
| PDF | Permanent Drying Facility |
| psf | pounds per square foot |
| PVC | polyvinyl chloride |
| QAPP | Quality Assurance Project Plan |
| RAWP | Removal Action Work Plan |
| RCRA | Resource Conservation and Recovery Act |
| ReMi | Refraction Microtremor |
| RGS | Rio Grande Southern Railroad |
| SAP | Sampling and Analysis Plan |
| SEH | Short Elliott Hendrickson Inc. |
| SPT | Standard Penetration Test |
| SWMMP | Solid Waste and Materials Management Program |
| TCLP | Toxicity Characteristic Leaching Procedure |
| UAO | Unilateral Administrative Order |
| US EPA | United States Environmental Protection Agency |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |

# 1.0 Introduction

This Engineering Design and Operations Plan (EDOP) has been prepared by AECOM Technical Services, Inc. (AECOM) on behalf of Atlantic Richfield Company (AR) in support of an Application for Certificate of Designation (CD) for a Solids Repository to be constructed at the Rico-Argentine Mine Site (also known as the St. Louis Ponds Site) near the Town of Rico in Dolores County, Colorado (see Figure 1).

The proposed Solids Repository is located within the Ponds/St. Louis Adit area of the Rico – Argentine Mine Site, an area of historic mining and mineral processing as described in Section 3.0 (see Figure 2). As discussed in more detail in Section 4.4, the Solids Repository to be constructed in accordance with this EDOP will be adjacent to the existing mine water treatment ponds system that will be upgraded or replaced by an alternative treatment system under the Unilateral Administrative Order for Removal Action (UAO) referenced in the following paragraph.

This EDOP has been prepared pursuant to the United States Environmental Protection Agency (US EPA) UAO, US EPA Region 8, CERCLA Docket No. CERCLA-08 2011-0005 (US EPA, 2011a) and accompanying Removal Action Work Plan, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU1, Rico, Colorado dated March 9, 2011 Removal Action Work Plan (RAWP) (US EPA, 2011b). The Solids Repository will also be designed, constructed and operated to comply with the Colorado Department of Public Health and Environment (CDPHE) Solid Waste and Materials Management Program (SWMMP)/Hazardous Materials and Waste Management Division (HMWMD) requirements of 6 CCR 1007-2, PART 1 – Regulations pertaining to Solid Waste Sites and Facilities (Last amended February 19, 2013, effective April 14, 2013), with appropriate accommodation of site-specific conditions.

The project advances the overall site strategy by providing a repository for the existing and potential future mine water treatment solids (and potentially other mining or mineral processing by-products on site) while satisfying the following criteria:

- Adequate storage (airspace) for present and future solids and/or other by-products assuming a 50-year operating period.
- Safe location with regards to both access, and potential groundwater intrusion and contamination.
- Long-term geotechnical stability and erosion protection.

This EDOP is organized as follows:

- Site history and general facility information/description, identification of the owner and operator of the proposed Solids Repository, and projected personnel/equipment [Section 1.0]
- Evaluation of location restrictions and site standards [Section 2.0]
- Characterization of the geologic and hydrogeologic conditions [Section 3.0]
- Design requirements for the Solids Repository [Section 4.0]

- Operational requirements for the Solids Repository [Section 5.0]
- Development of a Closure Plan [Section 6.0]
- Development of a Post-Closure Plan [Section 7.0]
- Final Engineering and Hydrogeologic Approvals [Section 8.0]
- References used in the preparation of the EDOP [Section 9.0]

## 1.1 Site History

The history of the proposed Solids Repository site area is dominated by historic mining/mineral processing-related activity and the associated narrow gauge railroading. Mining in the Rico area (known as the Pioneer District) began with the staking of the first claim on lower Silver Creek in 1869 and continued sporadically for more than a century. Important references for the historical information related to mining in the Pioneer District (including the St. Louis Ponds site) include Ransome (1901) for the early history of operations, and McKnight (1974) for the later history. Other references are noted in the text where appropriate.

The Rio Grande Southern Railroad (RGS) connecting Ridgeway to the north and Durango to the south arrived in Rico in 1891. The RGS provided freight and passenger service to Rico and the Pioneer District until the line was abandoned in 1951.

Mining at the St. Louis Ponds site (within which the proposed Solids Repository site lies) began with the driving of the St. Louis Tunnel by the St. Louis Smelting & Refining Co. (a division of National Lead Company, presently N.L. Industries) during 1930-1931, to explore for deep ore horizons beneath CHC Hill. A major crosscut to the north connected the St. Louis Tunnel to the active Mountain Springs mine also under CHC Hill. The St. Louis Ponds System (referred to herein as the Ponds System) is believed to have been initially constructed about this same time, followed by subsequent modifications and additions.

During 1955 a sulfuric acid plant was constructed and began operation at the St. Louis Ponds site.

Rico Argentine Mining Company ceased most mining operations in 1971. During 1973-1975, Rico Argentine Mining Company operated a leach heap just northwest of the proposed Solids Repository site, immediately adjacent to the Dolores River. All mining activities by Rico Argentine Mining Company ended in 1976-77, and exploration work ceased in 1978.

The Anaconda Company entered an Agreement in June 1978 with Rico Argentine Mining Company (by that time a division of Crystal Exploration and Production Company) under which The Anaconda Company obtained possession of Rico Argentine Mining Company's mineral properties in the Rico vicinity for exploration purposes. The Anaconda Company also acquired an option to purchase such properties under that Agreement. Pursuant to a June 1980 Letter Agreement and an August 1980 Closing Agreement with Crystal Exploration and Production Company, a subsidiary of Crystal Oil Company, The Anaconda Company acquired Rico Argentine Mining Company's surface and mineral properties in the Rico area.

The Anaconda Company conducted exploration drilling at a number of sites from 1980 to 1983, including at the St. Louis Ponds site, resulting in discovery of a deep molybdenum ore body beneath Silver Creek. However, development of this deposit was uneconomical, and no further exploration or

development occurred. Consequently, the Anaconda Company never produced ore or operated milling facilities in Rico. During this same time period, The Anaconda Company performed hazard reduction and environmental clean-up activities in the District, including at the St. Louis Ponds site.

As part of the acquisition of Rico Argentine Mining Company's surface and mineral properties in 1980, a pre-existing NPDES permit (No. CO-0029793) was transferred to The Anaconda Company. In 1984 The Anaconda Company began operation of a new slaked-lime addition plant to treat mine water discharge from the St. Louis Tunnel as it entered the Ponds System. Between 1984 and 1995, slaked lime was added to the tunnel discharge to improve water treatment and solids removal.

The acid plant and associated structures at the St. Louis Ponds site were demolished, and the site was regraded, capped with a soil cover, and revegetated during 1985-1986. Other miscellaneous grading has apparently occurred at various locations in the northern portion of the St. Louis Ponds site.

AR, a successor to The Anaconda Company, sold their Rico properties, including the St. Louis Ponds site, to Rico Development Corporation under a Purchase and Sale Agreement executed in May 1988. While owned by Rico Development Corporation, it is believed that additional borrow excavation over the portal area of the tunnel in about 1996 resulted in local collapse of the tunnel roof and walls.

Rico Development Corporation then sold/optioned their property holdings, including the St. Louis Ponds site, to others in April 1994. In 2001, dispersed surface flows resulting from the collapse were collected into a common channel, diverted through a Parshall flume, and re-routed to Pond 18 by AR.

AR received the UAO on March 17, 2011. The effective date was later modified to April 18, 2011. Task C of the accompanying RAWP requires the "Design and Construction of a Solids Repository" at the site and requires submittal of this EDOP to the US EPA. The US EPA is not requiring that a permit (or CD) be obtained for the Solids Repository, consistent with Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) response actions; however, US EPA recognizes that AR intends to obtain a CD for the Solids Repository and has provided a schedule to accommodate the permit review process. The current US EPA schedule requires the initial phase of repository construction commence in June 2014 with construction completing in October 2014.

## 1.2 Facility Location

The proposed Solids Repository site is located within the Ponds/St. Louis Adit area of the Rico – Argentine Mine Site, approximately 0.75 miles north of the northern boundary of the Town of Rico in Dolores County, Colorado (see Figure 1). The site lies at the base of Telescope Mountain approximately 500 feet east of the Dolores River. This location is in the NW1/4 of the NW1/4 of Section 25, T40N, R11W within the United States Geological Survey (USGS) Rico 7.5-minute Topographic Quadrangle.

The proposed site is near the source of materials to be placed in the Solids Repository. The Solids Repository site boundary lies wholly within the St. Louis Ponds site as shown on Figure 2, an area of historic mining, ore processing, and local disposal of waste rock and minor tailings. The Phase 1 area of the proposed Solids Repository site is approximately 1.5 acres and the overall area at full build-out is approximately 7.5 acres. The Solids Repository site is immediately up-gradient (east) of the existing Ponds System, an area which has historically been used to provided treatment of metals-bearing, surface water discharges from the St. Louis Tunnel (sometimes referred to as the St. Louis adit). The proposed site meets applicable site suitability criteria as discussed in Section 2.0, given the historic mining related impacts to the soils, surface water, and groundwater at the St. Louis Ponds site.

Existing land use at the proposed Solids Repository site is open space, as is that of the U.S. Forest Service land to the east. A Soil Lead Repository is located north of the proposed site and the adjacent land to the west and south of the proposed site is comprised of settling ponds used for treatment of water discharged from the St. Louis Tunnel. Telescope Mountain lies to the east. Long-term, future land use of the area around the Solids Repository is intended to be used for management and disposal of waste from past mining and minerals processing activities, as well as potentially compatible light industrial uses in adjacent flat areas.

The facilities physical address is:

Atlantic Richfield Company
13100 St Louis Road
Rico, CO 81332

Property owners within ½ mile of the Solids Repository boundary as of April 1, 2013 are listed in Table 1.

### 1.3 Applicant

AR is the applicant for the CD supported by this EDOP. AR will perform design and construction of the proposed Solids Repository. Contact information for Atlantic Richfield Company follows:

Atlantic Richfield Company
Anthony R. Brown, Project Manager
4 Centerpointe Drive, 4-435
La Palma, CA 90623
714.228.6770 (direct)

### 1.4 Facility Description

The Solids Repository will provide a permanent, on-site, disposal area for:

- Existing precipitated solids (generated during prior lime addition [as discussed in Section 1.1 above] and subsequent natural precipitation) from upper ponds (18, 15, 14, 13, 12, and 11);
- Solids previously removed from several of these ponds currently being stored in an Interim Drying Facility (IDF); and
- Future solids generated from either a lime-addition treatment system, or depleted matrix from operation of a wetlands treatment system, or possibly another technology, whichever is selected pursuant to the RAWP for mine water treatment at the Site.

At full build-out, the recommended Solids Repository location would provide additional and/or alternative capacity for disposal of other existing by-products, including calcines (from prior sulfuric acid production from pyrite at the Site) up to the planned maximum capacity of 365,000 cubic yards (cy). This capacity would accommodate all existing and estimated future by-products (excluding waste rock) assuming wetlands or lime treatment system for a 50-year operating period. Quantities are further discussed in Section 4.2. The Solids Repository will be designed, constructed and operated to comply with the requirements of the US EPA RAWP, CDPHE SWMMP/HMWMD and Dolores County including acquisition of a CD.

The area beneath The Solids Repository will be lined to capture leachate. The leachate will be routed initially through the St. Louis Ponds, but ultimately through the selected, final, water treatment system, prior to discharge to the Dolores River. The Solids Repository surface will be graded and covered with an interim cover while in operation. For final closure, the Solids Repository will be graded, capped with a liner, plant growth media, and vegetated. Hours of operation, as well as the number, classification, and job descriptions of projected personnel and the number, description, and uses of all equipment are provided in Section 5.0.

The proposed Solids Repository site is accessed via approximately 0.75 mile of an existing, maintained dirt road extending east and north from Colorado State Highway 145. Highway 145 provides access from Telluride (27 road miles) and Montrose (86 road miles via US Highway 550 and then State Highway 62) to the north and from Cortez (50 road miles) and Durango (92 road miles via US Highway 160) to the south.

# 2.0 Location Restrictions

The proposed Solids Repository site has been evaluated in terms of the location restrictions and site standards set forth in Section 3.1 of the Regulations pertaining to Solid Waste Sites and Facilities, as discussed below.

## 2.1 Proximity to Airports

This criterion is not applicable to the proposed Solids Repository site given that the repository will not be accepting putrescible wastes and thus will not pose a bird hazard to aircraft. Furthermore, the site is not located within 5 miles of any airport runway used by turbojet or piston-type aircraft.

## 2.2 Wetlands

There are no wetland features within the footprint of the proposed Solids Repository site based on a review of the U. S. Fish and Wildlife Service National Wetlands Inventory. The lowest, existing elevation within the Solids Repository footprint is approximately 40 to 50 feet above the Dolores River at its closest approach.

## 2.3 Faults and Seismicity

The proposed Solids Repository site is not located in a “seismic impact zone” as defined in the solid waste regulations. There are no known active or potentially active faults at or in the near vicinity of the Solids Repository site. Historic seismicity at the site is low. Potential future seismicity has been accommodated in the design of the Solids Repository (see related discussion in Section 3.1 and Section 4.6.3).

## 2.4 Topography / Unstable Areas.

The St. Louis Ponds and proposed Solids Repository site lie within the southwestern portion of the San Juan Mountains, in part on the lowermost, west-facing, colluvial slope of CHC Hill (at the base of 12,208 foot Telescope Mountain) and in part on the adjacent east edge of the original Dolores River floodplain (see discussion of site hydrology in Section 3.2). The current surface grade at the Solids Repository site ranges from approximately 8,840 to 8,860 feet above mean sea level (amsl). The existing ground at the site ranges from essentially flat lying to sloping at a maximum of approximately 2H:1V, and overall slopes downhill to the west. The lowest existing elevation at the Phase I portion of the repository site is approximately 40 to 50 feet above the typical elevation of the Dolores River, and 20-30 feet above the river in the area of the future build-out. The repository site is protected from flooding by a recently upgraded riprap-lined dike along the east bank of the Dolores River. The 100-year flood elevation on the west slope of the dike is at El. 8818.5 at closest proximity to the final repository footprint (opposite Pond 15).

The existing ground surface has been altered by grading (both excavation and filling) over most of the site area. The major grading is believed to have occurred as part of railroad construction in the late 19th century and active mining and mineral processing operations, mainly in the first half of the 20th century. Some additional grading is known to have occurred more recently, including grading to provide access roads for subsurface investigation activities in 2011-13.

The proposed Solids Repository site is not located in a geologically unstable area. The site location has been chosen to be outside the mapped limits of a large landslide mass on the lower slope of CHC Hill, which is located approximately 400 feet to the north of the proposed Solids Repository site at its closest approach. Further discussion of geologic hazards at the site is provided in Section 3.1.

A recent avalanche hazard assessment for the Rico-Argentine Mine Site shows that there are several, historically active avalanche chutes on the lower slopes of the CHC Hill (and adjoining NB Hill to the South). The proposed Solids Repository site is located within a known avalanche path; however avalanches typically occur in the San Juan Mountains from November through May. Both construction of the Solids Repository and operation of the facility will occur outside of this time period when avalanches could pose a threat to crews working within the facility. The only likely potential impact to the proposed Solids Repository from activation of any of these known avalanche chutes would be temporary blocking of access to the facility on the dirt road from Highway 145. Site access is not likely to be required during the winter months. Since it is not anticipated as necessary to regularly access the Solids Repository during the winter months, this hazard is not regarded as significant.

## 2.5 Prevailing Winds

Wind is not anticipated as a significant issue at the proposed Solids Repository site due to the nature of the waste to be deposited (i.e., primarily precipitation solids, free of litter). Protection against dust dispersal (if/as necessary) will be addressed, as necessary, by operational practices during the active life of the facility and by the final cover during the closure and post-closure periods (see Sections 5.0, 6.0, and 7.0, for additional discussion).

## 2.6 Flood plain

The proposed Solids Repository site lies within the Dolores River drainage basin at a location approximately 300 feet east of the river (at Full Build-out) but outside the 100-year flood plain as shown on Figure 3. The site was removed from the 100-year flood plain by construction during the 1970s. Further upgrades during 2011, which included a riprap-armored dike, provided a minimum of 3 feet of freeboard to contain the 100-year flood on the Dolores River adjacent to the Solids Repository site.

## 2.7 Waste Isolation

Suitable isolation of solid waste from exposure to the public and environment will be provided by:

- Location of the Solids Repository (as described in this Section 2.0);
- Liner and final cover designs (as described in Sections 4.0 and 6.0, respectively); and
- Management practices to be implemented during active operations and the post-closure period (as described in Sections 5.0 and 7.0, respectively).

## 2.8 Surface water

The precipitation catchment area up-gradient of the site is estimated to be approximately 26 acres. The run-off from this catchment area will be addressed by site run-on controls as discussed in Section 4.0. Surface water features in the vicinity of the Solids Repository are discussed in Section 3.3. The Solids Repository will not place wastes into surface water.

## 2.9 Groundwater

The Solids Repository will not place wastes below or into groundwater. The maximum recorded groundwater elevation within site monitoring wells MW-101 (8818.6 feet amsl), MW-102 (8817.9 feet amsl) and GW-7 (8825.1 feet amsl) are all 5 feet or more below the planned base elevation of the Phase 1 cell of the Solids Repository (8830 feet amsl). The locations of these monitoring wells are shown on Drawing G-140 (Appendix A). Considering the planned liner and leachate collection systems to be provided at the base of the repository, the lowest elevation of the repository is considered to be sufficiently above the groundwater table to avoid interference with these systems. Regardless, long-term groundwater monitoring is planned for the facility.

# 3.0 Geologic and Hydrogeologic Conditions

## 3.1 Geology

The geology of the proposed Solids Repository is described below and depicted in plan and section in Figure 4 and Figures 5A and 5B, respectively. Logs of the borings and test pits and profiles of refraction microtremor (ReMi) geophysical surveys are included in Appendix B. Results of geotechnical testing are included in Table 2.

**Bedrock**. The bedrock underlying the site at varying depths is comprised mainly of the Middle Pennsylvanian-age (240-250 million years old), Lower member of the Hermosa Formation, and local volcanic intrusions of Late Cretaceous to Lower Tertiary-age (about 65 million years old) hornblende latite porphyry.

The estimated stratigraphic thickness of this unit is greater than 880 feet. Although only locally exposed in the slope above the Solids Repository site, some additional information on the nature of the Hermosa Formation is available from unpublished, archival, geologic logs of the St. Louis tunnel, and published information on the Rico-Argentine mine complex (McKnight, 1974). The tunnel logs show the presence of several intervals of younger, hornblende, latite porphyry that has intruded the older Hermosa sedimentary rocks. Areas of outcropping hornblende, latite porphyry are locally present on the lower slope of CHC Hill due east of the Solids Repository site.

The bedrock is only of indirect significance to the proposed siting and design of the Solids Repository, being the primary source of the generally thick cover of talus/slopewash (or colluvial) soils, and a minor contributor to the generally shallower alluvial deposits. As shown on Figures 5A and 5B, the estimated depth to bedrock under any portion of the Solids Repository is everywhere greater than 100 feet. In the Phase I area of the proposed Solids Repository, Borings SSR-101 and -102 (near the starter dike) encountered what was interpreted as bedrock (weathered sandstone) at 142 to 136 feet below grade, respectively. Borings SSR-103 and -104 (upper east hillside) encountered apparent bedrock at 86 to 102 feet below grade, respectively.

**Morphology**. The Rico area lies at the center of a geologically young structural uplift that occurred about 65 million years ago during the Laramide Orogeny. A structural dome about 10 miles across and with a vertical relief of over a mile is centered over the south end of the St. Louis Ponds site. This is evidenced by the exposure of very old bedrock (Precambrian-age greenstone) in the lower hill slopes on both sides of the Dolores River in the vicinity of the Highway 145 Bridge. Development of this dome was accompanied by extensive faulting that variably offset and fractured all the older major bedrock units, including the Lower member of the Hermosa Formation. It was during this time that the hornblende, latite porphyry intruded the fractured Hermosa rocks.

A much more recent episode of structural and hydrothermal activity occurred in the Rico area about 3-5 million years ago. During that time, many of the older bedrock faults were reactivated and ore-bearing hydrothermal fluids moved into the fractured rock, locally resulting in the mineralization that characterizes the Pioneer Mining District.

The major structural features are the shallow (about 5-15º) bedding dips to the west-southwest in the Hermosa Formation, and a series of small to large bedrock faults ranging from a few feet to over 2,000

feet of offset. The closest, large, bedrock faults are the east-west trending Nellie Bly Fault that lies beneath the southern portion of the St. Louis Ponds site about 1,200 feet south of the Solids Repository site, and the northeast trending Princeton Fault crossing CHC Hill about 1,200 feet southeast at closest approach to the Solids Repository site. Neither of these, nor any of the numerous smaller bedrock faults in the vicinity, are active (i.e., capable of generating earthquakes) and thus are of no particular consequence to the Solids Repository siting or design.

**Geologic Hazards**. The proposed Solids Repository site is located specifically to avoid known geologic hazards in the North Rico (St. Louis Ponds site); those hazards including a large-scale, old landslide and local underground mine workings. These landslide and underground workings are described below.

A major landslide was mapped by McKnight (1974) and confirmed by subsequent mapping by AR on the hill slope several hundred feet to the north of the proposed Solids Repository site and the St. Louis Tunnel. This feature is interpreted to have developed in colluvium and/or highly weathered and fractured sedimentary bedrock on the lower slopes of CHC Hill. Ransome (1901) concluded that the slide debris was up to several hundred feet thick. Erosional undercutting at the base of CHC Hill by a much larger Dolores River flow than at present could have triggered the sliding. Use of this material, which could be taken from the potential borrow areas along the base of the slopes north of the Solids Repository, would need to be done with caution to avoid locally re-activating this landslide.

The only, known, underground mine workings in the immediate vicinity of the Solids Repository site are those associated with the St. Louis Tunnel. Borrowing of colluvial soils over the top of the tunnel, which occurred sometime in the mid-1990's, was the apparent cause of the collapse of several hundred lineal feet of the timber-supported reach of the tunnel. This area, which is immediately north of the Solids Repository site, will not be further disturbed by Solids Repository site construction or operations and is not judged to pose a hazard to the Solids Repository itself.

**Faulting and Seismicity**. Available data on geologically young faulting and historic seismicity in the region around the proposed Solids Repository site are provided in Appendix C. The closest, mapped potentially active fault zone, (the San Miguel Canyon Faults) is approximately 22 miles (35 km) north-northwest of the proposed Solids Repository site. These faults, interpreted as active during the Quaternary Period, apparently are related to salt tectonism (movement of deep-seated salt deposits). A M5 event is the estimated, maximum credible earthquake for this fault zone. The next closest potentially active fault, the Ridgway Fault, is approximately 30 miles due north of the site. The Ridgway Fault is interpreted to be potentially active, and is spatially associated with microseismicity that might have been caused by the filling of Ridgway Reservoir. The maximum credible earthquake inferred for this fault is M6.75. The source of the above information is: http://earthquake.usgs.gov/hazards/qfaults/map/ (USGS, 2013a).

The largest, recorded earthquake in the region was the 1994, M4.6 (4.4 per USGS) Norwood event (see map and associated data in Appendix C; see also website for "geosurvey" in Section 11.0). Although the Norwood event occurred close to the Ridgway Fault, detailed analysis suggests that it did not occur on that fault, but rather on a structure nearby that has not been identified at the surface. The epicenter of this event was approximately 30 miles north of Rico. Given this distance, no damage would have been expected to have occurred even to very susceptible structures in Rico, although the earthquake may have been felt by some of the residents in the area. The next largest event, (and the only other known, historic event in the region larger than >M4,) was the M4.3 Paradox Valley earthquake, which registered as an M4.3. It is suspected that the event was triggered by deep well injection. That event was located approximately 62 miles northwest of Rico. Known, historic, seismicity in the more immediate vicinity of the proposed Solids Repository site has been minor, with the closest, recorded event an M2.5 earthquake. That event occurred in 1987 and is thought to have been within

approximately three (3) miles of the site. The exact location of small events is difficult to ascertain because of the wide spacing of seismographs in the region. Note, however, the location error of such small events is typically more than 10-15 miles given the wide spacing of recording seismographs in the region.

An estimate of the likelihood of various levels of seismic shaking at the Solids Repository site from future earthquakes in the region is available from the U.S. Geological Survey earthquake hazards website (http://geohazards.usgs.gov/hazardtool/) (USGS, 2013b). A Seismic Hazard Curve presenting the Peak Ground Accelerations for a range of return periods derived from the data available on the USGS website has been prepared and is presented in Appendix C. Given the nature of the mining/milling by-products to be disposed at the proposed Solids Repository, a design criterion of horizontal, peak, ground acceleration (HPGA) with a probability of exceedance of 10 percent in 50 years is appropriate. This equates to a return period of the design ground shaking of about 500 years. At this level of probability, the predicted HPGA appropriate for use in design of the Solids Repository is 0.06g (see related discussion in Section 4.6.3).

**Unconsolidated Deposits**. Unconsolidated deposits in the immediate vicinity of the proposed Solids Repository include:

- Colluvium (including talus/slopewash)
- Alluvium
- Mining/processing-related waste materials (waste rock from construction of the St. Louis Tunnel and cross-cuts; precipitated solids from lime treatment of St. Louis Tunnel discharges; and calcines from roasting of pyrite to produce sulfuric acid)
- Railroad-related materials(predominantly local colluvium used as sidehill fills)
- Fill (pond embankments and miscellaneous fill to shape/level ground on access roads and at prior mine and mill building and yard sites)

These materials are described here, with more detailed information relevant to the Solids Repository site presented in the following subsection (Foundation Conditions). Subsurface information on these deposits was derived primarily from previous site investigations by Dames and Moore (1981), Colorado Department of Public Health and Environment (CDPHE, 2003), Short Elliott Hendrickson Inc. (ca 2000-2002), and more recent investigations by AECOM (2011-2013).

Colluvium: These deposits are extensive and deep on most of the lower mountain slopes in the Rico area, including on CHC Hill at the St. Louis Ponds site. Formed by weathering and gravity movement of the typically fractured and altered bedrock, these deposits were penetrated by mine workings at various locations (including on CHC Hill). The mine maps indicate variable horizontal thicknesses up to a few hundred feet. The colluvium is comprised of a wide range of grain sizes from fines (silt/clay) to very large rock fragments, on the order of several feet in largest dimension. Crude sorting occurs due to the gravity movement. There is evidence in one of the deep borings just north of the Solids Repository site to suggest that local undercutting of the toe of CHC Hill resulted in a rockfall-type failure involving very large blocks of sedimentary rock up to 20 to 30 feet across.

Alluvium: These deposits are present underlying the relatively flat-bottomed Dolores River valley, and locally inter-fingering with the colluvium at the toe of CHC Hill as shown schematically on Figures 5A and 5B. The alluvium is comprised typically of sand and gravel, with variable silt and clay fraction, and abundant cobbles and even some boulders present locally (typically higher in the soil column). The

alluvium becomes more sandy (with significantly less gravel and cobbles) with increasing depth. Given the geologic/geomorphic environment, it is likely that the range of grain sizes include fine-grained overbank sandy silts/clays to very coarse channel deposits visible in the active river channel, with lenses of predominantly sand also to be expected.

The coarser-grained materials tend to be rounded to sub-rounded and generally hard and strong.

To date, the maximum depth of colluvium, alluvium, and local rockfall debris penetrated by the borings to date is 185 feet in Boring CHV-101D. This boring is just north of the Solids Repository site and adjacent to the collapsed reach of the St. Louis Tunnel. Ongoing interpretation ReMi surveys in that area suggest that bedrock may locally be as deep as about 250 feet.

Mining/Mineral Processing-Related Materials: The proposed Solids Repository lies within an area of mining and ore processing activities that occurred sporadically over a period of nearly 50 years. Waste rock, calcines, leach heap material, and mining/processing-related debris are known to exist at the St. Louis Ponds site. The locations of these materials are generally known based on historic maps and photographs, historic correspondence, the available logs of test pits, borings and wells, and on-site observations as described below.

Waste rock from the original driving and subsequent extension of the St. Louis Tunnel and cross-cuts was disposed locally in the immediate vicinity of the tunnel portal. The main waste rock dump is a sidehill deposit approximately 1,100 feet long, up to 350 feet wide, and up to an estimated 30 to 40 feet thick. A portion of the waste rock underlies the footprint of the proposed Solids Repository as shown on Figure 4.

Calcine residues (calcines) resulting from sulfuric acid production (derived from roasting pyrite ore to high temperatures) were placed in Ponds 15-19 down-gradient of the proposed Solids Repository (HRI, 1979), and are locally present in some of the lower ponds to the south. Based on available borings and soundings, these fine- to very fine-grained, silty sand deposits are variable in thickness and are known to be up to at least 23 feet thick in places. Extensive calcines are present under the future build-out area of the Solids Repository (in the former Ponds 16/17 area) as shown on Figures 5A and 5B.

Reject ore from the sulfuric acid operations was reported to remain in a pile on the north side of the old acid plant site just north of the existing Soil Lead Repository as of 1995 (ESA, 1995). None of the reject ores is known to directly underlie the Solids Repository site.

A prior leach heap approximately 500 feet northwest of the Solids Repository site reportedly contained gold-silver bearing mine dump material derived from Newman Hill east of the Town of Rico as of 1979 (CDM, 1979). This material is believed to have been crushed on site prior to placement in the heap and leached with cyanide. Subsequent grading has redistributed the material, apparently by hauling offsite and/or filling lower ground immediately to the north. At least some portions of the original liner under the heap are still present based on the logs of two borings at the prior heap location. None of these leach heap materials are known to directly underlie the proposed Solids Repository site.

In the 1980s and 1990s, various reclamation activities decommissioned mining and milling facilities and reclaimed much of the solid waste remaining at the site primarily by covering with local colluvial soils.

Railroad-Related Materials: The RGS mainline followed the lowermost slopes of CHC Hill north of Rico on a cut/fill alignment located above the historic floodplain of the Dolores River (McCoy, et al., 1996). The remnant portion of the original portal of the adjacent St. Louis Tunnel is located immediately

beneath the RGS mainline alignment. The prior railroad alignment passes directly through the footprint of the Phase I area of the proposed Solids Repository. Although portions of the railroad grade are visible, it is possible, (if not likely), that at least remnants of the original railroad fill and ballast are present at or near the surface. The fill would almost certainly have been derived from local grading of the underlying natural colluvium, and thus be indistinguishable from that parent material. The rails, ties and any high-quality ballast have long since been removed.

Fill: Relatively minor amounts of placed, but not necessarily controlled, and dumped fill are present at and in the vicinity of the Solids Repository site. These include remnants of sidehill fill along the now abandoned RGS railroad alignment at the base of CHC Hill (Phase I Solids Repository area), and embankments impounding the various ponds at the St. Louis Ponds site (including ponds 15 and 18 immediately west of the future Solids Repository build-out area).

## 3.2 Hydrology

**Surface Water Features.** The proposed Solids Repository lies within the Dolores River drainage basin at a location approximately 200 to 400 feet east of the river but outside the 100-year flood plain. Flow in the Dolores River in the vicinity of Rico averages approximately 131 cfs based on historical data (1951 to present) from USGS gage No. 09165000 DOLORES RIVER BELOW RICO, CO.

Surface drainage from the Solids Repository site is through and around a series of settling ponds, known as the St. Louis Ponds System, with eventual discharge to the Dolores River (see Figure 2). The Solids Repository site is south of and adjacent to the St. Louis Tunnel which has a collapsed reach at and for about 300 feet up-gradient of the portal. The tunnel is an active drain for surface infiltration for many of the interconnected underground mine workings within the historic Pioneer Mining District at Rico, and flows from the tunnel are highly influenced by precipitation in the Rico area. Discharges from the tunnel average approximately 1.7 cfs (750 gpm) with a range of approximately 0.18 to 4.9 cfs (80 to 2,200 gpm). The tunnel discharge flows through the St. Louis Ponds which lie west and south of the Solids Repository site. The active ponds have a total water surface area of approximately 14 acres.

The local drainage area above the Solids Repository site extends up the slope of CHC Hill to the west. The catchment area is approximately 26 acres compared to the Solids Repository footprint area of approximately 1.5 acres (Phase I) and approximately 7.5 acres (full build-out). Run-on control measures for the Solids Repository are discussed in Section 4.7.

Other perennial streams within a two-mile radius of the site include Silver Creek, which discharges to the Dolores River downstream of the site and within the Town of Rico, and Horse Creek and Marguerite Creek which discharge to the Dolores River upstream of the St. Louis Ponds site. These streams are shown on Figure 6.

**Surface Water Quality.** Effluent from the Solids Repository site, including leachate and runoff during operations, will initially be routed, together with St. Louis Tunnel discharge, initially to the existing St. Louis Ponds treatment system. These waters will eventually flow to a new water treatment system to be designed and operated pursuant to the Site UAO and RAWP.

**Groundwater.** Information on domestic wells within one mile of the site is limited. State records show the following wells within a mile radius of the site as shown on Figure 6:

- Location: SE1/4 of the SE1/4 of Section 23, T40N R11W – Horse Creek drainage basin at the Ranger Station; well is located up-gradient of, and on the opposite side of the Dolores River approximately 1,500 feet from the Solids Repository site; Well Permit Number 68951. The well

is a 5.5-inch steel casing. The depth of the well is 50 feet below ground surface (bgs) with the original static water level at 38 feet bgs. The well yield was estimated at 9 gpm.

- Location: NW1/4 of the SW1/4 of Section 25, T40N R11W – Dolores River basin; well is located down-gradient of, and on the opposite side of the Dolores River approximately one-half mile from the Solids Repository site. Well Permit Number 139391. The well is a 4-inch polyvinyl chloride (PVC) casing. The depth of the well is 70 feet bgs with the original static water level at 50 feet bgs. The well yield was estimated at 10 gpm.
- Location: NE1/4 of the SE1/4 of Section 23, T40N R11W – Horse Creek drainage basin; well is located up-gradient of, and on the opposite side of the Dolores River approximately one-half mile north of the Solids Repository site. Well Permit Number 90477-VE. Well construction details are not listed in the permit database.
- Location: NE1/4 of the SE1/4 of Section 23, T40N R11W – Horse Creek drainage basin; well is located up-gradient of, and on the opposite side of the Dolores River approximately one-half mile north of the Solids Repository site. Well Permit Number 158777. The casing construction is not listed in the permit database. The depth of the well is 160 feet bgs with the original static water level at 35 feet bgs. The well yield was estimated at 4 gpm.

Monitoring well locations as of the end of 2012 within the St. Louis Ponds site are shown on figures within the Sampling and Analysis Plan (SAP) for Surface Water and Groundwater (provided as Appendix D) and accompanying Quality Assurance Project Plan (QAPP) for Surface Water and Groundwater (provided as Appendix E). The relevant figures in the SAP are being updated with the locations of additional monitoring wells installed in the Fall 2013. A revised version of the SAP is anticipated to be completed during the first quarter of 2014 and will be available upon request in the first quarter of 2014. Ground elevations and water levels measured from 2002-2013 in various wells are presented in Table 3. Groundwater quality data from the July 2013 monthly sampling of selected monitoring wells in the immediate vicinity of the Solids Repository site are provided in Table 4.

**Aquifer.** An unconfined aquifer underlies the proposed solids repository. Based on monitoring well MW-101, the average, saturated thickness is approximately 135 feet (water table El. 8818 minus bedrock El. 8682). Based on a number of monitoring wells in the St. Louis Ponds area, the general groundwater flow direction in the St. Louis ponds area (including the proposed repository) is south-southwest, towards the Dolores River.

The saturated thickness of the aquifer is made up primarily of medium dense to dense, silty and clean sands, with isolated, silty gravel layers in the upper section from 30 to 60 feet. The overall porosity is estimated at 25-35%, and the hydraulic conductivity is estimated at $1 \times 10^{-3}$ centimeters per second (cm/sec).

With the groundwater gradient taken as the difference in total head between the water table under the repository (El. 8818) and the Dolores River (8794), over a distance of 1,000 feet from the center of the repository to the south-southwest (Dolores River), the Darcy velocity assuming a horizontal hydraulic conductivity of $1 \times 10^{-3}$ cm/sec, is about 0.07 ft/day. Over the 50-year design life of the repository, groundwater in the alluvial aquifer is estimated to travel 1,300 feet (0.25 miles).

**Flood plain**. The Solids Repository site is located outside of the Dolores River 100-year floodplain by virtue of its elevated location at the toe of the slope of CHC Hill, and by a flood dike constructed as part of prior mining/mineral processing-related activities at the St. Louis Ponds site. The 100-year floodplain is shown on Figure 3. As noted previously, at Full Build-out, the lowest existing ground at the Solids Repository footprint is approximately 20-25 feet above the river.

**Potential Impacts.** Existing domestic wells within two (2) miles of the Solids Repository site will not be impacted by the Solids Repository due to:

- Designed capture and treatment in the Ponds System of any leachate that is generated from the Solids Repository;
- Two of the wells are located up-gradient of the Solids Repository site; and
- Location of the wells across the Dolores River from the Solids Repository site – the river will act as a hydraulic barrier preventing movement of groundwater from the Solids Repository to the opposite side of the river.

Constituent concentrations currently existing in groundwater beneath the St. Louis Ponds site are summarized in Table 4. Measures taken in the design of the Solids Repository will ensure that the existing condition of the groundwater is not degraded. These measures include provision of the repository liner and leachate collection systems which will direct any leachate liquid to the existing St. Louis Ponds passive treatment system and ultimately to a new treatment system as noted previously.

Calculations of potential discharge from the Solids Repository liner/leachate collection system indicate a peak daily flow of only approximately 113 cubic feet per day (0.59 gpm) under an unclosed Phase 1 condition. Flow would be even less under a closed condition. This very minor relative flow contribution to the existing treatment system can easily be accommodated and will not have a quantifiable impact on the quality of the Dolores River.

### 3.3 Existing Facilities

**Ponds System**. The proposed Solids Repository site is immediately adjacent to and upslope of the existing St. Louis Ponds mine discharge treatment system (see Figure 2). The current system is comprised of:

- An open, partially geomembrane-lined channel and Corrugated High Density Polyethylene (CHDPE) pipe from the St. Louis Tunnel (adit) portal to a distribution box (which allows water to be diverted to Pond 18 or Pond 15), and ultimately by piping to Pond 18;
- Pond 18, the most up-gradient pond in the hydraulic flow-through system, serving as the primary passive metals precipitation and settlement basin in the system;
- Ponds 15, 14, 12, 11, 9, 8, 7, 6, and 5, in upstream to downstream order, through which the mine discharge flows; and
- A concrete discharge channel to the Dolores River from Pond 5.

Ponds 10, 13 and a remnant of Pond 19 contain water but are not in the active flow-through pond system. Ponds 1, 2, 3, and 4 at the southern end of the system function as wetland ponds outside of the active flow-through system. These ponds are presumably fed by some combination of direct precipitation, surface water run-on, and groundwater inflow. Ponds 16 and 17 are currently dry, but contain four unlined cells constructed by AR in 2011 and used as an IDF for solids removed from Pond 18 responsive to requirements in the RAWP accompanying the Site UAO. Unsuitable material and wet soils/calcines (unsuitable for construction), from the Demonstration Wetland construction, has also been placed into cells 3 and 4 of the IDF.

**Lime Treatment Building**. The lime storage tank and a building that previously housed a slaked-lime feeder, and a masonry block structure at the original St. Louis Tunnel portal where lime slurry was

added to the tunnel discharge are still present, but all equipment has been removed from these facilities. Since approximately 1995 or 1996, lime has not been added to the mine discharge. However, the passive system is currently being used and solids continue to be deposited in the ponds as a result of ongoing natural geochemical and biologic processes providing passive treatment to the mine discharge water before it enters the Dolores River. Proposed Site Development

The proposed Solids Repository at the St. Louis Ponds site has been located to be compatible with currently envisioned adjacent future land uses as briefly discussed below.

**Mine Water Treatment System Upgrades**. Studies are currently underway by AR to support design of major upgrades to the St. Louis Ponds treatment system, including a new primary mine water treatment system that, based on current findings, would include either:

- Conversion of a number of the upper ponds to a passive wetlands treatment system; or
- Installation of some other treatment system or other technology and upgraded settling pond system.

These studies are also evaluating the planned, on-site, permanent disposal of dewatered solids generated from water treatment or disposal of spent wetlands media resulting from treatment of the mine water discharge that is the subject of this EDOP.

## 3.4 Foundation Conditions

Foundation conditions within the proposed Solids Repository footprint were investigated by geologic reconnaissance and mapping, field exploration (including monitoring wells, exploratory borings and test pits), and limited geotechnical laboratory testing on a number of occasions from 1981 to 2008. This included work performed by Dames and Moore (1981), Anderson Engineering Company, Inc. (AECI) (1996; 2008), Short Elliott Hendrickson Inc. (SHE, 2001; 2004), and CDPHE (2003). Subsequent exploration (borings, monitoring wells, cone penetrometer test [CPT] probes, test pits and surface geophysical ReMi lines) was completed by AECI/AECOM in 2011, 2012 and 2013. The locations of those exploration features proximate to the Solids Repository location are shown on Figure 4 and are included on Drawing G-140 (Appendix A). The field or final logs of the exploration features (older and recent) are included in alphabetical order by type (borings, probes, monitoring wells, test pits and ReMi lines) in Appendix B.

The pre-2011 investigations were performed for a variety of specific purposes, to varying standards, and details of the work performed are only partially known. The 2011-13 investigations were performed with detailed field stratification, material descriptions, laboratory testing and where possible, standard penetration testing during sampling, for the purpose of identifying subsurface conditions in the areas of potential Solids Repository locations, and is discussed in detail herein. For purposes of design, where differing interpretations are possible utilizing the prior information as compared to the recent (2011-13) information, greater weight is generally given to the more recent results, as they are much more detailed.

### 3.4.1 Soil Borings

For the 2011 to 2013 investigations, boreholes were drilled to target depths (or refusal if encountered shallower) specified in the *Field Sampling Plan for Solids Repository, Permanent Drying Facility and Pond Flood Dike and Embankment Improvements* (AR, 2011), *Supplement to Field Sampling Plan for Solids Repository, Permanent Drying Facility, and Flood Dike and Pond Embankment Improvements, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico,*

*Colorado* (AR, 2012), and *2013 Supplement to the Field Sampling Plan, Rico-Argentine Mine Site - Rico Tunnels, Operable Unit OU01, Rico, Colorado* (AR, 2013).

Drilling was accomplished with conventional, mud-rotary or sonic drilling equipment (either wheel-or track-mounted), supplemented with rock coring methods where bedrock was to be recovered. Based on soil type, most soil samples were recovered with split-barrel samplers via the Standard Penetration Test (SPT). A lesser number of softer, cohesive materials were sampled using Shelby tube sampling procedures.

The borings were logged by a professional geotechnical engineer or geologist in general accordance with the guidelines in the *Engineering Geology Field Manual* (USBR, 2001). If encountered, the depth to groundwater was noted. Separate samples were collected and sealed in Ziploc© type plastic bags to preserve in situ moisture content. Those samples were transported to the geotechnical laboratory for testing as described in Section 3.7. Shelby tube samples were capped and sealed with duct tape in the field, waxed, and crated for transport to the laboratory.

The boreholes were completed as monitoring wells or formally closed (abandoned) as noted on the boring logs. For monitoring well completions, standard 2-inch Schedule 40 PVC standpipe wells were installed, utilizing 0.010 inch screened (factory-slotted) intervals as noted on the logs. Boreholes not completed as monitoring wells were abandoned with Halliburton Holeplug 3/8" bentonite pellets that were hydrated after placement.

### 3.4.2 Test Pits

In 2011 and 2012, test pits were completed typically using tracked excavators, such as (mini-excavator, conventional trackhoe, or long-stick trackhoe, depending on location and required reach). Test pits in earlier vintages of exploration likely used track- or rubber-tire-mounted excavators or backhoes.

Test pits were excavated to refusal or to the maximum, safe safe-reach depth of the excavator, and logged by a professional geotechnical engineer or geologist in general accordance with the *Engineering Geology Field Manual* (USBR, 2001). Personnel did not enter the test pits, in compliance with OSHA safety regulations, but pit walls and spoil piles were photographed and horizon depths estimated with a survey rod and/or marked excavator arm. Representative bulk samples were collected of each soil horizon in five gallon buckets (except minor horizons generally thinner than one foot thick); moisture content samples were sealed separately in Ziploc© type bags. Samples were transported to the geotechnical laboratory for testing as described in Section 3.7.

### 3.4.3 Cone Penetrometer Soundings

In 2011, 17 CPT probes were completed in the overall St. Louis Ponds area to provide geotechnical information on the softer and fine-grained materials, including the calcines and finer-grained alluvial units that underlie the ponds and pond embankments. Of these, six soundings are proximate to the Solids Repository location as shown on Figure 4, and are discussed herein. The CPT probes were completed using a Gregg 20-ton, track-mounted rig.

CPT probes are typically suitable for loose to medium dense silts, soft to stiff clays, and fine granular materials. Typically, CPT probes are unable to penetrate gravels, cobbles, boulders and other dense strata. To obtain results in the units of interest, most probe locations had to be pre-drilled through coarse-grained units, or existing boreholes were re-used to access the target depths. In

cases where previously drilled boreholes were re-utilized, the probe was pushed through the bentonite-backfilled interval of the borehole to access a loose or soft, underlying stratum.

### 3.4.4 Geophysics

To supplement the test borings, subsurface conditions in the overall St. Louis Ponds area were evaluated using the ReMi test. This test measures shear wave velocities of subsurface materials using ambient surface vibrations, with the results not adversely affected by the grain size of the soils. In the ReMi test, a series of 22 to 24 geophones were placed on the ground in arrays with a 10-foot spacing.

After data processing, the results of the ReMi testing are presented on individual profiles that indicate variations in shear wave velocities laterally and with depth below the ground surface along the length of the array indicated by means of contours and/or color shading. It is of significance, as discussed later, that it has been found that materials having a shear wave velocity greater than about 650 feet per second are resistant to liquefaction, regardless of the magnitude of the earthquake.

## 3.5 Field Exploration Results

From 2011 through 2013, boreholes SSR-1 through -5, SSR-101 through -104, PDF-1 through -3, monitoring wells MW-5S/D, MW-101, MW-102 and MW-202, test pits TP2011-17 through -19 and TP2013-08 through -11, CPT probes CPT-1 through -6 and ReMi lines RM-2 and RM-4, were completed within or near the periphery of the full build-out footprint of the Solids Repository location as shown on Figure 4 and on Drawing G-140 (Appendix A). Selected borings and test pits are projected to Geologic Sections A and B as the basis for subsurface stratigraphic interpretations as shown on Figures 5A and 5B, respectively. A general discussion of the results of these explorations is included here. A more detailed discussion of results is provided in Appendix F.

Earlier explorations (boring logs, monitoring wells and test pits) in proximity to the Solids Repository are also shown on Figure 4 and Drawing G-140 (Appendix A) and the logs included in Appendix B. These are not discussed in detail except to clarify stratigraphy where appropriate. Selected borings and test pits are projected to Geologic Sections A and B as the basis for subsurface stratigraphic interpretations as shown on Figures 5A and 5B, respectively.

*Phase 1 Area*

The Phase 1 portion of the Solids Repository site has been sized to accept the existing solids located in the IDF and remaining in the upper ponds (Ponds 9, 11, 12, 14, 15, 18, and 19). Later expansion of the Solids Repository could be implemented to utilize some or the entire full build-out footprint. This would accommodate future treatment solids (or other on-site by-products, if needed) based on the results of ongoing studies and site response action (including especially a mine water treatment technology).

Borings SSR-3, SSR-101 and SSR-102 were completed near the location of the proposed starter dike. Those borings encountered 15 to 28 feet of variable fill consisting of loose to dense sand, gravel and waste rock, with significant silt and clay fraction, followed by 1 to 3 feet of buried topsoil (interpreted as former river overbank material). Below the fill and buried topsoil, extremely dense to medium dense silty gravels, sands and cobble/boulder layers extended to 39 to 58 feet bgs, followed by dense to medium dense, silty sands and silts interlayered with gravel. Weathered Hermosa bedrock or boulders were observed at 136 to 138 feet, followed by what was inferred as intact Hermosa bedrock to the maximum depth of exploration (150 to 169 feet bgs).

Borings SSR-1 and SSR-2 were completed at the toe and on the upper eastern hillside of the proposed Solids Repository Phase 1 area. Gravelly, lean clay with sand, silt, cobbles, and boulders was observed from existing grade to 22 to 23 feet. SPT N-values were typically 10 to 40 blows/foot, with a loose zone identified in SSR-2 at 15 feet. The upper strata are underlain by inferred alluvial deposits of gravelly, lean clay to 35 to 42 feet, then by interlayered sands and gravels (clean and silty/clayey), variably medium dense to extremely dense, to the maximum depth of exploration (100 feet bgs).

Test pit exploration confirmed the presence of some buried debris in the proposed Phase 1 area, including some broken brick and part of a PVC pipe (TP2011-18 and -19), a steel pipe (TP-22), and a buried concrete foundation (TP-19 at 4.4 feet). In general, the shallow soils on the upper eastern hillside (TP2011-17, -18 and -19) appear to consist of fill and/or colluvium, which typically consist of dark brown clayey and sandy gravels / clayey gravels with cobbles and boulders (up to 24-inch size).

ReMi Line RM-2 identified lower shear wave velocity materials in a range of 1000 to 1300 feet per second within the upper 25 to 30 feet of the ground surface, with higher variability with depth. The highest shear wave velocities were within the northern portion of the array at a depth beginning about 70 feet below grade. The shear wave velocity of this material is lower than expected for intact bedrock, which was inferred at more than 140 feet below grade in SSR-101 and -102. No potentially liquefiable materials were detected in the overburden.

First groundwater is indicated in MW-101 at about 28 feet below surface, El. 8845 ft, and in MW-102 at about 23 feet below surface, (El. 8839 feet) in MW-102. Boring SSR-1 encountered saturated strata at about 44 feet below surface (El. 8863 feet), and Boring SSR-2 had saturated strata at about 35 feet below surface (El. 8850 feet). These readings correspond to a groundwater elevation ranging from about 8815 to 8819 feet. These data indicate groundwater flow at depth beneath the Phase I Solids Repository at a gradient generally to the south-southwest on the order of 0.02 ft/ft. These gradients are consistent with the slightly higher groundwater levels at the extreme northern limit of the Solids Repository site as measured in MW-202, ranging from approximately 8824 feet to 8827 feet amsl. The base of the repository is several feet above even this highest recorded groundwater level at the periphery of the site; and higher yet above the nominal groundwater table underlying most of the site. During the limited duration of a 100-year flood event, the modest hydraulic conductivity of the underlying alluvium would not allow the water table to create uplift on the liner.

*Future Build-Out Area*

The western portion of the Solids Repository site (covered at present by the IDF) consists of 3 to 4 feet of solids excavated from Pond 18 during 2011 and unsuitable materials (approximately 6,000 cy) from the Demonstration Wetland Construction placed in 2013, over a thin but variable veneer of miscellaneous fill (locally including waste rock) which overlies medium dense to loose calcines to a depth of 25 feet bgs. These fill strata are in turn underlain by native alluvium (and locally colluvium at the easternmost extent of the calcines) in the form of medium dense to extremely dense, clean and silty sand and gravel with cobbles to the maximum depth of exploration at (60 to 62 feet bgs).

Borings PDF-1 through -3 encountered 1.5 to 3.5 feet of waste rock or IDF embankment fill followed mostly by calcines to 22.5 to 27 feet bgs. Below the calcine fill, clean to silty sand and gravel alluvium with some cobbles was observed to the maximum depth of exploration, (100 feet bgs). In PDF-3, the calcine fill is underlain by loose to medium dense, organic silty sand alluvium (possible

remnant of buried overbank deposits within a river meander) from 23 feet to the maximum depth of exploration at 31.5 feet bgs.

ReMi Line RM-4, at the west toe of the ultimate build-out footprint of the Solids Repository, suggests loose to very loose strata within about 30 feet of the ground surface. The shear wave velocities were as low as about 500 feet per second, which suggests that some of these soils have some potential for liquefaction, although the design earthquake for the site is relatively low (0.06g). With greater depth, soil strata were interpreted to be medium dense to very dense. Based on shear wave velocity, denser strata were detected at about 70 to 80 feet bgs.

In 2011, first groundwater was indicated in SSR-5 at 15.5 feet below grade, and in PDF-1, -2 and -3, respectively, at 14.5, 18 and 14 feet bgs. Based on the surface grades at those locations, the readings correspond to a groundwater El. 8817 to 8821 feet. These data indicate groundwater flow beneath the ultimate build-out portion of the Solids Repository at a gradient of approximately 0.6-0.7 ft/ft generally to the south/southwest.

## 3.6 Laboratory Testing

There was little geotechnical laboratory testing was performed on a limited basis prior to samples from the pre-2011 investigations. Selected soil samples from the 2011-2013 soil borings, monitoring wells and test pits were sent to Western Technologies, Inc. in Durango, Colorado, for index testing (moisture content, grain size, Atterberg limits and Standard Proctor), in general conformance with the applicable American Society for Testing and Materials (ASTM)/American Association of State Highway and Transportation Officials standards. The results of the laboratory testing completed to date on samples from the field investigations are discussed below and summarized in Table 2. Laboratory data sheets for these tests are available upon request.

Relatively undisturbed samples of drained solids from the bottom of Ponds 18 and 13 were collected using thin-wall Shelby tube sampling methods, then were sealed and shipped to AECOM's geotechnical laboratory in Vernon Hills, Illinois. The samples were tested for moisture content, specific gravity, unit weight, grain size, triaxial permeability, consolidation, laboratory vane shear and consolidated-undrained triaxial compression, in general conformance with the corresponding ASTM standards. The results of these tests are summarized in Tables 5A through 5F as discussed below. Laboratory data sheets for these tests are also available upon request.

Note that more detailed results of shear strength testing of existing embankment fill inferred to have been borrowed from on-site sources (predominantly colluvium, sometimes with lesser alluvium and/or waste rock) are presented in Table 6 as discussed below.

### 3.6.1 Embankment Fill

To evaluate the shear strength of existing dike fill materials, (which are also considered as typical of fill from processed, on-site colluvium), direct shear tests were completed on test pit samples recovered from the primary flood dike and pond embankments. Bulk samples of these materials were tested in a large shear box (12 by 12-inch in plan size) at the AECOM laboratory in Vernon Hills, Illinois. Although the shear box could accommodate a maximum particle size of 1-inch, the minus ¾-inch fraction was used, as this was the same portion of the overall samples used to complete the Standard Proctor compaction tests performed by Western Technologies. In general, the minus ¾-inch fraction represented 75 to 85 percent of the overall sample gradation.

Individual direct shear samples were compacted to 85 and 95 percent of the associated maximum Standard Proctor dry unit weight, and near the optimum moisture content. These two compaction percentages were chosen to represent modest and high levels of compactive effort, respectively. Two data points were collected at medium and high effective normal stresses (700 and 2,000 pounds per square foot [psf]) compared to the present embankment heights, then a second series of tests was added at low normal stress (150 psf), to evaluate the shape of the failure envelope nearer to the origin.

Based on a two-point regression envelope for shear strength versus normal stress, the effective angle of internal friction (rounded) indicates a range of 37 to 40 degrees at 85 percent relative compaction, and 42 to 47 degrees at 95 percent relative compaction. Using three data points, the typical curvature of the failure envelope near the origin, results in a higher effective angle of internal friction, with values of 38 to 41 degrees at 85 percent compaction; and 52 to 53 degrees at 95 percent compaction. The variation in effective angle of internal friction due to curvature of the failure envelope may be accounted for in design by taking the slope and intercept near the effective normal stress of interest.

Effective cohesion values reflect the presence of significant silt and clay fraction in the embankment fill. Using a two-point failure envelope, the results are significantly higher for 95 percent vs. 85 percent relative compaction (500 to 800 psf versus 160 to 410 psf). There is less variation for a three-point envelope (80 to 260 psf at 85 percent vs. 130 to 240 psf at 95 percent).

The results of the shear strength testing of representative embankment fill are summarized in Table 6. Given the angular nature of the coarse fraction, the full sample would be expected to have at least as high an effective angle of internal friction. The results presented here are thus conservative, provided that fill sources are reasonably well-graded.

### 3.6.2 Oxy-hydroxide Solids

Drained lime-treatment solids from the bottom of Pond 18 were excavated by backhoe and placed approximately 2 to 4 feet thick in the four cells of the IDF in early Fall 2011. Cell 1 includes solids placed directly on the exposed calcines subgrade; Cell 2 had an open-graded gravel blanket placed over the exposed calcines subgrade to promote drainage; Cell 3 included a sand filter over the gravel drainage blanket; and Cell 4 was prepared as for Cell 3 except the placed solids were to be tilled from time to time during fair weather months to promote further drainage and evaporative drying. Tillage of the solids in Cell 4 was completed in summer 2013, but subsequent samples have not yet been tested.

Initially, two to three samples were randomly collected approximately monthly (during non-winter months) since initial placement from three locations (A, B and C) in each cell, using thin-wall Shelby tube sampling methods augmented by a backhoe to hydraulically push and recover the tubes (due to access limitations for a drill rig). The tubes were sealed, packed and shipped to AECOM's geotechnical laboratory in Vernon Hills, Illinois. Round 1 sampling was completed in late October/November 2011, Rounds 2 through 8 were completed between April and late October 2012, and Round 9 in May 2013. Pertinent results are presented in Tables 5A through 5F and discussed herein.

*Specific Gravity and Atterberg Limits*

The drained solids have a specific gravity of 3.0, and classify as high-plasticity, inorganic silt (MH) per the Unified Soil Classification System. As summarized in Table 5A, liquid and plastic limits

range from 67 to 83 percent and 62 to 79 percent, respectively. These inherent index properties are not expected to change over time, but are presented for comparison to natural soil materials.

*Moisture Content and Dry Unit Weight*

Per Table 5B, the moisture content of the drained solids ranged from 110 to 340 percent (with one outlier value at 430 percent) soon after placement in October 2011, and decreased in bandwidth to 85 to 220 percent by June 2013 (20 months later). All cells showed significant decrease in moisture content of solids. No cell was clearly superior in terms of moisture content change, indicating that most of the decrease was from evaporative drying versus bottom drainage. It is noted, however, that these are previously drained solids from Pond 18. Undrained solids are expected to have more significant bottom drainage whereby the base condition of the individual drying cells would presumably have a greater impact.

The dry unit weight of the previously drained solids increased slightly from 2011 to 2012, varying from 13 to 43 pcf (all cells) in October 2011, increasing to 21 to 50 pcf by September 2012, and 22 to 49 pcf by June 2013. There are outlier values of 68 to 88 pcf in the October 2012 sampling event, but these may be from upper desiccated layers in certain cells. An ultimate maximum moist unit weight of 50 to 60 pcf for drained solids appears reasonable from review and extrapolation of the drying cell data collected to date. The dry unit weights are summarized together with moisture content in Table 5B.

*Undrained Shear Strength*

Undrained shear strengths from laboratory vane shear tests were measured starting with Round 2 sampling in April 2012. The measured shear strengths are summarized in Table 5C. There were no significant trends toward increasing peak or residual undrained shear strength for the period measured (April through September 2012). Among the four cells, the peak shear strength has a wider variation (from approximately 110 to 590 psf), while the residual undrained shear strength varied over a narrower range (20 to 90 psf, with one value at 170 psf). From corresponding peak and residual tests of the same specimens, the sensitivity value (peak / residual undrained shear strength) varies from about 3 to 11, with an average of 5, which is relatively high in comparison to natural cohesive soils (sensitivity less than 3).

*Hydraulic Conductivity*

Based on tests as summarized in Table 5D, hydraulic conductivity (by triaxial permeameter) indicated a reduction of about one order of magnitude, from about $1 \times 10^{-6}$ cm/sec to $1 \times 10^{-7}$ cm/sec, between Fall 2011 and Fall 2012 (not including one outlier value on the order of $1 \times 10^{-4}$ cm/sec). Hydraulic conductivity is known to vary by at least one order of magnitude between field and laboratory tests; therefore, the decrease in laboratory-measured hydraulic conductivity was not significant. The range of values appeared consistent with a silt-sized natural unconsolidated soil (moderately low but finite hydraulic conductivity).

*Consolidation/Swell*

The results from a total to date of 17 consolidation/swell tests are summarized on Table 5E. The initial void ratios, measured at setup from these tests, indicated initial void ratios of 5.3 to 10.5 in October 2011, and 5.7 in April 2013. This was due mostly to evaporative drying, with some minor self-weight consolidation in the drying cells. The maximum past pressure averaged 1,400 psf (range

of 900 to 1,900 psf). Final void ratios were in the range of 2.1 to 6.2. After loading to a maximum of 5,000 psf to simulate stacking of the material in a Solids Repository (40 feet of solids at a maximum of 100 pcf moist unit weight), the Cc and Cr values for the drained solids ranged from 0.5 to 5.7 and 0.02 to 0.15, respectively. Most of the Cc and Cr values were very high in comparison to natural cohesive soils (Cc <0.5 and Cr < 0.05), due to the extraordinarily high void ratios of the oxy-hydroxide solids.

*Triaxial Shear Strength*

The results of 13 multi-stage, consolidated-undrained triaxial shear tests are summarized in Table 5F. These test results indicated an average effective angle of internal friction of 29 degrees (range of 26 to 32 degrees), and an average effective cohesion of 160 psf (range of 50 to 300 psf, with little change from Fall 2011 to Spring 2013. For design of a Solids Repository, the relatively high effective angle of internal friction in the drained condition (long-term stability) must be tempered with the relatively high sensitivity of the solids in the undrained condition (soon after placement). In other words, the design and operation of the Solids Repository must accommodate drainage and reinforcement elements and delivery methods to survive initial placement to allow drained conditions to develop to the fullest extent possible over the long term.

# 4.0 Facility Design

This section presents the recommended Solids Repository design including such items as the proposed location, contents, phasing/capacity, site access/security, bottom liner/leachate design, geotechnical design, storm water controls, and other proposed design features.

## 4.1 Proposed Solids Repository Location

The recommended location for the Solids Repository is shown on Figure 2. This location was judged the most feasible with regard to:

- Initial (Phase 1) and full build-out footprint relative to capacity;
- Retention of existing, relatively level ground in the area north of the active ponds and St. Louis Tunnel;
- Long-term stability at full build-out;
- Constructability, including potential for phasing in multiple steps;
- Feasible relocation of the existing United States Forest Service (USFS) road through the site during Phase 1 and during subsequent phases (if implemented);
- Avoidance of interference with an existing right-of-way for a potential future access road in the north area of the St. Louis Ponds site;
- Proximity to the active Ponds System and potential wetlands treatment area;
- Favorable interrelationship with most other potential elements of the overall site response action; and
- Ability to accommodate the required Phase 1 volume of 30,000 cy, plus additional volume in future phases for treatment solids or other by-products if/as needed.

This location (all phases) is above the seasonal high water table and out of the 100-year floodplain of the Dolores River even in the event of a breach of the flood dike. A portion of the USFS access road will, however, require relocation to the west beyond the toe of the Solids Repository starter dike, and the upper branch access road will be covered by the Phase 1 Solids Repository. Relocation of the USFS access road will encroach upon a portion of the existing IDF; approximately 6,000 cubic yards of existing solids would have to be removed, stockpiled temporarily, and ultimately placed into the Solids Repository for permanent disposal. The current IDF is known to be underlain by significant amounts of buried calcines in the former Ponds 16/17 area and therefore relocation of the USFS access road would encroach onto these calcines. If removal of the affected calcines beneath the Solids Repository footprint proves necessary, it is assumed that the calcines would either be placed back in the original location following installation of a liner, or be stored in the Upper North Area until their final disposition is determined. Although not ideal, these measures are technically feasible and could be accomplished as part of the Phase 1 Solids Repository construction in time to meet the RAWP revised schedule deadline for construction completion of October 31, 2014 for initiating disposal in the Solids Repository.

## 4.2 Solids Repository Contents

The materials to be disposed in the Solids Repository may include a significant portion if not all of the existing lime-treatment solids on site, other mining and/or mineral processing by-products including calcines and waste rock, and future precipitated oxy-hydroxide solids or expended wetland treatment biomass (depending on the primary water treatment technology selected). Estimates of the volume of these by-products based on studies to date are summarized as follows:

- Existing oxy-hydroxide precipitated solids (existing lime-treatment solids): 30,000 cy
- Existing pyrite roaster residuals (calcines): 220,000 cy
- Existing St. Louis Tunnel muck (waste rock): 175,000 to 200,000 cy
- Future oxy-hydroxide precipitated solids (future solids): 2,300 cy per year (based on an annual average St. Louis Tunnel discharge of 1,100 gpm continuously buffered to a pH of 10 in an open-pond lime-addition treatment system); 115,000 cy for assumed 50-year project life
- Future depleted wetlands treatment matrix (wetlands matrix): 7,500 cy per 20-year replacement cycle; 19,000 cy for assumed 50-year project life

For purposes of sizing the Solids Repository with the design volume at Full Build-out, it is assumed that either lime addition or wetlands treatment, but not both technologies, will be selected as the primary technology for the St. Louis Tunnel discharge. It is also assumed that removal and on-site disposal of any significant quantity of waste rock will not be necessary as part of the overall response action. Studies are ongoing to assess the need for response action to address the calcines, including whether it is necessary to remove some or all of the calcines on site and store them in the Solids Repository. Therefore the design volume is 365,000 cy for the Solids Repository.

The Solids Repository contents will, at a minimum, include existing oxy-hydroxide precipitated solids from lime treatment. It is possible that some portion of the existing calcines may also be disposed in the Solids Repository. Both the existing oxy-hydroxide precipitated solids and calcines have been tested using Toxicity Characteristic Leaching Procedure (TCLP), and these materials are not RCRA characteristic wastes for the eight Resource Conservation and Recovery Act (RCRA) metals. Results are provided in Table 7. If other waste materials such as the waste rock or future depleted wetlands matrix material would require disposal in the Solids Repository, these materials would be tested to assure that they are not characteristically hazardous before being disposed in the Solids Repository.

## 4.3 Solids Repository Phasing and Capacity

The Solids Repository design and construction will be phased in order to meet the anticipated US EPA RAWP schedule update requiring that mobilization for Solids Repository construction begin during June 2014. Phasing of Solids Repository construction has been informally agreed to by EPA, and formal concurrence is anticipated in the near term. An initial Phase 1 Solids Repository will be designed and constructed that is capable of holding at least the estimated 30,000 cy of existing lime-treatment solids currently on site with some additional capacity. Whether the Phase 1 Solids Repository is used to hold existing solids, and if so whether only some versus all of those solids would be placed, will be determined based on ongoing work for final selection of the water treatment technology. The Phase 1 Solids Repository will be able to be expanded to hold a greater volume as future decisions on the water treatment technology and/or possible response actions for existing by-products and/or mine residues are made.

Based on the assumptions and currently known conditions, the following Final Build-out capacities are possible for the Solids Repository:

- Exiting oxy-hydroxide precipitated solids only – 30,000 cy
- Exiting oxy-hydroxide precipitated solids and calcines – 250,000 cy
- Exiting oxy-hydroxide precipitated solids and depleted wetlands treatment matrix – 49,000 cy
- Exiting oxy-hydroxide precipitated solids and future oxy-hydroxide precipitated solids – 145,000 cy
- Exiting oxy-hydroxide precipitated solids, calcines, and depleted wetlands treatment matrix – 269,000 cy
- Exiting oxy-hydroxide precipitated solids, calcines, and future oxy-hydroxide precipitated solids – 365,000 cy

The proposed Solids Repository currently has a Phase 1 capacity of approximately 31,000 cy, slightly exceeding the required storage criterion. At full build-out, the Solids Repository would have a maximum capacity of 365,000 cy, assuming stacking of materials on a currently envisioned maximum side slope of 3H:1V, consistent with material geotechnical testing.

After placement of existing solids in the Phase 1 cell, the surface of the solids would be graded slightly to drain surface moisture but would be below the top of the starter dike. Future phasing of the Solids Repository footprint will depend on the chosen mine water treatment technology, (and/or if other existing mining or mineral processing by-products need to be disposed in the Solids Repository). If lime amendment or wetlands treatment is chosen, the volume of future solids and/or depleted wetlands matrix will be further refined during the design of that system and used to design future phases of build-out for the Solids Repository, not to exceed the Full Build-out. If existing calcines or waste rock are required to be placed, those are already present on site and could be disposed as Solids Repository air-space allows. In either case, it is expected that an interim soil cover will be required to be placed over the waste materials at the end of any construction season to mitigate wind erosion and dispersal of the fines fraction of solids, depleted matrix or other existing mining/minerals processing by-products.

If the waste volume exceeds the height of the starter dike(s), a stacked repository would be constructed, starting over the Phase I area. Following primary consolidation in a drying cell, solids would be placed in lifts against CHC Hill and working westward, up to a maximum height of 40 feet. The lift thickness would be controlled to allow sufficient time to alleviate excess pore pressures in the waste. Intermittent geogrid reinforcement and drainage board would extend back from the face of the solids as needed to assist with global stability. The exposed face of the solids would be covered with a sloping soil cap as the repository is progressed up the slope. The face cap would act as a stability buttress as the repository gains in overall height.

### 4.4 Site Access and Security

The proposed design for the Solids Repository will require relocation of a portion of the existing USFS access road during both the Phase 1 and subsequent expansions. During the Phase 1 construction, the USFS access road will require relocation beyond the toe of the Solids Repository starter dike construction as shown on Drawing D-100 (Appendix A). The upper branch of that access road would still be covered by the Solids Repository, requiring a revised turnaround configuration north of the Solids Repository. Relocation of the USFS access road would encroach onto the solids in the IDF and existing calcines underlying the IDF as discussed in Section 4.1.

A six-foot chain link fence will be installed around the perimeter of the Solids Repository as shown on Drawing C-150 (Appendix A). The perimeter fence will be relocated as additional phases of the Solids Repository are constructed to maintain restricted access to the facility at all times.

## 4.5 Liner Design Components

The proposed liner and leachate collection system design is intended to provide adequate protection of groundwater by intercepting effluent from the waste at a textured HDPE liner, collecting the leachate in a gravel drain blanket, and routing it through a PVC pipe network and discharge pipe to existing surface water treatment. The following sections provide details of the liner system for the Solids Repository.

### 4.5.1 Subgrade Preparation

The bearing capacity of the subgrade has been evaluated and the maximum net allowable bearing pressure (without foundation improvement) is 2.5 to 3.0 kips per square foot (2,500 to 3,000 psf). This is approximately equal to the expected maximum applied pressure from 40 feet of stacked solids in the moist condition (40 feet x 60 to 85 pounds per cubic feet (pcf), or 2,400 to 3,400 psf). The moist unit weight for the solids is derived from 10 rounds of thin-walled tube sampling of solids in the IDF (see Table 5B). To provide adequate bearing capacity at the maximum stacked height and to provide for a more uniform settlement of the foundation, the design incorporates local ground improvement in the footprint of the starter dike via over-excavation and re-compaction of the base of the starter dike excavation prior to placing cushion and liner materials. Provision will be included in the specifications for local removal and replacement of unsuitable subgrade material if determined necessary during construction. Ultimately, while preparing the subgrade for liner installation, all deleterious materials that would otherwise compromise the integrity of the liner will be removed.

The maximum allowable bearing pressure for the granular colluvium/alluvium corresponds to 1 inch or less of total foundation settlement, and would be proportionally less for lower maximum applied pressures or compacted foundation materials. The foundation settlement is expected to occur during construction in the case of the starter dike, and relatively soon after each primary lift of solids is placed in the cells over time.

The Phase 1 subgrade will be graded to drain generally from east to west towards the west side of the starter dike at a slope of approximately two (2) percent. This slope will provide for drainage of leachate. The site will be excavated to provide a depression that is designed to provide for Solids Repository stability by minimizing the tendency of movement to occur on the relatively low shear strength liner materials. Sizable surface irregularities will then be removed, and protruding surficial cobble to boulder size materials will be minimized as necessary to provide a generally level grade for the liner section. Significant excess fill is estimated to be produced from the Phase I repository excavation and will be processed for use in the subgrade preparation and starter dike.

### 4.5.2 Cushion Layer

A 6-inch thick cushion layer will be placed over compacted subgrade to provide a suitably smooth base layer to protect the low permeability HDPE liner described below. The cushion layer is anticipated to consist of local borrow screened to remove 1/2-inch and larger particles that could potentially puncture the liner, or from imported material. The screened borrow will result in a soil classified as SC/SM (clayey or silty sand) and is expected to be of relatively low permeability due to the moderately high percentage of natural soil fines. If screening of on-site materials proves uneconomical, suitable material will be imported from an offsite borrow area.

### 4.5.3 Liner

On the bottom and side-slopes of the cell, the liner will consist of 60-mil, manufactured, flexible, field-seamed (heat-welded) panels made of textured HDPE. This material was chosen because it has a low transmissivity, less Solids Repository volume is devoted to the liner thickness than with compacted clay, and because of a general scarcity of clay borrow at the site.

The properties of the liner will be chosen to manage friction and sliding of the overlying soil and by-product materials, durability of the liner material, ease of installation (seaming requirements), and service life in the local climate. Slope stability of the liner system(s) is discussed in Section 4.6.3. Details of liner anchoring are depicted on Drawing C-160 (Appendix A).

### 4.5.4 Drainage Layer and Leachate Collection System

A minimally compacted, 12-inch thick (minimum) drainage layer consisting of clean gravel will mirror the slope of the subgrade and overlay the HDPE liner at the base of the Solids Repository. The drainage layer will be overlain by a graded sand (6-inches thick) to provide filtering of the typical oxy-hydroxide solids to be disposed in the Solids Repository. The drainage layer is designed to capture and route effluent from the waste to the nearby surface water treatment system. Using traditional filter criteria, the combined drainage and filter layer is designed to:

- Be filter-compatible with the overlying solids to prevent clogging of the drainage system;
- Provide adequate drainage capacity for expected flows; and
- Be of suitably small particle size to minimize damage to the HDPE liner from the stress of overlying solids (or other by-product) fill.

The currently envisioned gradation and evaluations of its filter compatibility with overlying solids to be disposed and its permeability are provided in Appendix G.

A leachate removal system comprised of a perforated pipe network with additional encapsulating granular drain material as appropriate will collect effluent from the drainage layer and route that drainage by gravity to a manhole near the northwest corner of the Phase 1 cell. The outflow from the manhole will be conveyed by underground gravity pipeline to surface water in Pond 15 or 18 (if lime treatment is chosen) or to a designated location within the wetlands system (for a wetlands treatment alternative). The cell bottom elevation of 8830 feet was chosen to allow a minimum pipe grade of 1/4 inch-per-foot (about 2 percent) from the bottom of the Solids Repository Phase 1 cell to discharge above the historical normal water elevation of the uppermost existing pond in the system (Pond 18 at Elev. 8823 feet amsl).

This leachate collection system has been designed to maintain less than a twelve (12)-inch depth of leachate over the liner, and to promote transport of leachate from the most distant point of the leachate collection system to the leachate removal system.

## 4.6 Slope Stability

### 4.6.1 Starter Dike

The side slopes of the starter dike are planned at 2H:1V, with a crest width of 15 feet. The dike will be constructed of site-excavated colluvium/alluvium, processed to remove stones larger than 4 inches. The material will then be placed as an engineered fill, with appropriate moisture and compaction control. Based on the results of large direct shear tests presented in Section 3.7.1, an effective angle of internal friction and effective cohesion of 38 degrees and 150 psf, respectively, are

adopted for design. The resulting factor of safety of the starter dike and its foundation is greater than 1.5 which is acceptable for long-term loading (see stability analysis results in Appendix G).

### 4.6.2 Stacked Solids

Phase I of the Solids Repository will be excavated to form a shallow depression for long-term stability so that any tendency to slip on the HDPE liner is forced to overcome significant buttressing action (passive resistance) of upward movement on the sides of the depression. Once the solids are required to be stacked above the top elevation of the starter dike, the solids are assumed to be stacked in a configuration similar to upstream tailings construction, whereby a compacted earth facing is placed on the starter dike, rising in advance of the stacked solids. For certain load cases, it is also possible that horizontal geogrid reinforcement, with or without horizontal drainage layers, will be required to be placed from the starter dike facing back into the stacked solids.

Depending on the phasing of the Solids Repository, at full build-out, the solids from a full-scale open pond lime treatment system may be stacked on the order of 40 feet above the base of the cell. Outer Solids Repository slopes have been restricted to no steeper than 3H:1V to benefit long-term stability and long-term erosion protection of the cap surface, and no shallower than 10% to promote runoff and reduce infiltration. Based on the laboratory data of solids placed in the IDF (Table 5), the effective angle of internal friction and effective cohesion of drained solids is estimated at 29 degrees and 150 psf, respectively. However, the solids exhibit a very high void ratio, even after 1-D consolidation to 5,000 psf, and also show low undrained shear strength (average peak and residual vane shear strength values of 270 and 50 psf) and relatively high sensitivity (greater than 5). Therefore, undrained strength is expected to control the slope stability behavior of the solids, at least until well into the future when long-term consolidation, cementation and aging effects may improve the undrained strength.

### 4.6.3 Slope Stability Modeling

Slope stability analyses were conducted utilizing the limit equilibrium program Slope/W (Version 12) developed by Geoslope International Ltd. Slope/W has analysis subroutines to evaluate stability for both wedge and circular failure surfaces, using a variety of analytical methods. Depending on the analysis method, both moment and/or force equilibrium can be satisfied to calculate the factor of safety. With the generally lower friction angle at the HDPE/soil interface at the base of the cell, block failure surfaces are the typical failure mode analyzed, although circular searches were completed to check the soil facing (i.e. upstream construction).

The foundation materials consist mostly of colluvium (native clayey sands and gravels SC to GC) in a medium dense state with occasional loose zones, and are expected to provide adequate strength to support the Solids Repository and limit settlement or consolidation to manageable levels (less than 1 inch of total settlement). Due to the overall granular nature of the colluvium, the settlement will occur relatively quickly during each loading event (construction or phased placement of by-product materials). Based on large-box, direct shear testing of the minus ¾-inch fraction of typical on-site colluvium from the Solids Repository area, an effective angle of internal friction and cohesion of 35 degrees and 50 psf were selected. As previously indicated, although the dry solids have a relatively high effective angle of internal friction (29 degrees), their low undrained strength, high sensitivity, and high void ratio suggest checking undrained (total stress) as well as drained (effective stress) parameters. The foundation colluvium and starter dike fill are thus stronger than the stored solids (and likely other by-products that may be disposed). Other materials (cover and drainage layer) are so thin and their friction angles higher than the HDPE liner material that they have a small impact on global stability. Along with the solids or other by-product materials, the friction at the interface of the textured HDPE liner is the critical

characteristic in terms of shear strength. Soil-textured HDPE interface friction angles are expected to be around 17 degrees based on significant prior experience with these materials.

Preliminary stability design cases for the Solids Repository include: 1) short-term stability using undrained strength parameters for the solids, with a minimum target factor of safety of 1.3; 2) long-term stability using effective stress parameters, with a minimum target factor of safety of 1.5;, and 3) stability during seismic events. For short-term stability, three cases are presented: peak undrained strength of 270 psf ($\phi = 0$); shear strength/effective vertical stress = 0.15 (Shansep analysis); and $\phi = 15$ degrees, Su = 100 psf. The long-term stability was evaluated for two cases: $\phi' = 15$ degrees, c' = 100 psf (deep wedge failure along the HDPE liner); and $\phi' = 15$ degrees, c' = 100 psf (circular search through the solids and soil facing). For the seismic analysis, three cases are presented for a pseudo-static earthquake load of 0.03g (typically one-half of the horizontal peak ground acceleration of 0.06g): $\phi$; = 15 degrees, c' = 100 psf (deep wedge failure); $\phi' = 15$ degrees, c' = 100 psf (circular search through the solids and soil facing); $\phi' = 15$ degrees, c' = 100 psf (with geogrid reinforcement).

Stability analyses for critical sections for the relevant short- and long-term cases are presented in Appendix G. The factors of safety are above 1.3 or 1.5, except for the undrained case using $\phi = 0$ and Su = 270 psf. This indicates that if no frictional contribution is assumed, horizontal reinforcement is required.

### 4.7 Storm Water Controls

To minimize treatment of clean storm water (rain and snowmelt), each phase of the Solids Repository will be graded to minimize run-on from outside the footprint, and to encourage runoff of direct precipitation (rain or snowmelt) on the Solids Repository surface to reduce infiltration through materials placed in the Solids Repository. Infiltration of precipitation (and wind-induced erosion) will be reduced by placing clean intermediate and final soil cover over the stockpiled materials and will be as governed by the sequencing of waste placement. Intermediate and final cover soil will consist of processed on-site material from the excess cut material generated during the Phase 1 construction.

Specifically, the storm water controls are designed to:

- Control run-on. Provide routing of run-on for the 100 year, 24-hour storm event during the construction, operation, closure, and post-closure periods.
- Control erosion and sediment during construction. Provide erosion and sediment control from all disturbed areas during construction until those areas are fully stabilized (vegetated or covered with riprap or other suitable erosion-resistant material). This includes the starter dike, laydown areas, haul roads, and other disturbed areas.
- Control direct precipitation during operation. Provide run-off collection (detention) within the open Solids Repository for the 100-year, 24-hour storm event during operation, when Solids Repository is in an open condition.
- Control run-off during post-closure. Provide stabilized routing of run-off from the final cover surface for the 100-year, 24-hour storm event during the post-closure period.

The run-on control system consists of two storm water drainage channels around the northeast and southeast sides of the Solids Repository to route storm water run-on from the catchment basin west of the Solids Repository. The storm water drainage channels will be trapezoidal in shape, approximately two feet deep and ten feet wide at the base and will be constructed during grading of the high (east) slope of the Phase I Solids Repository. Storm water calculations and drainage channel sizing

calculations are provided in Appendix G. The channels will be lined with a textured, 30 mil, HDPE textured membrane and covered with 6 inches of gravel mulch. Gravel mulch may consist of crushed gravel, stone gravel, or pea gravel with a D50 of approximately 1-inch. Routed water will be discharged to the ponds downstream of the Solids Repository. The overall Ponds System already includes a run-on control ditch, and the routed storm water from the Solids Repository will be combined with this control system.

Erosion and sediment control during construction will be achieved primarily through the use of best management practices such as silt fence, wattles, drainage channels, and sediment traps located down-gradient of the areas disturbed during construction. The current site Storm Water Management Plan, provided in Appendix G, will be updated to include erosion and sediment control measures to be implemented prior to the start of construction for the Solids Repository.

Control of run-off from uncapped areas during operation will be achieved primarily through grading so that run-off collects within the open Solids Repository until that runoff evaporates or infiltrates. Infiltrated runoff will become leachate and handled according to Section 4.5.4. Water routed from uncapped areas will be discharged to the existing Ponds System downstream of the Solids Repository to provide detention during 100-year, 24-hour storm events.

The approximate locations of storm water controls are shown on Drawing C-100 (Appendix A). A site-wide Storm Water Management Plan is provided as Appendix H. Design storm water run-on/run-off computations using the NRCS TR-55 method are provided in Appendix G.

## 4.8 Drying Facility Reconfiguration

It is intended to utilize the existing IDF during initial operation of the Phase 1 Solids Repository, assuming that such use is compatible with other facilities and operations of the overall site response action. If necessary, the subgrade of the existing IDF could be modified to incorporate a liner and leachate collection system similar in concept and operation to the adjoining Phase 1 Solids Repository. This system would be constructed after the existing solids in the IDF are placed in the Phase 1 Solids Repository. A portion of the existing IDF (currently estimated as about 40 percent) will be unavailable for use during the time the lower branch of the existing Forest Service access road is being relocated. The adequacy of the available portion of the IDF footprint will be further assessed as decisions are made as to the materials, volumes and timing of disposal planned for the Phase 1 Solids Repository.

If lime-treatment is selected as the mine water treatment technology at the site, then a new Permanent Drying Facility (PDF) for drying lime-treatment solids removed from the Ponds System would be sited, designed and constructed. Under this scenario, it appears that a PDF would most likely be located north of the Solids Repository. This would maintain the expansion potential of the Solids Repository and utilize a portion of the site not yet identified for an alternative long-term facility or use. The area north of the Solids Repository could also be used if the existing IDF proves neither feasible nor adequate during the life of the Phase 1 Solids Repository due to material type, volume, or sequencing issues.

If wetlands treatment (or another low-volume treatment residuals process) is selected and no existing calcines or waste rock need to be relocated to the Solids Repository, then it may be feasible to utilize a portion of the ultimate build-out footprint of the Solids Repository as a staging and drying area. Alternatively, as previously indicated, the area north of the Solids Repository could be used for this purpose.

## 4.9 Groundwater Monitoring

The proposed Solids Repository design includes a low-permeability cover (discussed in Section 6), a liner to encapsulate the waste (discussed in Section 4.5.3), and a leachate collection system (discussed in Section 4.5.4) with the outfall of that leachate collection system piped a piped to direct any leachate generated to the existing (and future upgraded) surface water treatment system at the St. Louis Ponds site. This design minimizes the generation of leachate and provides positive control of minor leachate flows by routing them to the adjacent treatment system. For these reasons, groundwater is not anticipated to be impacted as a result of the Solids Repository. However, groundwater is currently monitored across the site as a result of impacted groundwater from previous mining and mineral processing operations at the site. Therefore, a separate groundwater monitoring program specifically for the Solids Repository will not be implemented as long as the site-side monitoring program remains in effect. A Sampling and Analysis Plan for Surface Water and Groundwater (Atlantic Richfield, 2013a) as well as a Quality Assurance Project Plan for Surface Water and Groundwater (Atlantic Richfield, 2013b) have been developed for groundwater monitoring of the overall St. Louis Ponds area. The SAP and the QAPP (which are included in this EDOP as Appendix D and Appendix E, respectively), include monitoring of all applicable groundwater parameters and those that might be associated with unanticipated releases from the Solids Repository.

## 4.10 Explosive Gas Monitoring

The Solids Repository is not anticipated to generate explosive gases based on the nature of material to be disposed and therefore monitoring for explosive gases will not be required. If wetlands matrix materials (with the potential to generate methane) are disposed within later phases of the Solids Repository, then vertical gas vents and a routine explosive gas monitoring program for explosive gases may be developed and installed at the time required.

## 4.11 Construction Reporting

After construction of the Solids Repository and prior to the acceptance of solids or other by-products, AR will submit a report to CDPHE and Dolores County to document that the construction has been completed in accordance with the approved plan. The report will be signed by a Colorado registered professional engineer, approved by CDPHE, and placed in the operating record. A Construction Quality Assurance Project Plan has been prepared for the project and is included in Appendix I.

# 5.0 Operations Plan

This section of the EDOP presents the operations plan for the proposed Solids Repository pursuant to applicable requirements in Sections 3.3 and 3.4 of the CDPHE regulations pertaining to Solid Waste Sites and Facilities.

## 5.1 General Data

Solids Repository Physical Address:

Atlantic Richfield Company
13100 St Louis Road
Rico, CO 81332

County: Dolores County

Legal Description: NW1/4 of the NW1/4 of Section 25, T40N, R11W

Site Description: The proposed Solids Repository site is located within the Rico – Argentine Mine Site approximately 0.75 miles north of the northern boundary of the Town of Rico in Dolores County, Colorado.

Type of Landfill and Waste: The proposed Solids Repository is a disposal site for existing solids present in upper ponds (18, 15, 14, 13, 12, and 11), solids currently being stored in the IDF, and future solids generated from a lime-addition treatment system or depleted matrix from operation of a wetlands water treatment activities. The Solids Repository will be lined to capture leachate and the surface will be graded and capped with a final cover. Phase 1, with a volume of 30,000 cy and a surface area of approximately 1.5 acres, will be bounded by a starter dike. The Full Build-out of the Solids Repository will have a capacity of approximately 365,000 cy and a surface area of approximately 7.5 acres acres. The facility will not accept raw sludge from wastewater or treatment plants, septic tanks, chemical toilet waste, or any liquid wastes, or wastes with free liquid. In addition, the facility will not accept wastes brought from an off-site location.

Service Area/Transportation Corridor and Site Access: The service area includes only the Rico – Argentine Mine Site. Access to the Solids Repository is through the St. Louis Ponds site (also controlled by the applicant) for which entry is from Colorado Highway 145 just south of the bridge over the Dolores River at the north end of the Town of Rico.

## 5.2 Operational Data

Point of Contact for Operations:

Atlantic Richfield Company
Anthony R. Brown, Project Manager
4 Centerpointe Drive, 4-435
La Palma, CA 90623
714.228.6770 (direct)

Operating Schedules:

The Solids Repository is anticipated to be open 10 hours/day, 7am - 5pm, Monday through Saturday during periods of active waste placement. The Solids Repository is not anticipated to operate during periods of inclement weather winter conditions (typically November 1 to May 1).

Types and Volumes of Wastes and Expected Life of Site:

- Types of waste – existing lime-treatment solids, mining and/or mineral processing by-products including calcines and waste rock, and future water treatment generated solids.
- Volume of Waste Generation – after initial solids placement, the solids would be removed from the upper ponds or treatment system on a periodic basis (every three to seven years). After drying, the placed volume is estimated at 7,000 to 16,000 cy per event.
- Total Volume of Waste – the maximum volume of waste at Full Build-out would be approximately 365,000 cy.
- Facility Life – 50 years estimated.

Staffing Plan:

- During Initial Operation/Loading – one administrative (part time), one dozer/grader operator, two haul truck operators, one loader operator, one water truck operator/laborer (full time contractor personnel), engineering and survey assistance (part time consultant). During Long Term Periodic Operation – one administrative (limited-part time), periodic local contractor and/or consultant assistance.

Equipment Needs:

Anticipated equipment to be used during active operations/loading of the Solids Repository includes a D-4 to D-6 bulldozer (or equivalent), water truck, front-end loader, several haul trucks as needed, and a grader (all contractor provided) as needed.

Solids Repository Staging/Placement:

Staging and placement of waste within the Solids Repository will be completed as follows:

- Initial Solids or Other By-products Placement – During the latter stages of Phase I Solids Repository construction, removal of solids from the Interim Drying Facility (former Pond 16/17 area) will be coordinated with Solids Repository construction until the “initial Solids Repository construction” includes the placement of at least 12 inches of waste solids over the combined sand/gravel filter / drainage layer. Ingress and egress into the Phase I Solids Repository will be from an access ramp at the south end of the Solids Repository. The initial waste will be carefully pushed out over the drainage layer and will be extended to cover and protect the full extent of the drainage layer from erosion. The drainage layer and sand filter placement will be staged up the lower side slopes of the Phase I cell to stay ahead of the level of the waste materials. The surface of the waste will be graded for internal slope stability. Phase I construction will include provisions for run-on and run-off control.
- Placement to Fill Excavated Depression – Either as a continuation of initial solids or other by-product placement or as a subsequent phase of Solids Repository operation, placement will

proceed from the east (back) of the Solids Repository to the west (front) leaving a drainage slope down to the run-off control storm inlet. Extending from the slope down to the inlet, solids or other by-products will be placed on a relatively flat surface (2 percent slope) until the depression excavated during initial Solids Repository construction is filled, with onsite runoff directed as described above.

- Ongoing Solids or Other By-products Placement - After the depression is filled, solids or other by-products placement will continue at the back of the Solids Repository with the gravel drainage layer and sand filter placed in advance of the solids or other by-products placement. These activities will continue until final grades (bottom of cap/top of waste elevations) are reached for the Phase I cell.
- Future Solids or Other By-products Placement – Depending on the final treatment technology, future material to be disposed in the Solids Repository could include: the remaining solids in the upper ponds (drained in a drying bed prior to placement in the Solids Repository); future solids (e.g., depleted wetlands media or sludge) generated from treatment of mine discharge water by lime amendment (also drained prior to placement in the Solids Repository); and/or calcines; and/or depleted wetlands media. The volumes and required staging of these materials will determine if, and if so, the manner in which the Solids Repository is expanded beyond the Phase I area. The likely expansion method would be a starter dike to the west of the Phase I starter dike, followed by placement in the depression between, and ultimately, stacking of solids or other by-products above the Phase I starter dike to the maximum elevations shown on Drawing C-180 (Appendix A).

The activities of the selected construction contractor will be overseen by AR or an AR representative on a full-time, on-site basis. Depending on actual conditions encountered during the course of the work, appropriate adjustments in the means and methods of construction and/or initial placement of solids may be identified. Any such adjustments will be presented to the approving agencies for timely review and approval, and upon approval, implemented by the construction contractor.

In addition to observing the quality of the work, AR and its contractor will also track and record by survey, the depth and volume of solids removed from the IDF, Pond 13, and if applicable the upper ponds, and the location and time of placement in the Solids Repository. Periodic surveys will be made of the solids deposited in the Solids Repository to document the amount and rate of ongoing consolidation.

Daily Cover Material Requirements: A waiver to the requirement for a clean earthen cover over disposed material at the end of each operating day is requested for the Solids Repository. The basis for this request is the nature of the materials that may be disposed. These materials do not include disease related materials, nor litter, but should not be subject to wind erosion with an intermediate cover. Also, adequate amounts of water for use in dust control, if needed, are available at the Rico St. Louis Ponds site.

Intermediate Cover Material Requirements: Intermediate cover will be used after the initial (Phase 1) volume of solids, or other by-products, has been placed within the Solids Repository. The intermediate cover will be placed at a thickness of 18 inches and will likely consist of processed onsite borrow material plus topsoil. The primary purpose of the intermediate cover is to provide protection against wind erosion until such time as additional solids or other by-products are placed in the Solids Repository or until the Solids Repository is closed with a final cover. Adequate cover material volume (excess cut material) will be generated during grading for Phase 1 construction and stored on-site for future use.

Fencing/Site Security: A six foot high chain link fence will be constructed around the Solids Repository site to protect against potential trespassing. During initial operation, the contractor will be responsible for site security. During long-term operation, the operator will be responsible for security. The location of the fence is shown on Drawing C-150 (Appendix A).

Nuisance Control/Wind Blown Solids Control: Solids, or other by-products, will be spread upon receipt at the Solids Repository. A water truck will be provided as needed to control dust. During initial operations, additional care will be exercised to identify conditions, if any, which could result in loss of wind-blown solids, and the operations plan will be modified accordingly. Water for use in dust control can be drawn by pumping from one of the existing lower ponds within the Ponds System or brought in to the site by truck. Anticipated quantities for use in this purpose are minimal.

Fire Prevention: No open burning/incineration will be permitted on the site.

Contamination of Waters: Monitoring of surface and groundwater is ongoing as part of the Ponds System operations and in accordance with the Sampling and Analysis Plan (provided as Appendix D). Additional monitoring of groundwater and surface water specific to the Solids Repository operations is therefore not anticipated.

## 5.3 Waste Characterization Plan

The Solids Repository will not be receiving waste from off-site and will only receive existing solids or other by-products associated with the historic mining/minerals processing operations onsite; therefore a waste characterization plan is not be required. However, if materials such as waste rock or depleted wetlands matrix material require disposal in the Solids Repository, and no analytical data is available to adequately characterize it, the material will be tested to verify that it is not a characteristically hazardous waste for RCRA metals.

## 5.4 Contingency Plan

Hazardous wastes are not expected to be generated from remediation activities associated with the historic mining operations at the site; however, if a material is determined to be hazardous, it will be disposed off-site at an appropriate facility.

If at any point impacts associated with the materials placed within the Solids Repository are suspected of contaminating surface water or groundwater at the site, the source of the impacts will be immediately investigated to determine the cause and remedial measures conducted to remedy the occurrence.

The most likely nuisance condition expected outside of the site boundary would be dust from the solids placed into the Solids Repository. These materials are expected to crust over at the surface, thereby minimizing dust generation from them. However, if dust becomes a problem, dust will be suppressed by application of water or a temporary cover will be placed over the solids to minimize dust generation.

## 5.5 Recordkeeping

Operating records shall be maintained at the site, when they become available, and will include:

- Incoming solids or other by-products volumes – to be documented daily during active periods of operations and loading

- Water quality monitoring results
- Construction as-built details – to be maintained during construction and operation
- Variations from approved design and/or operations procedures
- Location restriction demonstrations – as provided within Section 2.0 of this EDOP
- Inspection records and training procedures
- Design documentation for controlling leachate – as provided within Section 4.0 of this EDOP
- Any demonstrations, certifications, findings, data or documents required by the groundwater sampling and analysis plan (Appendix D) – the HMWMD and the local governing body will be notified of any changes to the groundwater sampling and analysis plan
- Any closure and post-closure care plans, along with any required monitoring, testing, or analytical data
- Cost estimates and financial assurance documentation
- Any demonstration and waiver documentation required in the regulations

A waiver of the requirement to keep records of explosive gas monitoring results is requested. This is consistent with the inapplicability of gas monitoring due to the nature of the solids or other by-products known or potentially to be disposed.

Following closure the operator or owner shall:

- Record a notation on the deed or other instrument normally examined during title search; and
- Notify the CDPHE and the County that the notation has been recorded and a copy placed in the operating record

The notation on the deed must, in perpetuity, notify potential purchasers of the property that the land has been used as a Solids Repository, and that its use is restricted under Section 3.6.1 (7) of the Regulations.

# 6.0 Closure Plan

This section of the EDOP presents the closure plan for the proposed Solids Repository pursuant to applicable requirements in Section 3.5 of the CDPHE regulations pertaining to Solid Waste Sites and Facilities.

## 6.1 Notification

The Owner or Operator shall notify the CDPHE and Dolores County of the intent to close the Solids Repository (or a phase of the Solids Repository). The notice shall be in writing at least sixty days in advance of the closure date. The notice of intent to close shall be placed in the operating record after approval.

## 6.2 Method of Closure

Once placement of solids or other by-products into the Solids Repository is complete, a cover system will be placed over the placed materials and the facility shall be left in a condition of orderliness and good aesthetic appearance capable of blending with the natural surroundings. The cover system is designed to minimize infiltration and erosion.

During operations and solids or other by-products placement into the Solids Repository, final surface contours will be established and constructed. Grades will be determined consistent with anticipated maximum capacity at Final Build-out and provision of proper drainage for the Solids Repository. The entire Solids Repository may remain open until final closure, or, as sections of the Solids Repository are brought to final grade during operation, there is an option to close these sections with the final cover prior to final closure.

## 6.3 Final Cover System

A final cover system will be designed and constructed to protect the solids or other by-products materials from long-term erosion and to limit infiltration into these materials.

Final design grades and drawings will be prepared based on the volume in the Solids Repository and the conditions present at the time of closure. Typically, final grades will include a slope no less than 5.0 percent and no greater than 25.0 percent for proper drainage. However, a variance will likely be requested to allow a maximum final grade up to 33 percent on side slopes. The final cover will extend beyond the limits of solids or other by-products placed in the Solids Repository. The approximate area to be covered by the final cover is estimated to be approximately 1.5 acres if only Phase 1 is built and up to approximately 7.5 acres for a full build-out. The permeability of the final cover shall not exceed that of the bottom liner. The final cover design shall consist of a geomembrane barrier layer and an 18-inch protective soil cover. Detailed discussion of the cover system design is provided in the following subsections.

### 6.3.1 Geomembrane Barrier Layer

The purpose of this layer is to prevent infiltration into the waste solids and thus to prevent the generation of leachate. The barrier layer shall consist of a textured, 60 mil HDPE geomembrane. The barrier layer selection was based on permeability requirements (permeability must be less than

or equal to the permeability of the bottom liner system) and the ability of the geomembrane to handle expected stresses from settlement as well as any predictable mechanical, chemical, and thermal stress during the installation period and during the anticipated long-term use. The geomembrane shall be installed according to the manufacturers' recommended QA/QC procedures and shall include the use of anchor trenches to secure the liner against pullout during the initial stages of final cover construction. If unsuitable subsurface conditions are present for placement of the geomembrane, a 6-inch soil layer of processed, earthen material will be placed beneath the barrier layer to provide a suitable cushioned foundation for placement of the geomembrane.

### 6.3.1 Drainage Layer

The purpose of this layer is to protect the geomembrane barrier layer during installation of the remaining portions of the cover system and to drain the water off of the Repository footprint that collects on the geomembrane. It is anticipated that this layer shall be constructed from granular materials with a minimum thickness of 12 inches and a minimum hydraulic conductivity of $1x10^{-2}$ cm/sec. To ensure that the geomembrane is not damaged, granular material will be free of angular gravel, rocks, or other foreign material that could compromise the integrity of the geomembrane.

### 6.3.2 Protective Soil Cover

Topsoil or processed/amended construction fill will be placed on top of the 12 inch drainage layer to an approximate uncompacted depth of 6 inches. The protective soil cover will be vegetated to provide erosion control and evapotranspiration properties, which minimize infiltration and long-term cover maintenance. The proposed type of vegetation will be native grasses, with root depth compatible with soil cover depth (i.e., no deep taproots), and limited need for fertilizer. The type of vegetation selected shall be based on information gathered from the local NRCS and successful practice at other reclaimed mine sites in similar environments in the general vicinity.

## 6.4 Run-on Control

The run-on control system, discussed in Section 4.7, will be maintained at the east (upslope) side of the Solids Repository to direct offsite drainage away from the Solids Repository during operation and throughout the Solids Repository life (including closure and post-closure periods). The ditch will be constructed to the extent practicable at a location that requires minimal modifications during the life of the facility. Routed water will be discharged to the ponds downstream of the Solids Repository. The overall Ponds System already includes a run-on control ditch, and the routed storm water from the Solids Repository will be combined with this control system. All permanent surface water diversion structures remaining after closure shall control run-on and run-off from the design event, a 100 year, 24-hour storm event.

## 6.5 HELP Modeling

The Hydrological Evaluation of Landfill Performance (HELP) model (Version 3.07) was utilized to model the behavior of the Solids Repository cap and liner system with regard to infiltration to check the adequacy of the design to provide protection of groundwater. The HELP model is a quasi-two-dimensional model accounting for flow across, into, through and out of landfills. The model inputs include weather, soil/materials (including GCL liners), and design data. Model parameters include snowmelt, runoff, infiltration, evaporation, vegetative growth, and vertical drainage. The model creates a water balance to estimate the volume of leachate generated and determine the overall effectiveness of the proposed cover system.

Data inputs and their sources used for modeling the Solids Repository are as follows:

- Evapotranspiration Data. Program default for Grand Junction as modified by monthly climatic data for Rico.
- Historical Precipitation Data. Program default for Grand Junction as modified by monthly climatic data for Rico. Used 100-year synthetic data generation option.
- Temperature Data. Program default for Grand Junction as modified by monthly climatic data for Rico. Used 100-year synthetic data generation option.
- Solar Radiation. Program default for Grand Junction as modified by location (latitude) for Rico.
- Soil Information. Soil data were selected from the built-in set of 42 default textures based on USCS classification and/or USDA classification as appropriate for each soil unit and/or estimated and modified as necessary.

Model results were computed for the following three conditions:

1) Solids repository, closed with final cover after Full Build-out
2) Solids repository, closed with final cover after Phase 1
3) Solids repository, unclosed after Phase 1 (no final cover)

For the Full Build-out closed condition (condition 1 above), the results of the water balance show that approximately 83% of the annual average precipitation is produced as runoff or evapotranspiration from the Solids Repository. The remaining 17% is almost entirely captured by the final cover system. The HELP model has estimated that only 0.056% of the average annual precipitation is expected to infiltrate past the final cover liner and into the solids repository waste to generate leachate. Approximately 97% of the leachate (correlating to approximately 216 cubic feet each year) is captured by the leachate collection system. The remaining leachate seeps through the bottom liner (through pinholes and deficiencies within the liner) and into the subgrade. This correlates to approximately 6.6 cubic feet per year of seepage to the foundation.

For the Phase 1 closed condition (condition 2 above), the results of the water balance show that approximately 83% of the annual average precipitation is produced as runoff or evapotranspiration from the Solids Repository. The remaining 17% is almost entirely captured by the final cover system. The HELP model has estimated that only 0.01% of the average annual precipitation is expected to infiltrate past the final cover liner and into the solids repository waste to generate leachate. Approximately 97% of the leachate (correlating to approximately 16 cubic feet each year) is captured by the leachate collection system. The remaining leachate seeps through the bottom liner (through pinholes and deficiencies within the liner) and into the subgrade. This correlates to approximately 0.2 cubic feet per year of seepage to the foundation.

For the Phase 1 unclosed condition (condition 3 above), the results of the water balance show that approximately 95% of the annual average precipitation is produced as runoff or evapotranspiration from the Solids Repository. The remaining 5% infiltrates into the solids repository waste to generate leachate. Approximately 97% of the leachate (correlating to approximately 5,927 cubic feet each year) is captured by the leachate collection system. The remaining leachate seeps through the bottom liner (through pinholes and deficiencies within the liner) and into the subgrade. This correlates to approximately 31 cubic feet per year of seepage to the foundation.

The model input and output summary is presented in Appendix G.

## 6.6 Reporting Requirements

Upon final closure of any phase, AR will submit a report to CDPHE signed by a Colorado registered professional engineer documenting completion in accordance with the approved closure plan. After approval of the report it will be placed in the operating record.

## 6.7 Closure Schedule

Closure activities of each phase will be started within 30 days of reaching final grades or a request for extension of commencement will be made based on conditions that do not result in a threat to human health and the environment.

Closure activities of each phase will be completed within 180 days following the beginning of closure or an extension will be requested based on the need for greater time and conditions that do not result in a threat to human health and the environment.

# 7.0 Post-Closure Plan

This section of the EDOP presents the post-closure plan for the proposed Solids Repository pursuant to applicable requirements in Section 3.6 of the CDPHE regulations pertaining to Solid Waste Sites and Facilities. The name, address, and telephone number of the person or office to contact about the facility during the post-closure period will be included in this plan prior to closure.

## 7.1 Notification

At the completion of the post-closure care period, AR will notify the CDPHE and Dolores County that post-closure care has been completed in accordance with the post-closure plan and that this condition is certified to by a Colorado registered professional engineer with the certification placed in the operating record.

## 7.2 Post Closure Care

Following closure, post-closure care will be conducted which will, at a minimum, consist of nuisance control, periodic inspections and maintenance, and continued groundwater monitoring.

### 7.2.1 Nuisance Control

Provisions will be implemented for control of any nuisances identified during the operational phase of the project that are anticipated to continue during post-closure.

### 7.2.2 Inspections and Maintenance

Inspection will be scheduled on a routine basis, at a minimum annually after the spring runoff and after major storms, or more frequently if found necessary through operational experience. The final cover will be inspected for any detrimental effects of settlement, subsidence, or erosion. The storm water control systems will be inspected for potential damage or blockage within drainage channels and ponds. Any damage to the final cover or storm water controls will be repaired once identified. The leachate collection system will be periodically observed for discharge rate, changes in discharge rate or appearance, and to ensure that the conduit is free of blockage. Maintenance and inspections will be properly documented including date, findings and action taken.

### 7.2.3 Groundwater Monitoring

The groundwater monitoring system will be maintained in accordance with the overall site SAP (Appendix D) and QAPP (Appendix E).

## 7.3 Future Land Uses

A description of planned uses of the property during post-closure will be provided at the time of final closure when the final geometry of the Solids Repository is determined. Proposed uses will be consistent with the requirements of the regulations and will not disturb the function or integrity of the final cover, liner, monitoring systems, or any other component of the Solids Repository, unless necessary to comply with the requirements in the CDPHE regulations. CDPHE may approve disturbance of the final cover, liner, or other components if AR demonstrates that this disturbance,

including any removal of waste, will not increase the potential threat to human health or the environment.

## 7.4 Post-Closure Care Period

Typically, the post-closure care will be maintained for a minimum of thirty (30) years. However, a reduction in the post-closure care period from the normal minimum of 30 years to that of a 10-year period is requested in this application due to the characteristics of the materials to be disposed. Potential issues, if any, will be identified in this period and settlement and erosion conditions stabilized, allowing cessation of post-closure monitoring, maintenance and care activities.

## 7.5 Certification

Following completion of the post-closure care period AR will notify CDPHE that a certification signed by an independent Colorado registered professional engineer or approved by CDPHE and Dolores County, verifying that post-closure care has been completed in accordance with the post-closure plan, has been placed in the operating record.

# 8.0 Final Engineering and Hydrogeologic Approvals

This EDOP, including all portions of the facility design, associated figures, and closure and post-closure plans, has been reviewed and sealed by a duly registered Colorado professional engineer.

# 9.0 References

AR, 2011. *Initial Solids Removal Plan, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico, Colorado*; submitted by Atlantic Richfield Company to EPA May 2, 2011.

AR, 2012. *Pond 15 Solids Removal Work Plan, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico, Colorado*; submitted by Atlantic Richfield Company to EPA, August 3, 2012.

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AR, 2013a. *Quality Assurance Project Plan For Surface Water and Groundwater, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico, Colorado*; submitted by Atlantic Richfield Company to EPA May 23, 2013.

AR, 2013b. *Sampling and Analysis Plan For Surface Water and Groundwater, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico, Colorado*; submitted by Atlantic Richfield Company to EPA May 23, 2013.

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USEPA, 2011b. *Removal Action Work Plan, Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Rico*, Colorado dated March 9, 2011.

USGS, 2013a. United States Geological Survey, Earthquake Hazard Program. Provides an interactive fault map graphically presenting Quaternary Fault and Fold Database of the United States. http://earthquake.usgs.gov/hazards/qfaults/map/, Accessed December 11, 2013.

USGS, 2013b. United States Geological Survey, Geologic Hazards Science Center. This web application provides access to hazard curves generated for the 2008 National Seismic Hazard Mapping Project (NSHMP). http://geohazards.usgs.gov/hazardtool/, Accessed December 11, 2013.

# Tables

# Table 1 - List of Property Owners within 1/2 Mile of Proposed Solids Repository Site Boundary

| PIN | Owner | Address | City | State | Zip |
|---|---|---|---|---|---|
| 504725200003 | HURLEY WILLIAM F. C/O CAROL GENTRY | P.O. BOX 312 | RIFLE | CO | 816500000 |
| 504725200038 | HURLEY WILLIAM F. C/O CAROL GENTRY | P.O. BOX 312 | RIFLE | CO | 816500000 |
| 504726400007 | JAMMER, LLC | 785 MANOR HILL PLACE | SUGAR GROVE | IL | 605540000 |
| 504725200002 | MAGNESS JEAN ET AL | P.O. BOX 176 | CAHONE | CO | 813200000 |
| 504725200039 | MAGNESS JEAN ET AL | P.O. BOX 176 | CAHONE | CO | 813200000 |
| 504724300010 | MATZICK HELEN M. | 1555 BLAKE ST #908 | DENVER | CO | 802020000 |
| 504726100012 | MATZICK HELEN M. | 1555 BLAKE ST #908 | DENVER | CO | 802020000 |
| 504726100018 | MATZICK HELEN M. | 1555 BLAKE ST #908 | DENVER | CO | 802020000 |
| 504725200005 | MC CLELLAN CASEY & RICHARD (TIC) | P.O. BOX 1646 | CORTEZ | CO | 813210000 |
| 504725200037 | MC CLELLAN CASEY & RICHARD (TIC) | P.O. BOX 1646 | CORTEZ | CO | 813210000 |
| 504723400019 | MOORE MURLENE C. TESTAMENTARY TRUST | 28655 PORTSMOUTH DR. | SUN CITY | CA | 925860000 |
| 504725200057 | RICO DEVELOPMENT CORPORATION C/O JANICE GRAHAM | 34693 POWELL MESA ROAD | HOTCHKISS | CO | 814190000 |
| 504724400006 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504724400043 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725100001 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725100012 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725100041 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200009 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200016 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200025 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200036 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200040 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725300023 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725300047 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725400010 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725400028 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725400035 | RICO HIGH ALTITUDE INVESTMENTS | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504724300012 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504724300021 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504724400024 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725100006 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725100007 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200004 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725200027 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725300049 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725300050 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725400015 | RICO MOUNTAIN LIFE LLC. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504724300027 | RICO PROPERTIES L.L.C. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504725300054 | RICO PROPERTIES L.L.C. | P.O. BOX 924 | DOLORES | CO | 813230000 |

## Table 1 - List of Property Owners within 1/2 Mile of Proposed Solids Repository Site Boundary

| PIN | Owner | Address | City | State | Zip |
|---|---|---|---|---|---|
| 504725400008 | RICO PROPERTIES L.L.C. | P.O. BOX 924 | DOLORES | CO | 813230000 |
| 504701100002 | SAN JUAN NATIONAL FOREST, DEPT. OF AGRICULTURE | 15 BURNETTE COURT | DURANGO | CO | 813010000 |
| 504724400030 | SELL, DAVID L. C/O MC MICHAEL, SELL & AGRESTI | 12122 W. ATLANTIC DR. | LAKEWOOD | CO | 802280000 |
| 504725200026 | SILVER CREEK LAND, LLC | P.O. BOX 1511 | IDAHO SPRINGS, | CO | 805420000 |
| 504723400013 | YOUNG, JONATHAN M. & NEUMANN, MELISSA (JT) | P.O. BOX 3043 | TELLURIDE | CO | 814350000 |

**Notes:**

Information provided by County Assessors Office, 2012

# Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| AR-104 | 0.5-2.5 | - | 12 | - | - | - | - | 25 | 6 | - | - | - | - | - |
| AR-104 | 3-5 | - | 13.6 | - | - | - | - | - | - | - | - | - | - | - |
| AR-104 | 5.5-7.5 | - | 18.1 | - | - | - | - | - | - | - | - | - | - | - |
| AR-104 | 8-10 | - | 13.3 | - | - | - | - | - | - | - | - | - | - | - |
| AR-104 | 10-12.5 | - | 12.4 | - | - | - | - | - | - | - | - | - | - | - |
| AR-104 | 13-15 | - | 18.2 | - | - | - | - | - | - | - | - | - | - | - |
| B-1 | 13 | - | - | - | - | - | 14 | - | - | - | - | - | - | - |
| B-2 | 9.5 | - | - | - | 37 | 41 | 22 | 32 | 15 | - | - | - | - | - |
| B-3 | 6 | - | - | - | - | - | 42 | - | - | - | - | - | - | - |
| B-4 | 9.5 | - | 15 | - | 41 | 37 | 22 | 27 | 6 | - | - | - | - | - |
| B-5 | 20 | - | - | - | - | - | 43 | - | - | - | - | - | - | - |
| MW-202 | 0-1.5 | SONIC | 19 | - | 57 | 30 | 13 | NV | NP | - | - | - | - | - |
| MW-202 | 1.5-6 | SONIC | 20 | - | 35 | 40 | 25 | 30 | 21 | 128 | 9 | - | 2.65 | - |
| MW-202 | 6-9 | SONIC | 14.1 | - | - | - | - | - | - | - | - | - | - | - |
| MW-202 | 9-12 | SONIC | 18.2 | - | - | - | - | - | - | - | - | - | - | - |
| MW-202 | 12-18 | SONIC | 24 | - | 20 | 70.7 | 9.3 | 30 | 21 | 125.1 | 10.4 | - | 2.65 | - |
| MW-202 | 18-23 | SONIC | 13.1 | - | 20 | 70.7 | 9.3 | 30 | 21 | 125.1 | 10.4 | - | 2.65 | - |
| MW-202 | 23-30 | SONIC | 36 | - | 20 | 70.7 | 9.3 | 30 | 21 | 125.1 | 10.4 | - | 2.65 | - |
| MW-202 | 30-35.5 | SONIC | 9.7 | - | - | - | - | - | - | - | - | - | - | - |
| MW-5D | 7 | SS | 28.2 | - | - | - | - | - | - | - | - | - | - | SP |
| MW-5D | 6-15 | BULK | - | - | 0 | 64 | 36 | - | - | 104.8 | 28.5 | - | 4.48 | SC* |
| MW-5D | 17 | SS | 60 | - | - | - | - | NP | NP | - | - | - | - | SP-SM |
| MW-5D | 15-20 | BULK | - | - | 0 | 30 | 70 | - | - | 95.7 | 35.1 | - | 4.59 | ML* |
| MW-5D | 22 | SS | - | - | - | - | - | - | - | - | - | - | - | Org. ML-OL |
| MW-5D | 26 | SS | 18.7 | - | - | - | - | - | - | - | - | - | - | GW-GM |
| MW-5D | 25-30 | BULK | - | - | 70 | 20 | 10 | - | - | - | - | - | - | GW-GM* |
| MW-5D | 31 | SS | 41 | - | - | - | - | - | - | - | - | - | - | GW-GM |
| MW-5D | 30-35 | BULK | - | - | 72 | 21 | 7 | - | - | - | - | - | - | GW-GM |
| MW-6D | 1 | SS | 7.8 | - | - | - | - | - | - | - | - | - | - | GW-GM |
| MW-6D | 0-3.5 | BULK | - | - | 55 | 28 | 17 | - | - | 136.1 | 8.2 | - | - | GW-GM |
| MW-6D | 5 | SS | 9.8 | - | - | - | - | 26 | 6 | - | - | - | - | GC |
| MW-6D | 3.5-7.5 | BULK | - | - | 47 | 34 | 19 | - | - | 127 | 12.1 | - | - | GC |
| MW-6D | 10 | SS | 9.1 | - | - | - | - | - | - | - | - | - | - | GC |
| MW-6D | 14 | SS | 6 | - | - | - | - | - | - | - | - | - | - | GW-GM |
| MW-6D | 18 | SS | 26.4 | - | - | - | - | 42 | 14 | - | - | - | - | ML-OL |
| MW-6D | 17.5-20 | BULK | - | - | 19 | 29 | 52 | - | - | - | - | - | - | ML-OL |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| MW-6D | 25 | SS | 18.4 | - | - | - | - | 22 | 4 | - | - | - | - | SC |
| MW-6D | 33 | SS | 24.1 | - | - | - | - | - | - | - | - | - | - | GW |
| MW-6D | 31.5-36.5 | BULK | - | - | 48 | 30 | 22 | - | - | - | - | - | - | GM* |
| PDF-1 | 1 | SS | 8.5 | - | 57 | 31 | 12 | - | - | - | - | - | - | GW-GM* |
| PDF-1 | 4 | SS | 15.5 | - | 0 | 72 | 28 | NP | NP | - | - | - | - | SM |
| PDF-1 | 11 | SS | 22.3 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-1 | 16 | SS | 216.7 | - | 0 | 57 | 43 | - | - | - | - | - | - | SM |
| PDF-1 | 21 | SS | 46.5 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-1 | 33 | SS | 10.9 | - | 65 | 26 | 9 | - | - | - | - | - | - | GW-GM* |
| PDF-1 | 38 | SS | 29.1 | - | - | - | - | - | - | - | - | - | - | SW |
| PDF-1 | 43 | SS | 15.5 | - | - | - | - | - | - | - | - | - | - | SW |
| PDF-1 | 48 | SS | 23.7 | - | 1 | 75 | 24 | - | - | - | - | - | - | SM* |
| PDF-2 | 2 | SS | 17.5 | - | - | - | - | NP | NP | - | - | - | - | SM |
| PDF-2 | 2-5 | BULK | - | - | 0 | 75 | 25 | - | - | - | - | - | - | SM |
| PDF-2 | 6 | SS | 20.4 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-2 | 11 | SS | 29.9 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-2 | 10-15 | BULK | - | - | 0 | 63 | 37 | - | - | - | - | - | - | SM |
| PDF-2 | 17 | SS | 55.9 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-2 | 21 | SS | 62.6 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-2 | 20-25 | BULK | - | - | 4 | 51 | 45 | - | - | - | - | - | - | SM |
| PDF-2 | 28 | SS | 41 | - | - | - | - | - | - | - | - | - | - | GW-GM |
| PDF-2 | 27-30 | BULK | - | - | 66 | 18 | 16 | - | - | - | - | - | - | GM* |
| PDF-3 | 0-3.5 | BULK | - | - | 34 | 51 | 15 | - | - | 131.7 | 7.8 | - | - | SM* |
| PDF-3 | 4 | SS | 19 | - | - | - | - | 27 | NP | - | - | - | - | GC |
| PDF-3 | 9 | SS | 30.2 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-3 | 10-12 | BULK | - | - | 0 | 8 | 92 | - | - | - | - | - | - | ML* |
| PDF-3 | 19 | SS | 39.5 | - | - | - | - | - | - | - | - | - | - | SM |
| PDF-3 | 24 | SS | 53.7 | - | - | - | - | 40 | NP | - | - | - | - | ML-OL |
| PDF-3 | 23-25 | BULK | - | - | 0 | 16 | 84 | - | - | - | - | - | - | ML-OL |
| SSR-1 | 1 | SS | 9.6 | - | - | - | - | 29 | 12 | 136.8 | 6.8 | - | - | CL |
| SSR-1 | 7 | SS | 9.5 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-1 | 10 | SS | 4 | - | 60 | 27 | 13 | 24 | NP | - | - | - | - | GC* |
| SSR-1 | 17 | SS | 8.2 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-1 | 24 | SS | 12.1 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-1 | 30 | SS | 10 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-1 | 35 | SS | 11 | - | - | - | - | - | - | - | - | - | - | CL |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| SSR-1 | 48 | SS | 5.8 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-1 | 57 | SS | 9.7 | - | - | - | - | - | - | - | - | - | - | SW |
| SSR-1 | 63 | SS | 11.3 | - | - | - | - | - | - | - | - | - | - | GM |
| SSR-1 | 76 | SS | 16 | - | - | - | - | - | - | - | - | - | - | SM |
| SSR-1 | 90 | SS | 10.7 | - | - | - | - | - | - | - | - | - | - | SW |
| SSR-101 | 0-1.5 | SS | 14 | - | 48 | 33.9 | 18.1 | - | - | - | - | - | - | - |
| SSR-101 | 2.5-4 | SS | 13.9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 5-6.5 | SS | 27.5 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 7.5-9 | SS | 12.9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 10-11.5 | SS | 13.1 | - | 42 | 37.3 | 20.7 | - | - | - | - | - | - | - |
| SSR-101 | 12.5-14 | SS | 17.4 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 15-16.5 | SS | 15.9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 17.5-19 | SS | 9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 20-21.5 | SS | 24 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 25-25.5 | SS | 6.8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 27.5-29 | SS | 10.8 | - | 40 | 37.8 | 22.2 | - | - | - | - | - | - | - |
| SSR-101 | 28-28.5 | SS | 34.7 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 28.5-29 | SS | 44.9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 31.5-32.5 | SS | 9.6 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 35-36.5 | SS | 13.7 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 45-46.5 | SS | 30.7 | - | - | - | 13.5 | - | - | - | - | - | - | - |
| SSR-101 | 50-51.5 | SS | 15.8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 56.5-58 | SS | 14 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 60-61.5 | SS | 17 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 65-66.5 | SS | 12.4 | - | - | - | 16 | - | - | - | - | - | - | - |
| SSR-101 | 70-71.5 | SS | 24.8 | - | 0 | 80.6 | 19.4 | - | - | - | - | - | - | - |
| SSR-101 | 75-76.5 | SS | 24 | - | - | - | 15.3 | - | - | - | - | - | - | - |
| SSR-101 | 80-81.5 | SS | 25 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 85-86.5 | SS | 23.5 | - | - | - | 8.1 | - | - | - | - | - | - | - |
| SSR-101 | 91.4-92.9 | SS | 22 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 95-96.5 | SS | 14.6 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 100-101.5 | SS | 13.3 | - | 9 | 84.7 | 6.3 | - | - | - | - | - | - | - |
| SSR-101 | 105-106.5 | SS | 18.4 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 110-111.5 | SS | 18.1 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 115-116.5 | SS | 26.5 | - | - | - | 10.4 | NV | NP | - | - | - | - | - |
| SSR-101 | 120-121.5 | SS | 16.3 | - | - | - | - | - | - | - | - | - | - | - |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| SSR-101 | 125-126.5 | SS | 31.8 | - | - | - | 54.7 | - | - | - | - | - | - | - |
| SSR-101 | 132-133.5 | SS | 26.5 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 137-138.5 | SS | 21.6 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 156-157.5 | SS | 6.8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-101 | 160.5-162 | SS | 34.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 2.5-4 | SS | 7.9 | - | 26 | 47 | 27 | - | - | - | - | - | - | - |
| SSR-102 | 5-6.5 | SS | 11.2 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 7.5-9 | SS | 14.7 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 10-11.5 | SS | 12.1 | - | 42 | 36.4 | 21.6 | NV | NP | - | - | - | - | - |
| SSR-102 | 12.5-14 | SS | 8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 15-16.5 | SS | 11.1 | - | - | - | 11.4 | - | - | - | - | - | - | - |
| SSR-102 | 17.5-19 | SS | 12.1 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 20-21.5 | SS | 19.4 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 24.5-26 | SS | 14.9 | - | 52 | 33.1 | 14.9 | - | - | - | - | - | - | - |
| SSR-102 | 27.5-29 | SS | 25.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 32.5-34 | SS | 16.2 | - | 35 | 35.8 | 29.2 | - | - | - | - | - | - | - |
| SSR-102 | 45.5-46.5 | SS | 17.7 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 50.5-52 | SS | 19.1 | - | - | - | 19.1 | - | - | - | - | - | - | - |
| SSR-102 | 57-58.5 | SS | 15.9 | - | - | - | 15.9 | - | - | - | - | - | - | - |
| SSR-102 | 61-62.5 | SS | 17.5 | - | - | - | 17.5 | - | - | - | - | - | - | - |
| SSR-102 | 66.5-68 | SS | 25.4 | - | - | - | 25.4 | - | - | - | - | - | - | - |
| SSR-102 | 71.5-73 | SS | 25.5 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 76.5-78 | SS | 24.5 | - | - | - | - | NV | NP | - | - | - | - | - |
| SSR-102 | 81.5-83 | SS | 25.5 | - | - | - | 79 | NV | NP | - | - | - | - | - |
| SSR-102 | 86.5-88 | SS | 25.9 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 91.5-93 | SS | 24.8 | - | - | - | 94.6 | - | - | - | - | - | - | - |
| SSR-102 | 96.5-98 | SS | 21.2 | - | - | - | 51.4 | - | - | - | - | - | - | - |
| SSR-102 | 101.5-103 | SS | 27.4 | - | - | - | 83.2 | NV | NP | - | - | - | - | - |
| SSR-102 | 106.5-108 | SS | 31 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 111.5-113 | SS | 26.9 | - | - | - | 52.5 | - | - | - | - | - | - | - |
| SSR-102 | 121.5-123 | SS | 10.6 | - | 42 | 45.7 | 12.3 | - | - | - | - | - | - | - |
| SSR-102 | 126.5-128 | SS | 17.4 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-102 | 136-136.3 | SS | 7.7 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-103 | 0-5 | BAGGIE | 11.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-103 | 10-13 | BAGGIE | 12.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-103 | 25-30 | BAGGIE | 7.2 | - | - | - | - | - | - | - | - | - | - | - |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| SSR-103 | 5-35 | BULK | 2.4 | - | 43 | 37.1 | 19.9 | 28 | 8 | - | - | - | - | - |
| SSR-103 | 60-65 | BAGGIE | 10.8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-103 | 37-70 | BULK | 6.5 | - | 29 | 42 | 29 | - | - | - | - | - | - | - |
| SSR-103 | 80-86 | BAGGIE | 11.1 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-103 | 70-87 | BULK | 8.8 | - | 17 | 47.9 | 35.1 | - | - | - | - | - | - | - |
| SSR-104 | 0-5 | SONIC | 6.7 | - | 44 | 34.5 | 21.5 | - | - | - | - | - | - | - |
| SSR-104 | 5-8 | SONIC | 5.4 | - | 52 | 28.4 | 19.6 | - | - | - | - | - | - | - |
| SSR-104 | 8-10 | SS | 15.5 | - | 0 | 0 | 0 | - | - | - | - | - | - | - |
| SSR-104 | 10-15 | SS | 41.8 | - | 0 | 0 | 0 | - | - | - | - | - | - | - |
| SSR-104 | 17.5-20 | SONIC | 5.6 | - | 51 | 33.7 | 15.3 | NV | NP | - | - | - | - | - |
| SSR-104 | 17.5-32.5 | SONIC | - | - | - | - | - | - | - | 131.5 | 8.1 | - | 2.65 | - |
| SSR-104 | 20-22.5 | SS | 8.1 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 22.5-25 | SONIC | 4.9 | - | - | - | 20.5 | - | - | - | - | - | - | - |
| SSR-104 | 25-27.5 | SS | 8.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 30-32.5 | SONIC | 7 | - | - | - | 16.5 | - | - | - | - | - | - | - |
| SSR-104 | 32.5-35 | SONIC | 8.2 | - | - | - | - | 26 | 7 | - | - | - | - | - |
| SSR-104 | 35-40 | SS | 1.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 40-45 | SONIC | 10 | - | 41 | 38.3 | 20.7 | NV | NP | - | - | - | - | - |
| SSR-104 | 45-47.5 | SONIC | 11.5 | - | - | - | 25.7 | - | - | - | - | - | - | - |
| SSR-104 | 47.5-48.5 | SS | 10.3 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 48.5-50 | SONIC | 7.1 | - | - | - | 23 | - | - | - | - | - | - | - |
| SSR-104 | 50-52.5 | SONIC | 12.4 | - | 47 | 34.3 | 18.7 | 27 | 9 | - | - | - | - | - |
| SSR-104 | 52.5-55 | SS | 8.1 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 55-56.5 | SONIC | 9.3 | - | - | - | 24.1 | - | - | - | - | - | - | - |
| SSR-104 | 56.5-60 | SS | 8.5 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 60-62.5 | SONIC | 13.6 | - | - | - | 20.6 | - | - | - | - | - | - | - |
| SSR-104 | 62.5-65 | SONIC | 6.4 | - | 52 | 32.1 | 15.9 | 27 | 7 | - | - | - | - | - |
| SSR-104 | 65-70 | SONIC | 4.9 | - | - | - | 16.6 | - | - | - | - | - | - | - |
| SSR-104 | 70-71.5 | SS | 7.5 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 71.5-75 | SONIC | 8.8 | - | - | - | 18.5 | - | - | - | - | - | - | - |
| SSR-104 | -76.5&77.5-81 | SONIC | 10.7 | - | 42 | 33 | 25 | 33 | 10 | - | - | - | - | - |
| SSR-104 | 76.5-77.5 | SS | 8 | - | - | - | - | - | - | - | - | - | - | - |
| SSR-104 | 81.5-85 | SONIC | 7.6 | - | - | - | 18 | - | - | - | - | - | - | - |
| SSR-104 | 85-89 | SONIC | 8.9 | - | 41 | 31.1 | 27.9 | 28 | 9 | - | - | - | - | - |
| SSR-104 | 89-93 | SONIC | 10 | - | - | - | 34.5 | - | - | - | - | - | - | - |
| SSR-104 | 93-96 | SS | 3.2 | - | - | - | - | - | - | - | - | - | - | - |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| SSR-104 | 96-102 | SONIC | 4.4 | - | - | - | 14.3 | - | - | - | - | - | - | - |
| SSR-104 | 102-104 | SONIC | 9.7 | - | - | - | - | 30 | 11 | - | - | - | - | - |
| SSR-2 | 2 | SS | 9.8 | - | - | - | - | 28 | 9 | - | - | - | - | CL-OL* |
| SSR-2 | 0-6 | BULK | - | - | - | - | - | - | - | 118.8 | 10.4 | - | - | ML |
| SSR-2 | 7 | SS | 6.9 | - | - | - | - | 28 | 10 | - | - | - | - | CL |
| SSR-2 | 6-12 | BULK | - | - | - | - | - | - | - | 121.1 | 9.9 | - | - | CL |
| SSR-2 | 12 | SS | 7.9 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-2 | 17 | SS | 12.4 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-2 | 24 | SS | 16 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-2 | 31 | SS | 20.5 | - | - | - | - | 28 | 11 | 11 | - | - | - | CL* |
| SSR-2 | 36 | SS | 28.8 | - | - | - | - | - | - | - | - | - | - | GC |
| SSR-2 | 66 | SS | 10.4 | - | 56 | 30 | 14 | - | - | - | - | - | - | GM |
| SSR-2 | 75 | SS | 37.7 | - | 55 | 34 | 11 | - | - | - | - | - | - | GM |
| SSR-3 | 2 | SS | - | - | - | - | - | - | - | - | - | - | - | GW-GC |
| SSR-3 | 8 | SS | - | - | - | - | - | - | - | - | - | - | - | GC |
| SSR-3 | 13 | SS | 15.4 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-3 | 18 | SS | - | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-3 | 30 | SS | 15 | - | - | - | - | - | - | - | - | - | - | CL |
| SSR-3 | 37 | SS | 20.2 | - | - | - | - | - | - | - | - | - | - | GC |
| SSR-3 | 39 | SS | 11.1 | - | - | - | - | - | - | - | - | - | - | GW-GC |
| SSR-3 | 53 | SS | 11.6 | - | - | - | - | - | - | - | - | - | - | GW-GC |
| SSR-3 | 70 | SS | 8.1 | - | - | - | - | - | - | - | - | - | - | GW-GC |
| SSR-3 | 76 | SS | 7.5 | - | - | - | - | - | - | - | - | - | - | SP |
| SSR-3 | 87A | SS | 7.9 | - | - | - | - | - | - | - | - | - | - | SP |
| SSR-3 | 87B | SS | 8.5 | - | - | - | - | - | - | - | - | - | - | SP |
| SSR-3 | 91 | SS | 19.3 | - | - | - | - | - | - | - | - | - | - | SW |
| SSR-3 | 95 | SS | 18.5 | - | - | - | - | - | - | - | - | - | - | SP-SM |
| SSR-4 | 0-4 | BULK | 7.5 | - | 36 | 38 | 26 | 24 | 4 | 126.6 | 10.3 | - | - | SM* |
| SSR-5 | 0-4 | BULK | 6.5 | - | 57 | 33 | 10 | - | - | 132.8 | 7.3 | - | - | GW-GM* |
| SSR-5 | 6 | SS | 12.4 | - | 21 | 48 | 31 | 25 | 2 | - | - | - | - | SM* |
| SSR-5 | 9 | SS | 29.3 | - | 12 | 23 | 65 | - | - | - | - | - | - | ML* |
| SSR-5 | 13 | SS | 25.6 | - | - | - | - | - | - | - | - | - | - | SM |
| SSR-5 | 17 | SS | 42.9 | - | 1 | 30 | 69 | - | - | - | - | - | - | ML* |
| SSR-5 | 22 | SS | 76.7 | - | 2 | 42 | 56 | - | - | - | - | - | - | ML* |
| SSR-5 | 27 | SS | 13.2 | - | - | - | - | 21 | 1 | - | - | - | - | GC |
| SSR-5 | 32 | SS | 10.3 | - | - | - | - | - | - | - | - | - | - | - |

## Table 2 - Summary of Laboratory Index Test Results

| Sample Location | | | ASTM D2216 | ASTM D6938 | CP-31[1] | | | ASTM D4318 | | ASTM D698 | | Hand Penet. | AASHTO T85 | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring/ Test Pit | Depth (ft) | Type | Natural Moisture Content (%) | Dry Unit Weight (pcf) | Gravel > #4 (%) | Sand (%) | Fines < #200 (%) | LL | PI | MDD (pcf) | OMC (%) | Unconfined Compressive Strength (psf) | Specific Gravity | Soil Classification |
| SSR-5 | 40 | SS | 23.8 | - | - | - | - | - | - | - | - | - | - | SW |
| SSR-5 | 40-45 | BULK | - | - | 4 | 85 | 11 | - | - | - | - | - | - | SW-SM* |
| SSR-5 | 48 | SS | 26.9 | - | - | - | - | - | - | - | - | - | - | SP |
| SSR-5 | 47-50 | BULK | - | - | 0 | 61 | 39 | - | - | - | - | - | - | SM* |
| SSR-5 | 57 | SS | 27.9 | - | - | - | - | - | - | - | - | - | - | SM |
| SSR-5 | 55-60 | BULK | - | - | 0 | 51 | 49 | - | - | - | - | - | - | SM |
| TP2004F | 0-12.0 | BULK | - | - | - | - | - | - | - | - | - | - | - | - |
| TP2004G | 0-12.0 | BULK | - | - | - | - | - | - | - | - | - | - | - | - |
| TP2004H | 0-12.0 | BULK | - | - | - | - | - | - | - | - | - | - | - | - |
| TP2004I | 0-12.0 | BULK | - | - | - | - | - | - | - | - | - | - | - | - |
| TP2011-17 | 0-20 | BULK | - | - | 47 | 36 | 17 | 30 | 18 | 124.6 | 11.5 | - | 2.65 | GC |
| TP2011-18 | 0-20 | BULK | - | - | 43 | 41 | 16 | 29 | 8 | - | - | - | - | GC |
| TP2011-19 | 0-20 | BULK | - | - | 45 | 39 | 16 | 28 | 7 | 127.1 | 9.6 | - | - | GC-CM |
| TP2013-08 | | | | | | | | | | | | | | |
| TP2013-09 | | | | | | | | | | | | | | |
| TP2013-10 | | | | | | | | | | | | | | |
| TP2013-11 | | | | | | | | | | | | | | |

**Notes:**

[1] CP-31 is a sieve analysis method established by the Colorado Department of Transportation that modifies AASHTO T11 and T27.

# Table 3 - Groundwater Well Elevations (Repository Design)

| Date | GW-5 | GW-6 | GW-7 | GW-8 | EB-1 | EB-2 | MW-5 DEEP | MW-5 SHALLOW | MW-6 DEEP | MW-6 SHALLOW | MW-101 | MW-102 | MW-202 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-02 | 8823.5 | 8823 | 8820.00 | 8806.00 | | | | | | | | | |
| Nov-04 | 8819.88 | 8822.49 | 8818.70 | 8810.62 | 8819.40 | 8818.83 | | | | | | | |
| May-05 | 8824.79 | 8823.85 | 8825.05 | 8821.34 | | | | | | | | | |
| Aug-05 | 8822.44 | 8822.20 | 8822.69 | 8817.57 | | | | | | | | | |
| Jan-06 | 8818.60 | 8818.76 | 8817.25 | 8814.98 | | | | | | | | | |
| Jul-06 | 8819.91 | 8818.80 | 8818.61 | 8815.77 | 8819.58 | 8813.62 | | | | | | | |
| Jul-10 | | | | | | | | | | | | | |
| Jul-10 | 8820.48 | 8814.35 | 8819.87 | | | 8814.26 | | | | | | | |
| Jul-10 | 8820.14 | 8814.07 | 8819.35 | | | 8814.05 | | | | | | | |
| Aug-10 | 8820.27 | 8817.76 | 8818.96 | | | 8814.04 | | | | | | | |
| Sep-10 | 8819.67 | 8817.33 | 8818.52 | | | 8813.67 | | | | | | | |
| Oct-10 | 8819.27 | 8816.68 | 8818.04 | | | 8813.49 | | | | | | | |
| Nov-10 | 8817.88 | 8816.03 | 8817.23 | | | 8813.07 | | | | | | | |
| Dec-10 | 8817.72 | 8815.97 | 8818.89 | | | 8812.92 | | | | | | | |
| Jan-11 | 8818.27 | | | | | | | | | | | | |
| Feb-11 | | | | | | | | | | | | | |
| Mar-11 | 8817.66 | | | | | 8813.10 | | | | | | | |
| Apr-11 | 8819.79 | 8817.73 | 8819.19 | | | 8814.23 | | | | | | | |
| Apr-11 | 8820.02 | 8816.3 | 8819.34 | | | 8814.47 | | | | | | | |
| Apr-11 | 8820.33 | 8816.55 | 8819.64 | | | 8814.69 | | | | | | | |
| May-11 | 8821.02 | 8818.81 | 8815.85 | | 8804.51 | 8803.54 | | | | | | | |
| Jun-11 | 8821.65 | 8817.78 | 8821.95 | | 8804.44 | 8808.57 | | | | | | | |
| Jul-11 | 8820.07 | 8816.33 | 8820.14 | | 8803.50 | 8807.47 | | | | | | | |
| Aug-11 | 8819.04 | 8815.32 | 8818.93 | | 8802.32 | 8806.81 | | | | | | | |
| Sep-11 | 8818.37 | 8814.48 | 8817.89 | | 8801.58 | 8806.61 | | | | | | | |
| Oct-11 | 8818.32 | 8816.68 | 8817.38 | | 8801.88 | 8806.75 | | | | | | | |
| Nov-11 | 8818.09 | CNO | 8817.41 | | 8801.65 | 8806.56 | 8813.67 | 8815.1 | 8807.37 | 8807.74 | | | |
| Dec-11 | 8817.65 | CNO | 8817.00 | | 8801.22 | 8806.44 | 8813.4 | 8814.76 | 8806.95 | 8807.35 | | | |
| Jan-12 | 8817.30 | CNO | 8816.80 | | 8801.00 | 8806.30 | 8813.15 | 8814.40 | 8806.72 | 8807.07 | | | |
| Feb-12 | 8817.30 | CNO | 8816.80 | | 8817.36 | 8813.23 | 8813.12 | 8814.15 | 8806.70 | 8807.09 | | | |
| Mar-12 | 8818.22 | CNO | 8817.08 | | 8801.83 | 8806.46 | 8813.67 | 8814.24 | CNO | 8807.78 | | | |

# Table 3 - Groundwater Well Elevations (Repository Design)

| Date | GW-5 | GW-6 | GW-7 | GW-8 | EB-1 | EB-2 | MW-5 DEEP | MW-5 SHALLOW | MW-6 DEEP | MW-6 SHALLOW | MW-101 | MW-102 | MW-202 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr-12 | 8819.48 | CNO | 8819.30 | | 8819.32 | 8814.44 | 8814.54 | 8816.03 | 8808.30 | 8808.93 | | | |
| May-12 | 8818.85 | CNO | 8820.48 | | 8818.75 | 8813.87 | 8814.19 | 8815.59 | 8807.74 | 8808.23 | | | |
| Jun-12 | 8818.29 | CNO | 8817.79 | | 8818.19 | 8813.42 | 8813.78 | 8815.20 | 8807.27 | 8807.72 | | | |
| Jul-12 | 8817.95 | CNO | 8817.42 | | 8817.96 | 8813.24 | 8813.57 | 8815.05 | 8807.21 | 8807.62 | | | |
| Aug-12 | 8817.62 | 8815.98 | 8817.09 | | 8817.56 | 8812.98 | 8813.39 | 8814.86 | 8807.13 | 8807.47 | | | |
| Sep-12 | 8817.28 | 8815.72 | 8816.91 | | 8800.85 | 8806.00 | 8813.16 | 8814.57 | 8806.80 | 8807.20 | | | |
| Oct-12 | 8818.56 | 8816.67 | 8817.09 | | 8802.13 | 8806.63 | 8813.84 | 8814.51 | 8807.25 | 8807.68 | | | |
| Nov-12 | 8818.02 | 8815.24 | 8817.12 | | 8801.53 | 8806.37 | 8813.55 | 8814.52 | 8806.55 | 8807.45 | 8818.15 | 8817.50 | CNO |
| Dec-12 | 8817.36 | 8815.77 | 8816.86 | | 8800.93 | 8805.98 | 8813.17 | 8813.39 | CNO | 8807.18 | 8817.64 | 8817.05 | CNO |
| Jan-13 | 8816.92 | 8815.43 | | | 8800.52 | 8805.73 | 8812.92 | 8813.99 | 8806.61 | 8806.9 | 8818.32 | 8816.66 | CNO |
| Feb-13 | 8817.00 | CNO | 8816.59 | | 8816.89 | 8812.59 | 8812.94 | 8813.83 | 8806.51 | 8806.75 | 8817.02 | 8816.67 | CNO |
| Mar-13 | 8817.07 | CNO | 8816.49 | | 8816.67 | 8812.45 | 8812.89 | 8813.65 | 8806.57 | 8806.86 | 8817.137 | 8816.494 | CNO |
| Apr-13 | 8817.92 | 8816.91 | 8817.11 | | 8818.78 | 8813.71 | 8813.93 | 8815.17 | 8807.81 | 8808.24 | 8818.417 | 8817.734 | 8825.606 |
| May-13 | 8819.15 | 8816.5 | 8817.69 | | 8818.09 | 8813.45 | 8813.82 | 8815.19 | 8807.44 | 8807.82 | 8818.61 | 8817.93 | 8824.51 |
| Jun-13 | 8817.81 | 8816.19 | 8817.12 | | 8817.75 | 8814.18 | 8813.54 | 8814.87 | 8807.05 | 8807.34 | 8818.207 | 8817.514 | 8824.57 |
| Jul-13 | 8817.11 | 8815.59 | 8816.73 | | 8817.05 | 8812.73 | 8813.07 | 8814.45 | 8806.72 | 8807 | 8817.507 | 8816.824 | 8826.826 |
| Aug-13 | 8817.03 | 8815.98 | 8816.7 | | 8816.98 | 8812.72 | 8813.22 | 8814.58 | 8806.89 | 8807.17 | 8817.607 | 8816.924 | 8824.806 |
| **Average** | 8819.05 | 8817.34 | 8818.43 | 8814.38 | | | 8813.51 | 8814.64 | 8807.11 | 8807.53 | 8817.90 | 8817.15 | 8825.06 |
| **Max** | 8824.79 | 8823.85 | 8825.05 | 8821.34 | | | 8814.54 | 8816.03 | 8808.30 | 8808.93 | 8818.61 | 8817.93 | 8825.61 |
| **Min** | 8816.92 | 8814.07 | 8815.85 | 8806.00 | | | 8812.89 | 8813.39 | 8806.51 | 8806.75 | 8817.02 | 8816.49 | 8824.51 |

**Notes:**

CNL - Could Not Locate

CNO - Could Not Observe

# Table 4: Groundwater Quality Data

| | | | Location ID | GW-5 | MW-101 | MW-102 | MW-5-D | MW-5-S | MW-6-D | MW-6-S |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sample Date | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/18/2013 | 7/18/2013 |
| **Constituent** | | **Analytical Method** | **Units** | | | | | | | |
| Aluminum | Dissolved | 200.8 | µg/L | 177 | 1340 | 26.8 | 510 | 25900 | 329 | 643 |
| Aluminum | Total | 200.8 | µg/L | 16400 | 12200 | 41700 | 4140 | 36800 | 2810 | 13600 |
| Aluminum | POTD | 200.8 | ug/l | 9570 | 1390 | 6060 | 1340 | 29800 | 1110 | 5070 |
| Antimony | Dissolved | 200.8 | µg/L | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 2.5 | < 0.50 | < 0.50 |
| Antimony | Total | 200.8 | µg/L | 2.6 | 0.50 | 0.96 | 0.63 | 3.6 | < 0.50 | 0.59 |
| Antimony | POTD | 200.8 | ug/l | 1.2 | < 1.0 U | < 1.0 U | < 1.0 U | < 5.0 U | < 1.0 | < 1.0 |
| Arsenic | Dissolved | 200.8 | µg/L | 43.5 | 2.0 | < 0.50 | 113 | 259 | 18.1 | 28.3 |
| Arsenic | Total | 200.8 | µg/L | 352 | 15.5 | 59.6 | 219 | 384 | 48.1 | 88.8 |
| Arsenic | POTD | 200.8 | ug/l | 271 | 2.0 | 4.1 | 168 | 373 | 43.1 | 70.4 |
| Barium | Dissolved | 200.8 | µg/L | 17.4 | 31.6 | 12.4 | 11.3 | 8.1 | 18.2 | 17.1 |
| Barium | Total | 200.8 | µg/L | 110 | 168 | 322 | 75.1 | 90.0 | 46.1 | 106 |
| Barium | POTD | 200.8 | ug/l | 13.5 | 26.6 | 61.4 | 14.7 | 6.5 | 24.9 | 24.1 |
| Beryllium | Dissolved | 200.8 | µg/L | < 0.20 | 0.24 | < 0.20 | 1.7 | 7.1 | 0.59 | 0.88 |
| Beryllium | Total | 200.8 | µg/L | 1.5 | 1.1 | 3.9 | 1.9 | 7.0 | 0.70 | 1.5 |
| Beryllium | POTD | 200.8 | ug/l | 1.3 | 0.33 J | 2.2 | 1.6 | 6.7 | 0.62 | 1.1 |
| Cadmium | Dissolved | 200.8 | µg/L | 1.5 | 0.93 | 0.29 | < 0.080 | 157 | < 0.080 | 0.12 |
| Cadmium | Total | 200.8 | µg/L | 116 | 6.8 | 8.3 | 4.1 | 185 | 1.5 | 9.9 |
| Cadmium | POTD | 200.8 | ug/l | 88.6 | 2.6 | 5.0 | 1.1 | 197 | 0.88 | 7.8 |
| Calcium | Dissolved | 200.8 | µg/L | 585000 | 319000 | 221000 | 332000 | 424000 | 302000 | 414000 |
| Calcium | Total | 200.8 | µg/L | 619000 | 340000 | 242000 | 356000 | 476000 | 285000 | 378000 |
| Calcium | POTD | 200.7 | ug/l | 595000 | 309000 | 203000 | 325000 | 351000 | 279000 | 376000 |
| Chromium | Dissolved | 200.8 | µg/L | 0.52 | 2.0 | < 0.50 | < 0.50 | < 2.5 | < 0.50 | < 0.50 |
| Chromium | Total | 200.8 | µg/L | 18.6 | 20.2 | 55.3 | 3.5 | 16.5 | 2.3 | 11.9 |
| Chromium | POTD | 200.8 | ug/l | 10.3 J+ | 3.7 J+ | 7.2 J+ | 1.3 J+ | 8.7 J+ | 1.7 J+ | 3.8 J+ |
| Cobalt | Dissolved | 200.8 | µg/L | 7.8 | 4.0 | < 0.50 | 9.4 | 76.0 | 3.0 | 4.2 |
| Cobalt | Total | 200.8 | µg/L | 47.5 | 10 | 83.6 | 11.4 | 89.2 | 3.9 | 10.9 |
| Cobalt | POTD | 200.8 | ug/l | 23.0 | 4.2 | 11.8 | 9.2 | 87.2 | 3.0 | 7.5 |
| Copper | Dissolved | 200.8 | µg/L | 19.2 | 11.2 | 1.7 J+ | 0.69 J+ | 4.2 J+ | 1.3 J+ | 0.70 J+ |
| Copper | Total | 200.8 | µg/L | 1600 | 106 | 186 | 70.5 | 1090 | 15.1 | 59.4 |
| Copper | POTD | 200.8 | ug/l | 587 | 24.3 | 67.2 | 18.9 | 656 | 9.6 | 32.8 |
| Iron | Dissolved | 200.8 | mg/L | 4.05 | 5.36 | < 0.0500 | 68.4 | 448 | 19.7 | 47 |

# Table 4: Groundwater Quality Data

| | | | Location ID | GW-5 | MW-101 | MW-102 | MW-5-D | MW-5-S | MW-6-D | MW-6-S |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sample Date | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/18/2013 | 7/18/2013 |
| **Constituent** | | **Analytical Method** | **Units** | | | | | | | |
| Iron | Total | 200.8 | mg/L | 76.5 | 33.9 | 68.9 | 90.7 | 596 | 24.9 | 67.9 |
| Iron | POTD | 200.8 | mg/L | 48.3 | 7.06 | 5.87 | 69.8 | 453 | 22.2 | 58.3 |
| Lead | Dissolved | 200.8 | µg/L | 211 | 119 | 0.25 | 2.6 | 1070 | 0.26 | < 0.10 |
| Lead | Total | 200.8 | µg/L | 16700 | 1150 | 297 | 553 | 7010 | 31.2 | 117 |
| Lead | POTD | 200.8 | ug/L | 4720 | 438 | 116 | 299 | 3270 | 23.5 | 110 |
| Magnesium | Dissolved | 200.8 | µg/L | 49400 | 36800 | 20300 | 58300 | 134000 | 43400 | 59800 |
| Magnesium | Total | 200.8 | µg/L | 52700 | 39100 | 47900 | 53400 | 133000 | 43500 | 61200 |
| Magnesium | POTD | 200.7 | ug/l | 48300 | 35100 | 19800 | 53400 | 113000 | 39400 | 52800 |
| Manganese | Dissolved | 200.8 | µg/L | 5480 | 967 | 10.1 | 11400 | 26000 | 7620 | 9180 |
| Manganese | Total | 200.8 | µg/L | 8470 | 1440 | 10900 | 11800 | 28000 | 7830 | 9220 |
| Manganese | POTD | 200.8 | ug/l | 7460 | 988 | 1360 | 10900 | 25900 | 7240 | 8850 |
| Mercury | Dissolved | 245.1 | µg/L | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Mercury | Total | 245.1 | µg/L | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Mercury | POTD | 245.1 | ug/l | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Molybdenum | Dissolved | 200.8 | µg/L | 11.0 | 2.2 | 0.55 | 12.6 | < 2.5 | 6.3 | 4.8 |
| Molybdenum | Total | 200.8 | µg/L | 31.8 | 8.0 | 19.9 | 17.0 | 8.0 | 7.0 | 8.2 |
| Molybdenum | POTD | 200.8 | ug/l | 5.1 | < 1.0 U | < 1.0 U | 6.2 | < 5.0 U | 4.7 | 3.5 |
| Nickel | Dissolved | 200.8 | µg/L | 10.1 J+ | 8.3 J+ | 4.2 J+ | 8.1 J+ | 142 | 2.3 J+ | 2.3 J+ |
| Nickel | Total | 200.8 | µg/L | 65.3 | 16.7 | 64.1 | 11.4 | 157 | 4.4 | 16.1 |
| Nickel | POTD | 200.8 | ug/l | 38.0 | 4.2 J+ | 10.6 | 6.2 J+ | 161 | 3.2 J+ | 8.9 J+ |
| Potassium | Dissolved | 200.8 | µg/L | 5520 | 4080 | 1850 | 8130 | 2360 | 6620 | 12500 |
| Potassium | Total | 200.8 | µg/L | 8720 | 6200 | 6800 | 9340 | 5160 | 6700 | 13500 |
| Potassium | POTD | 200.7 | ug/L | 6390 | 4220 | 2210 | 8910 | 2540 | 6260 | 12200 |
| Selenium | Dissolved | 200.8 | µg/L | < 0.50 | 3.3 | 2.3 | < 0.50 | 4.8 | 0.79 | < 0.50 |
| Selenium | Total | 200.8 | µg/L | 5.6 | 6.3 | 9.8 | 1.2 | 10.5 | 1.4 | 1.8 |
| Selenium | POTD | 200.8 | ug/l | 2.1 | 3.2 | 5.6 | 0.45 J | 7.4 | < 1.0 | 1.1 |
| Silver | Dissolved | 200.8 | µg/L | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 2.5 | < 0.50 | < 0.50 |
| Silver | Total | 200.8 | µg/L | 69.1 | 5.3 | 0.81 | 1.7 | 22.5 | < 0.50 | < 0.50 |
| Silver | POTD | 200.8 | ug/l | < 0.50 | < 0.50 | 0.50 J | < 0.50 | < 2.5 | < 0.50 | < 0.50 |
| Sodium | Dissolved | 200.8 | µg/L | 8990 | 9610 | 6990 | 7550 | 19400 | 5170 | 4310 |
| Sodium | Total | 200.8 | µg/L | 8940 | 9310 | 7050 | 7220 | 22200 | 4780 | 3960 |

# Table 4: Groundwater Quality Data

| | | | Location ID | GW-5 | MW-101 | MW-102 | MW-5-D | MW-5-S | MW-6-D | MW-6-S |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sample Date | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/18/2013 | 7/18/2013 |
| **Constituent** | | **Analytical Method** | **Units** | | | | | | | |
| Sodium | POTD | 200.7 | ug/l | 9520 | 9880 | 6780 | 8260 | 19200 | 5160 | 4500 |
| Thallium | Dissolved | 200.8 | µg/L | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.50 | < 0.10 | < 0.10 |
| Thallium | Total | 200.8 | µg/L | 2.2 | 0.62 | 0.77 | 0.25 | 0.86 | < 0.10 | 0.41 |
| Thallium | POTD | 200.8 | ug/l | < 1.0 U | < 1.0 U | < 1.0 U | < 1.0 U | < 5.0 U | < 1.0 | < 1.0 |
| Vanadium | Dissolved | 200.8 | µg/L | 0.39 | 2.0 | < 0.10 | < 0.10 | 1.4 | < 0.10 | < 0.10 |
| Vanadium | Total | 200.8 | µg/L | 27.6 | 19.2 | 69.4 | 6.2 | 13.5 | 5.2 | 17.6 |
| Vanadium | POTD | 200.8 | ug/l | 17.8 | 2.6 J+ | 5.0 J+ | < 1.0 U | < 5.0 U | 1.9 J+ | 4.2 J+ |
| Zinc | Dissolved | 200.8 | µg/L | 5390 | 331 | 55.3 | 9480 | 119000 | 331 | 620 |
| Zinc | Total | 200.8 | µg/L | 40900 | 979 | 1640 | 11000 | 129000 | 759 | 2290 |
| Zinc | POTD | 200.8 | ug/l | 36900 | 471 | 793 | 9390 | 120000 | 656 | 1980 |
| Alkalinity, bicarbonate | | SM2320B | mg/L | 234 | 320 | 201 | 99.7 | < 20.0 | 179 | 147 |
| Alkalinity, carbonate | | SM2320B | mg/L | < 20.0 | < 20.0 | < 20.0 | < 20.0 | < 20.0 | < 20.0 | < 20.0 |
| Alkalinity, total | | SM2320B | mg/L | 234 | 320 | 201 | 99.7 | < 20.0 | 179 | 147 |
| Chloride | | 300.0 | mg/L | 1.6 | 1.3 | 1.1 | 1.5 | 3.6 | 1.0 | 1.1 |
| Cyanide | | SM4500-CN E | µg/L | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| Nitrogen, NO2 plus NO3 | | EPA 353.2 | mg/L | < 0.10 | 0.38 | 0.83 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Sulfate | | 300.0 | mg/L | 1790 | 684 | 466 | 1170 | 3480 | 732 | 1090 |
| Sulfide, Total | | SM 4500-S-2 D | mg/L | 1.2 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 UJ | < 0.050 UJ |
| Total Dissolved Solids | | SM2540C | mg/L | 2240 | 1200 | 844 | 1650 | 4190 | 1250 | 1710 |
| Total Organic Carbon | | SM 5310C | mg/L | 0.61 | 0.73 | 0.52 | 0.55 | < 0.50 | < 0.50 | 0.82 |
| Total Suspended Solids (TSS) | | SM2540D | mg/L | 331 | 335 | 892 | 344 | 228 | 99.0 | 306 |
| Hardness as CaCO3 | | 200.8 | mg/L | 1760 | 1010 | 803 | 1110 | 1740 | 890 | 1190 |
| Salinity (as dissolved solids) | | CALC | mg/L | 1570 | 902 | 703 | 1100 | 1790 | 908 | 1170 |
| Salinity (as seawater) | | CALC | PSU | 1.3 | 0.70 | 0.54 | 0.87 | 1.4 | 0.71 | 0.92 |
| Silica | | 200.8 | µg/L | 81800 | 53100 | 137000 | 33700 | 77800 | 26200 | 65600 |
| Specific Conductance | | 2510B | umhos/cm | 2730 | 1890 | 1160 | 1850 | 3960 | 1420 | 1830 |
| Dissolved Oxygen, Field | | FIELD | mg/L | 0.52 | 0.76 | 1.04 | 0.91 | 0.11 | 0.23 | 0 |
| Oxidation Reduction Potential, Field | | FIELD | mV | -81.1 | -12.8 | 27.6 | -86.5 | 71 | -63.8 | -65.9 |
| pH, Field | | FIELD | std units | 6.79 | 6.23 | 6.45 | 6.4 | 4.45 | 6.27 | 6.07 |

# Table 4: Groundwater Quality Data

| | | | Location ID | GW-5 | MW-101 | MW-102 | MW-5-D | MW-5-S | MW-6-D | MW-6-S |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sample Date | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/9/2013 | 7/18/2013 | 7/18/2013 |
| **Constituent** | | **Analytical Method** | **Units** | | | | | | | |
| Specific Conductivity, Field | | FIELD | umhos/cm | 2925 | 1801 | 1315 | 2246 | 3697 | 1885 | 2414 |
| Temperature, Field | | FIELD | deg C | 9.99 | 13.08 | 12.23 | 11.41 | 11.18 | 11.62 | 11.19 |

**Notes:**

POTD = Potentially Dissolved
µg/L = micrograms per liter
mg/L = milligrams per liter
PSU = practical salinity units
mV = millivolt
std units = standard units
umhos/cm = micromhos per centimeter
deg C = degree Celsius

**Data Validation Qualifier Definitions**

J = estimated concentration
J+ = estimated concentration, high bias indicated
J- = estimated concentration, low bias indicated
U = evaluated to be undetected at the reporting limit/concentration, due to evidence of contamination
UJ = undetected, reporting limit is estimated

# Table 5A: IDF Solids - Specific Gravity and Atterberg Limits

| Cell / Location | Specific Gravity | Atterberg Limits (%) | | |
|---|---|---|---|---|
| | | LL | PL | PI |
| 1A (Round 8) | 2.95 | - | - | - |
| 3A (Round 8) | 2.99 | - | - | - |
| Pond 18 (0-30") | 3.00 | 67 | 62 | 5 |
| Pond 18 (0-30") | 2.99 | 83 | 79 | 4 |
| Pond 18 (12-42") | 3.00 | 77 | 74 | 3 |

## Table 5B: IDF Solids - Moisture Content (%) / Dry Unit Weight (pcf)

| | Sampling Round | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cell / Location** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| | | | | | | | | | | |
| 1A | 169.8/27.6 | | 257.9/20.8 | 214.9/22.3 | 210.3/25.4 | 133.0/31.0 | | 217.7/23.8 | 95.5/48.4 | |
| 1B | 189.0/27.8 | 261.0/20.3 | 183.2/27.2 | 150.0/32.4 | | | 145.1/33.7 | 27.6/87.2 | 86.2/41.5 | 86.3/49.2 |
| 1C | 111.6/42.7 | | | | 98.1/44.3 | 87.8/47.1 | 71.5/47.4 | | | 128.1/29.4 |
| | | | | | | | | | | |
| 2A | 129.4/38.7 | 139.0/30.2 | 93.4/14.0 | 104.1/38.5 | | 122.4/32.4 | | 50.0/68.0 | 148.4/28.4 | 144.6/32.3 |
| 2B | 320.4/22.3 | 91.2/49.8 | 238.8/21.0 | 158.5/31.5 | 240.6/26.8 | | 218.5/24.1 | | 195.9/32.6 | 44.8/81.5 |
| 2C | 129.8/38.0 | | | | 212.8/23.1 | 80.5/52.9 | 95.1/45.3 | 277.9/20.7 | | |
| | | | | | | | | | | |
| 3A | 314.0/18.5 | 225.5/23.0 | | 241.0/20.8 | 233.7/22.7 | 261.6/21.0 | | 78.3/30.9 | 223.3/24.2 | 254.0/21.5 |
| 3B | 141.2/32.2 | | 261.2/20.9 | 247.4/22.9 | | | 234.2/21.6 | 207.5/25.3 | 117.9/32.9 | |
| 3C | 248.2/21.3 | | 237.8/22.0 | | 202.0/26.8 | 239.8/22.1 | 219.3/23.8 | | | 253.6/21.7 |
| | | | | | | | | | | |
| 4A | 227.8/23.8 | | 197.0/26.1 | | 184.7/25.3 | 211.8/25.4 | 206.8/27.6 | | 215.8/26.7 | 227.6/25.3 |
| 4B | 170.1/28.9 | | 205.0/23.4 | 330.1/16.6 | | | | 207.4/23.3 | | |
| 4C | 196.6/27.0 | | | 268.1/20.2 | 255.4/19.5 | 232.4/21.1 | 223.9/21.4 | 192.5/22.5 | 221.5/22.6 | |
| Average $\gamma_d$ / $w_c$ | 195.7 / 29.1 | 179.2 / 30.8 | 209.3 / 21.9 | 214.3 / 25.7 | 204.7 / 26.7 | 171.2 / 31.6 | 176.8 / 30.6 | 157.4 / 37.7 | 163.1 / 32.2 | 162.7 / 37.3 |
| Average $\gamma_t$, pcf | 86.0 | 86.0 | 67.7 | 80.8 | 81.4 | 85.7 | 84.7 | 97.0 | 84.7 | 98.0 |

**Note:**
Round 1 of IDF sampling came approximately one month after moving solids from Pond 18.

## Table 5C: IDF Solids - Undrained Shear Strength (Peak / Residual - psf)

| | Sampling Round | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cell / Location** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| | | | | | | | | | | |
| 1A | | | 211 / 53 | | 426 / 168 | | | | 391 / 96 | |
| 1B | | 238 / 48 | | 437 / 65 | | | | 210 / 46 | | |
| 1C | | | | | 134 / 24 | | 592 / 53 | | | 94 / 28 |
| | | | | | | | | | | |
| 2A | | 143 / 30 | | 425 / 46 | | | | 119 / 25 | | 79 / 8 |
| 2B | | | 142 / 40 | | | | 327 / 44 | | 210 / 67 | |
| 2C | | | | | 310 / 57 | 135 / 20 | | | | |
| | | | | | | | | | | |
| 3A | | 189 / 50 | | | 387 / 74 | | | 173 / 52 | | |
| 3B | | | | 278 / 52 | | | 238 / 38 | | 150 / 65 | |
| 3C | | | 107 / 31 | | | 226 / 50 | | | | 187 / 19 |
| | | | | | | | | | | |
| 4A | | | 538 / 85 | | 276 / 64 | | 365 / 65 | | | 108 / 6 |
| 4B | | 262 / 44 | | | | | | 246 / 33 | | |
| 4C | | | | 468 / 50 | | 189 / 59 | | | 127 / 35 | |
| Average | -- | 208 / 43 | 250 / 52 | 402 / 53 | 277 / 55 | 244 / 74 | 381 / 50 | 187 / 39 | 220 / 66 | 117 / 15 |

Overall Average for Design (rounded) = 250 psf / 50 psf

# Table 5D: IDF Solids - Hydraulic Conductivity (cm/sec)

| | Sampling Round | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cell / Location** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| | | | | | | | | | | |
| 1A | 1.0E-05 | | | | | | | | | |
| 1B | | | 8.9E-07 | | | | | | 3.9E-06 | |
| 1C | | | | | | | 2.3E-06 | | | |
| | | | | | | | | | | |
| 2A | | 8.3E-07 | | | | | | | | 2.0E-05 |
| 2B | | | | 6.6E-06 | | | | | | |
| 2C | | | | | | | | 5.8E-05 | | |
| | | | | | | | | | | |
| 3A | | 6.6E-07 | | | | | | 1.1E-05 | | |
| 3B | | | 1.1E-06 | | | | | | | |
| 3C | | | | | | | | | | 7.3E-06 |
| | | | | | | | | | | |
| 4A | 2.8E-04 | | | | | | 2.8E-06 | | | |
| 4B | | | | | | | | | | |
| 4C | | | | 2.5E-06 | | | | | 4.3E-06 | |

Average (geometric mean - all data) = 5.2E-06 cm/sec

# Table 5E: IDF Solids - Consolidation Data

| Sampling Round | Cell | $e_0$ | $e_f$ | Cc | Cr | $\sigma'_v$,mp (psf) | $\sigma'_v$,max (psf) |
|---|---|---|---|---|---|---|---|
| 1 | 1A | 10.5 | 5.0 | 5.7 | 0.06 | 1200 | 5000 |
| 1 | 3A | 5.3 | 4.6 | 1.2 | 0.10 | 1500 | 5000 |
| 1 | 4A | 4.9 | 3.6 | 1.5 | 0.08 | 1100 | 5000 |
| 2 | 1B | 8.2 | 4.8 | 4.0 | 0.10 | 900 | 5000 |
| 2 | 2B | 2.7 | 2.1 | 1.4 | 0.02 | 1000 | 5000 |
| 4 | 1B | 9.2 | 5.4 | 5.0 | 0.15 | 950 | 5000 |
| 4 | 3B | 6.5 | 4.9 | 3.1 | 0.12 | 1700 | 5000 |
| 5 | 2B | 7.8 | 6.9 | 1.9 | 0.12 | 1600 | 2500 |
| 5 | 4A | 6.0 | 4.5 | 2.9 | 0.08 | 1500 | 2500 |
| 6 | 1C | 3.2 | 2.9 | 0.5 | 0.02 | 1600 | 5000 |
| 6 | 3C | 4.7 | 3.1 | 2.2 | 0.06 | 1100 | 5000 |
| 7 | 2C | 2.5 | 2.3 | 0.5 | 0.12 | 1500 | 5000 |
| 7 | 4C | 3.7 | 3.3 | 0.5 | 0.05 | 1100 | 5000 |
| 8 | 1A | 6.7 | 6.2 | 1.5 | 0.11 | 1900 | 5000 |
| 8 | 3A | 4.5 | 3.9 | 1.3 | 0.06 | 1800 | 5000 |
| 9 | 2A | 5.7 | 4.3 | 2.5 | 0.11 | 1400 | 5000 |
| 9 | 4A | 5.7 | 5.0 | 1.7 | 0.09 | 1700 | 5000 |
| 10 | 1B | 2.8 | 2.6 | 0.2 | 0.01 | 1700 | 5000 |
| Average | -- | 5.6 | 4.2 | 2.1 | 0.08 | -- | -- |

## Table 5F: IDF Solids - Triaxial Test Results

| Sampling Round | Cell | $e_0$ | $e_f$ | Φ' | c' (psf) | $\sigma'_c$ (psf) |
|---|---|---|---|---|---|---|
| 1 | 1A | 5.8 | 3.3 | 29.6 | 55 | 300, 1580, 4000 |
| 1 | 4A | 8.4 | 3.8 | 28.7 | 76 | 860, 1580, 4000 |
| 2 | 3A | 7.1 | 5.1 | 29.2 | 157 | 680, 1600, 4000 |
| 4 | 1B | 4.6 | 3.4 | 26.2 | 220 | 720, 1600, 4000 |
| 4 | 4B | 9.4 | 4.3 | 28.2 | 302 | 720, 1600, 4100 |
| 6 | 2A | 5.0 | 3.8 | 29.5 | 124 | 720, 1600, 4000 |
| 6 | 3C | 8.3 | 4.8 | 27.3 | 179 | 720, 1600, 4000 |
| 7 | 4C | 7.3 | 3.7 | 29.8 | 100 | 720, 1600, 4000 |
| 7 | 1C | 6.7 | 3.2 | 29.2 | 137 | 280, 1600, 4000 |
| 8 | 2C | 8.1 | 4.7 | 29.5 | 137 | 300, 1600, 4000 |
| 8 | 3B | 6.2 | 2.5 | 31.1 | 64 | 300, 1600, 4000 |
| 9 | 1A | 3.0 | 2.3 | 32.1 | 246 | 340, 1600, 4000 |
| 9 | 4A | 6.6 | 4.1 | 28.8 | 254 | 340, 1500, 4000 |
| 10 | 3A | 7.4 | 3.6 | 29.0 | 246 | 340, 1600, 4000 |
| 10 | 4A | 6.5 | 3.5 | 27.1 | 171 | 360, 1600, 4000 |
| Average | -- | 6.7 | 3.7 | 29 degrees (rounded) | 160 psf (rounded) | -- |

# Table 6 - Embankment Fill – Direct Shear Test Results

| | 85 % Standard Proctor at Optimum Moisture Content | | 95% Standard Proctor at Optimum Moisture Content | |
|---|---|---|---|---|
| Test Pit | 2-point envelope | 3-point envelope | 2-point envelope | 3-point envelope |
| TP2011-03 | 40° / 280 psf | NT | 44° / 800 psf | NT |
| TP2011-04 | 38°/ 410 psf | 41° / 260 psf | 42° / 600 psf | NT |
| TP2011-06 | 40° / 290 psf | NT | 45° / 780 psf | 53° / 240 psf |
| TP2011-08 | 37° /160 psf | 38°/ 80 psf | 47° / 500 psf | 52° / 130 psf |
| TP2013-08 | | | | |
| TP2013-11 | | | | |

**Notes:**

Tests completed on minus 3/4-inch fraction of each sample

NT = case not tested

## Table 7: Waste Characterization Data

| Waste Type | Oxy-hydroxide Solids Pond 5 | | Oxy-hydroxide Solids Pond 11 | | Oxy-hydroxide Solids Pond 13 | | Oxy-hydroxide Solids Pond 15 | | Oxy-hydroxide Solids Pond 18 | | Oxy-hydroxide Solids Pond 15 | | Oxy-hydroxide Solids Pond 18 | | Calcines | | Calcines | | Calcines | | Calcines | | Calcines | | Calcines | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface Sample | | Surface Sample | | Surface Sample | | Surface Sample | | Surface Sample | | Mixed Sample | | Mixed Sample | | No 1 | | No 2 | | No 3 | | No 4 | | No 5 | | No 6 | |
| Date Sampled | May-95 | | May-95 | | May-95 | | May-95 | | May-95 | | Dec-01 | | Dec-01 | | 1982 | | 1982 | | 1982 | | 1982 | | 1982 | | 1982 | |
| Units | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | | mg/L | |
| Arsenic TCLP | 0.1 | U | 0.1 | U | 0.1 | U | 0.1 | U | 0.1 | U | 1 | U | 1 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U |
| Barium TCLP | 0.5 | | 0.4 | U | 0.4 | U | 0.4 | U | 0.4 | U | 20 | U | 20 | U | 0.06 | | 0.06 | | 0.07 | | 0.05 | U | 0.05 | U | 0.06 | |
| Cadmium TCLP | 0.01 | U | 0.02 | | 0.36 | | 0.09 | | 0.03 | | 0.25 | | 0.54 | | 0.008 | | 0.001 | | 0.006 | | 0.003 | | 0.004 | | 0.004 | |
| Chromium TCLP | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | | 1 | U | 1 | U | 0.005 | | 0.005 | | 0.005 | | 0.005 | | 0.005 | U | 0.005 | |
| Iron TCLP | | | | | | | | | | | | | | | 17.9 | | 68.6 | | 232 | | 63.1 | | 359 | | 41.3 | |
| Lead TCLP | 0.5 | | 0.05 | U | 0.05 | U | 0.05 | | 0.05 | U | 1 | U | 1 | U | 0.01 | U | 0.16 | | 0.03 | | 0.01 | U | 0.1 | | 0.01 | U |
| Mercury TCLP | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.04 | U | 0.04 | U | 0.0005 | U | 0.0005 | U | 0.0005 | U | 0.0005 | U | 0.0005 | U | 0.0005 | U |
| Selenium TCLP | 0.1 | U | 0.1 | U | 0.1 | U | 0.1 | U | 0.1 | U | 0.2 | U | 0.2 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U |
| Silver TCLP | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 1 | U | 1 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U |
| Zinc TCLP | | | | | | | | | | | | | | | 0.52 | | 0.24 | | 0.76 | | 0.58 | | 0.94 | | 0.58 | |

**Notes:**

**Data Validation Qualifier Definitions**

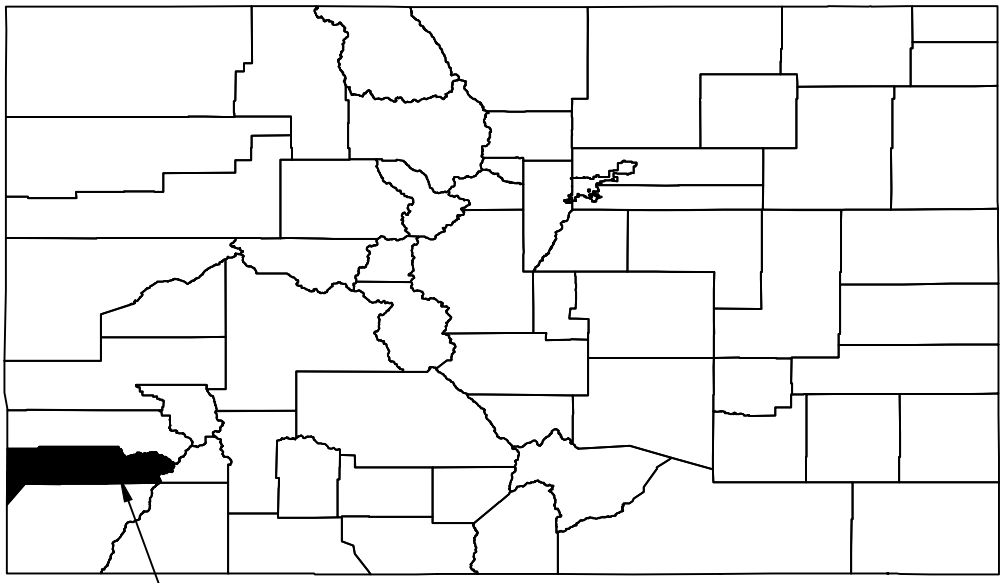
B = The associated numerical value was detected below the CRDL, but greater than the method detection limit and is therefore an estimate (qualified by laboratory software). Presence of the compound is reliable.

J = The associated numerical value was detected above the Method Detection Limit (MDL) but below the Practical Quantitation Limit (PQL) or because Quality Control Criteria were not met. Presence of the analyte is reliable. -or-
The associated numerical value is an estimated quantity because the quality control criteria were not met. Presence of the element is reliable.

U = Not detected at the reported value. -or- The analyte was not detected at or above the reported amount. The reported amount is the detection limit. -or- The analyte was not detected at reported concentration (qualified by laboratory software).

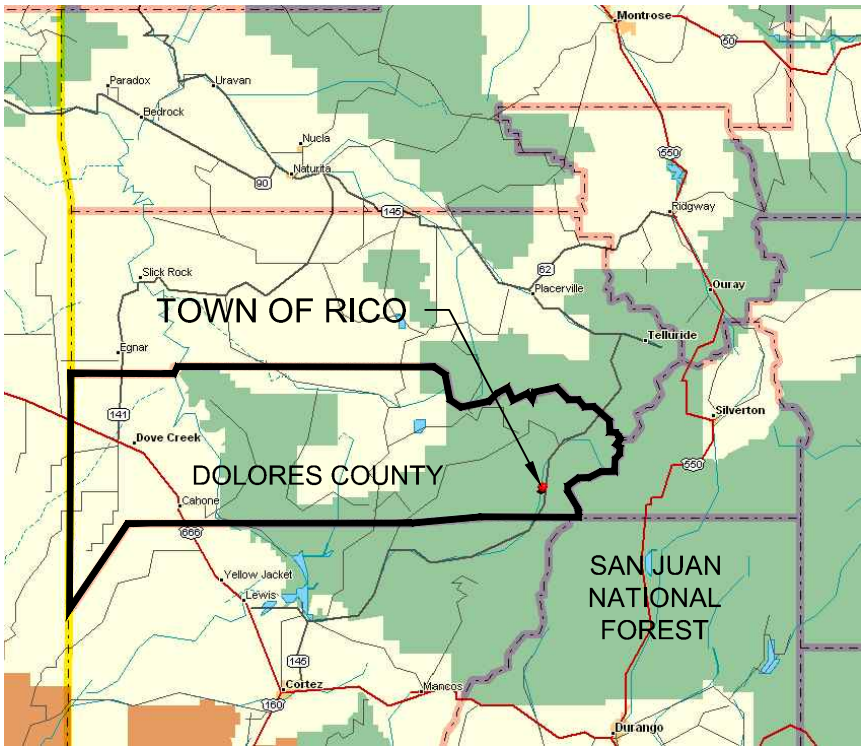
U,J = The reported amount is estimated because quality control criteria were not met. The analyte was not detected.

# Figures




**STATE OF COLORADO**

NOT TO SCALE




**DOLORES COUNTY**

NOT TO SCALE

# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 1 - SITE LOCATION MAP

AECOM

60306858

Filename: Z:_CURRENT_PROJECTS\ATLANTIC RICHFIELD\60157757 RICO\000_CADD\06-EXHIBITS\40-2013 SR ED&OP FIGURES\2013-SR_ED&OP_FIG-1_SITE-LOCATION-MAP_RICO.DWG Last saved by: RODDENA Last Plotted: 12/2/2013 1:04 PM Project Management Initials: Designer: _____ Checked: _____ Approved: _____ ANSI A 8.5" x 11"

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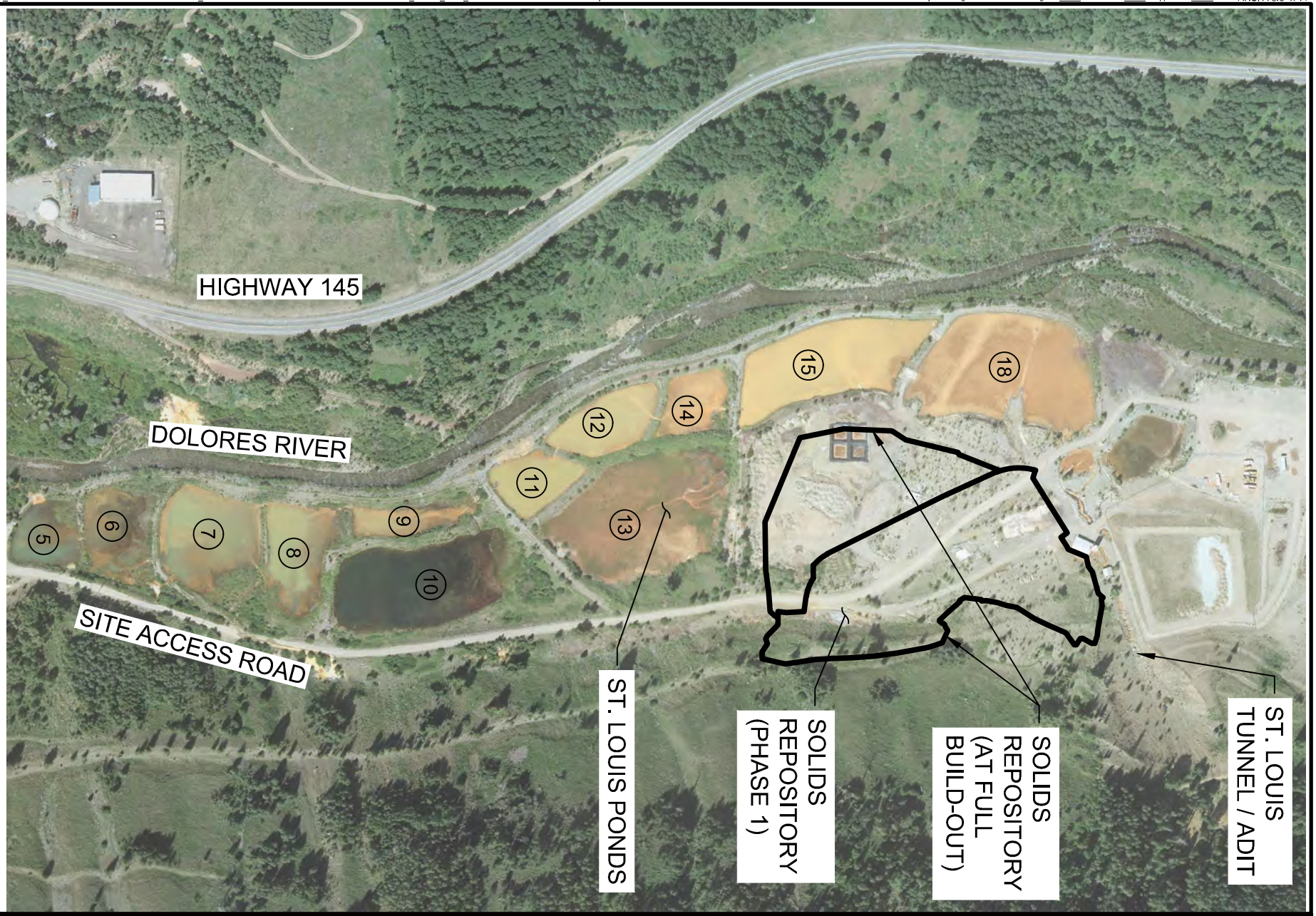



# RICO-ARGENTINE SITE-OU01

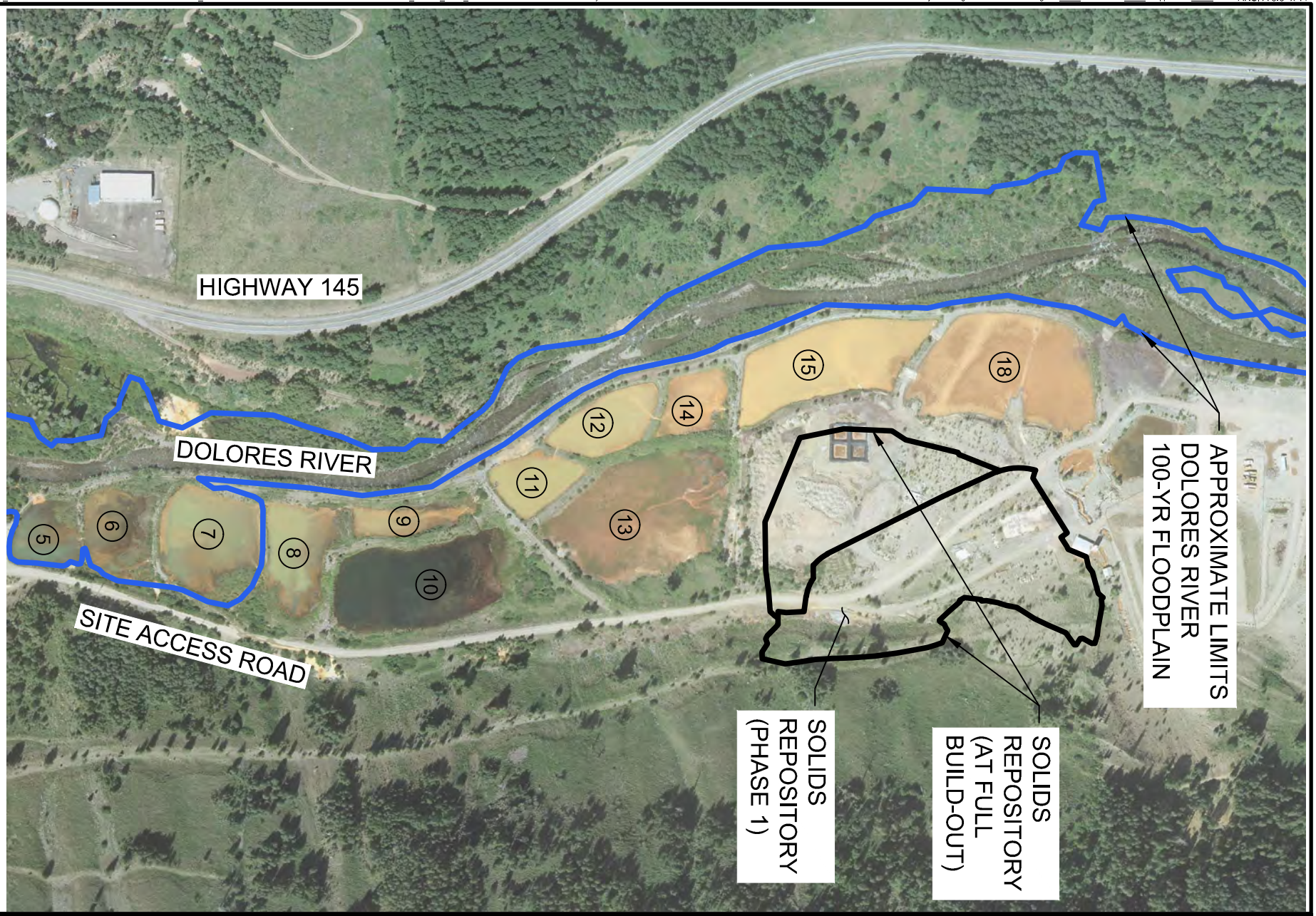
SOLIDS REPOSITORY

FIGURE 2 - RICO-ARGENTINE SITE MAP

AECOM

60306858

Filename: Z:_CURRENT_PROJECTS\ATLANTIC RICHFIELD\60157757 RICO\000_CADD\06-EXHIBITS\40-2013 SR ED&OP FIGURES\2013-SR_ED&OP_FIG-3_100-YR-FLOOD.DWG Last saved by: RODDENA Last Plotted: 12/2/2013 1:25 PM Project Management Initials: Designer: ____ Checked: ____ Approved: ____ ANSI A 8.5" x 11"




# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 3 - 100-YR FLOODPLAIN MAP

AECOM

60306858

## LEGEND

### GEOLOGY

- LIME TREATMENT SOLIDS/ MISCELLANEOUS FILL (LS)
- SOIL LEAD REPOSITORY (EMBANKMENT FILL AND LEAD-BEARING SOIL) (LR)
- FLOOD DIKE (ANGULAR RIPRAP) (FD)
- CALCINES (CA)
- MISCELLANEOUS EMBANKMENT AND OTHER FILL (MF)
- OLD FLOOD DIKE (ROUNDED RIPRAP) (OD)
- UNDIFFERENTIATED FILL AND COLLUVIUM (FC)
- WASTE ROCK (WR)
- ALLUVIUM (AL)
- COLLUVIUM (CO)
- HERMOSA FORMATION (BEDROCK) (BR)

GEOLOGIC CONTACT:

DASHED WHERE APPROXIMATE
DOTTED WHERE HIDDEN

GROUND WATER MEASUREMENTS:

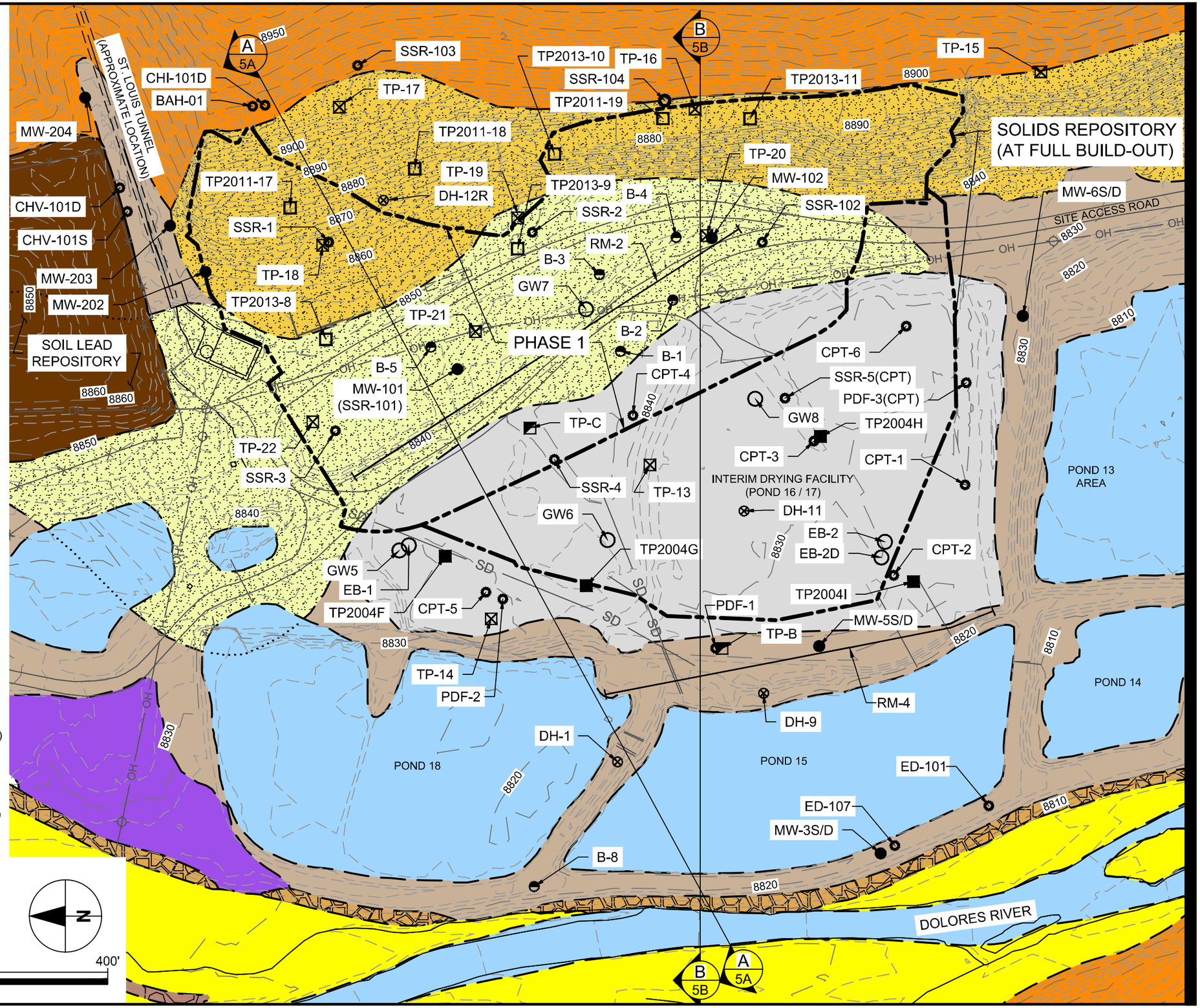
MAXIMUM MINIMUM

### 2011-PRESENT FIELD INVESTIGATIONS

- TEST PIT
- EXPLORATORY BORING
- MONITORING WELL
- REFRACTION MICROTREMOR GEOPHYSICAL PROFILE
- (CPT) CPT PERFORMED ADJACENT TO BORING

### PRE-2011 FIELD INVESTIGATIONS

- DH-1 (ANDERSON ENGINEERING/SEH, 2008)
- B-1 (DAMES AND MOORE, 1981)
- MONITORING WELLS (CDPHE, 2002)
- TP-1 (ANDERSON ENGINEERING/SEH, 2008)
- TP-2004A (SEH, 2004)
- TP-A (SEH, 2001)




## GEOLOGIC PLAN

Scale: 1:100

0 100' 200' 400'

N

AECOM

60306858

# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 4 - GEOLOGIC PLAN

ANSI B 11" x 17"

Approved: ____ Checked: ____ Designer: ____ Project Management Initials: ____

Last saved by: RODDENA Last Plotted: 12/3/2013 11:25 AM

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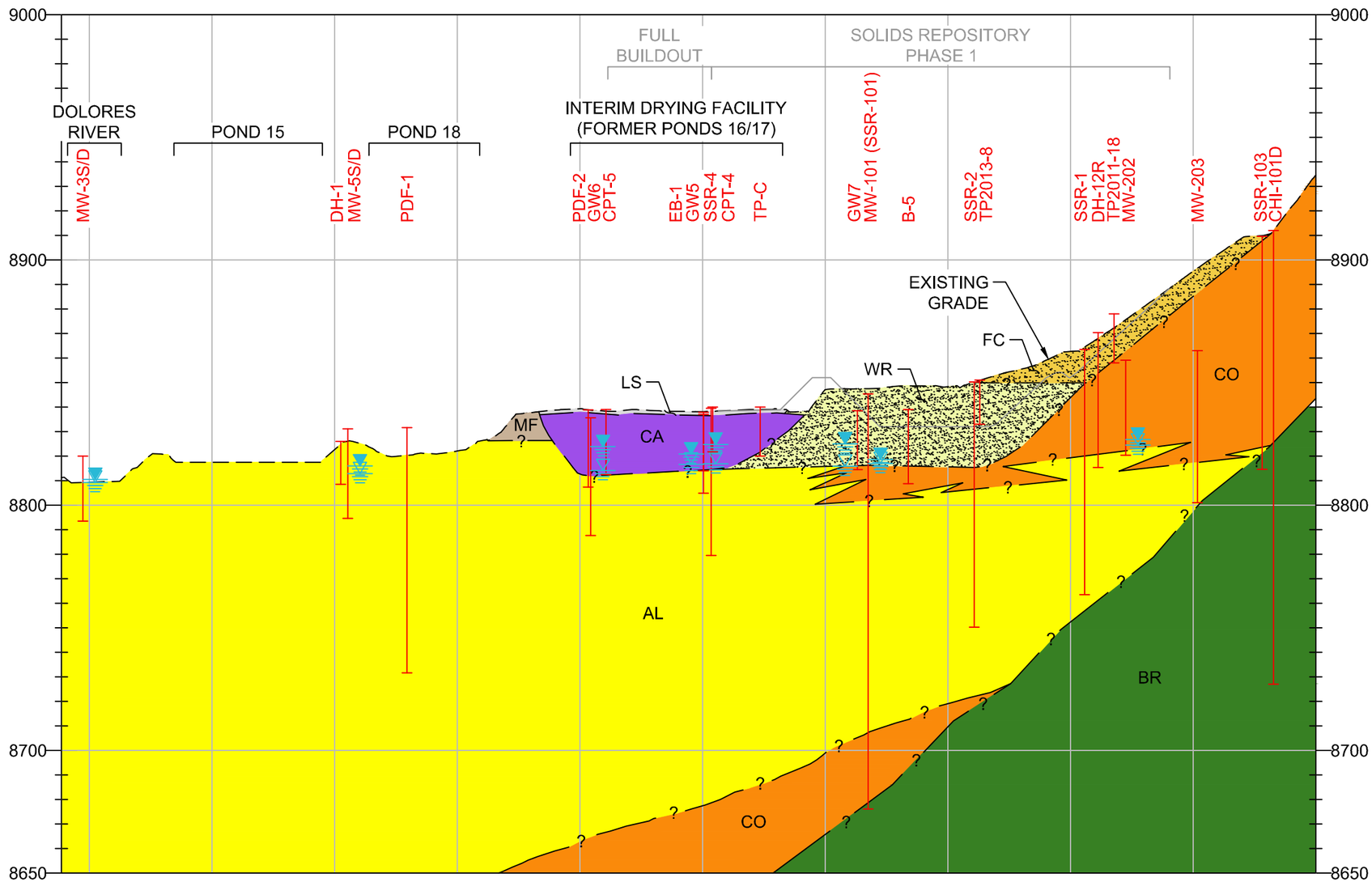



VIEW LOOKING NORTH (SEE FIGURE 4 FOR LEGEND AND SECTION LOCATION)

## A | GEOLOGIC SECTION A

Scale: H 1":100'
Scale: V 1":50'

0 100' 200' 400'

0 50' 100' 200'

AECOM

60306858

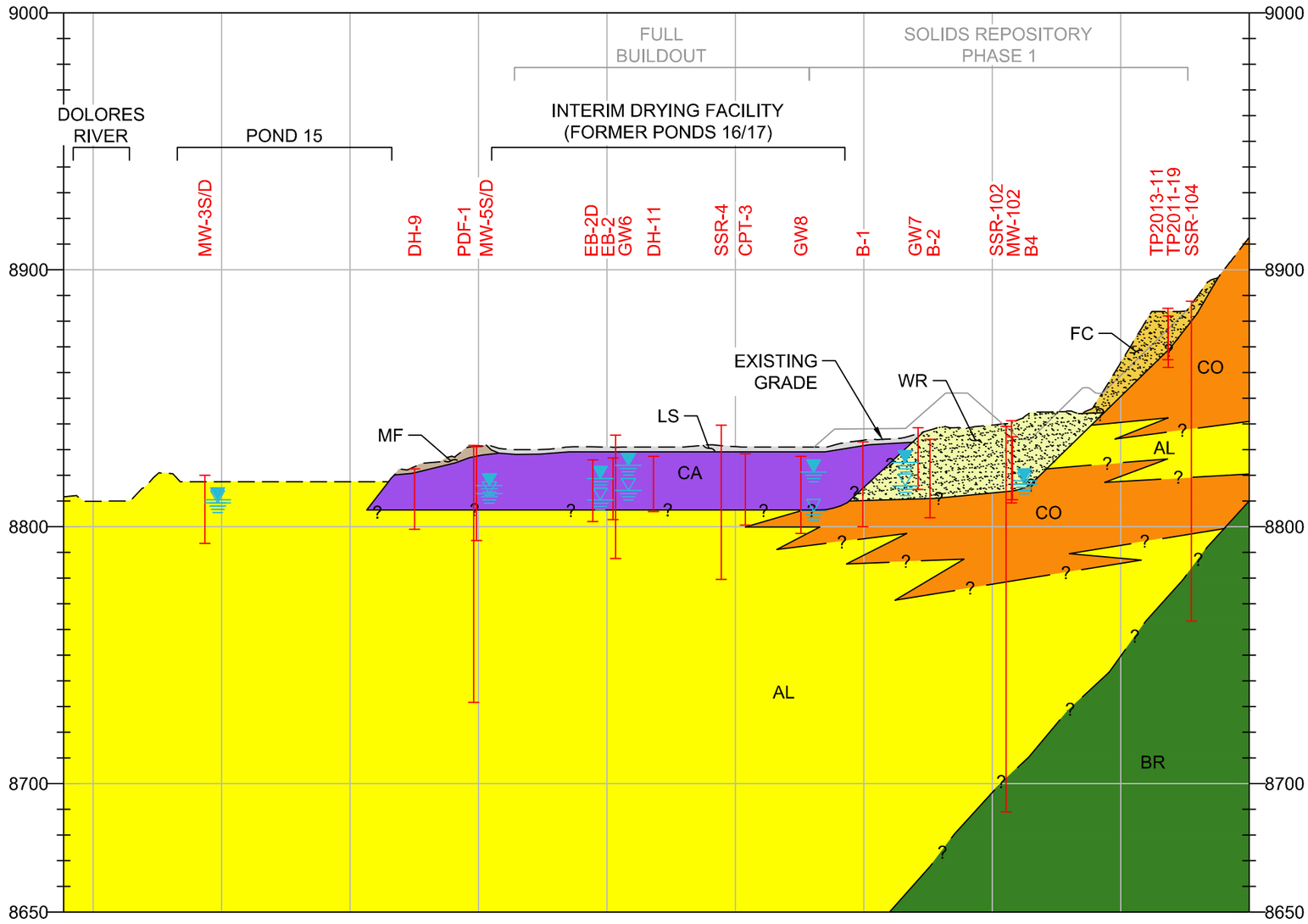
# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 5A - GEOLOGIC SECTION A

Filename: Z:_CURRENT_PROJECTS\ATLANTIC RICHFIELD\60157757 RICO\000_CADD\05-EXHIBITS\10-2013 SR ED&OP FIGURES\2013-SR_ED&OP_FIG-5A_GEO-SECTION_RICO.DWG Last saved by: BODDENA Last Plotted: 12/13/2013 11:28 AM

Project Management Initials: Designer: Checked: Approved: ANSI B 11" x 17"




VIEW LOOKING NORTH (SEE FIGURE 4 FOR LEGEND AND SECTION LOCATION)

## B GEOLOGIC SECTION B

Scale: H 1":100'
Scale: V 1":50'

0 100' 200' 400'

0 50' 100' 200'

AECOM

60306858

# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 5B - GEOLOGIC SECTION B

Filename: Z:_CURRENT_PROJECTS\ATLANTIC HIGHFIELD\60157757 RICO\000_CAD\306-EXHIBITS\4D-2013 SR ED&OP FIGURES\2013-SR_ED&OP_FIG-5B_GEO-SECTION_RICO.DWG Last saved by: RODDENA Last Plotted: 12/13/2013 11:30 AM

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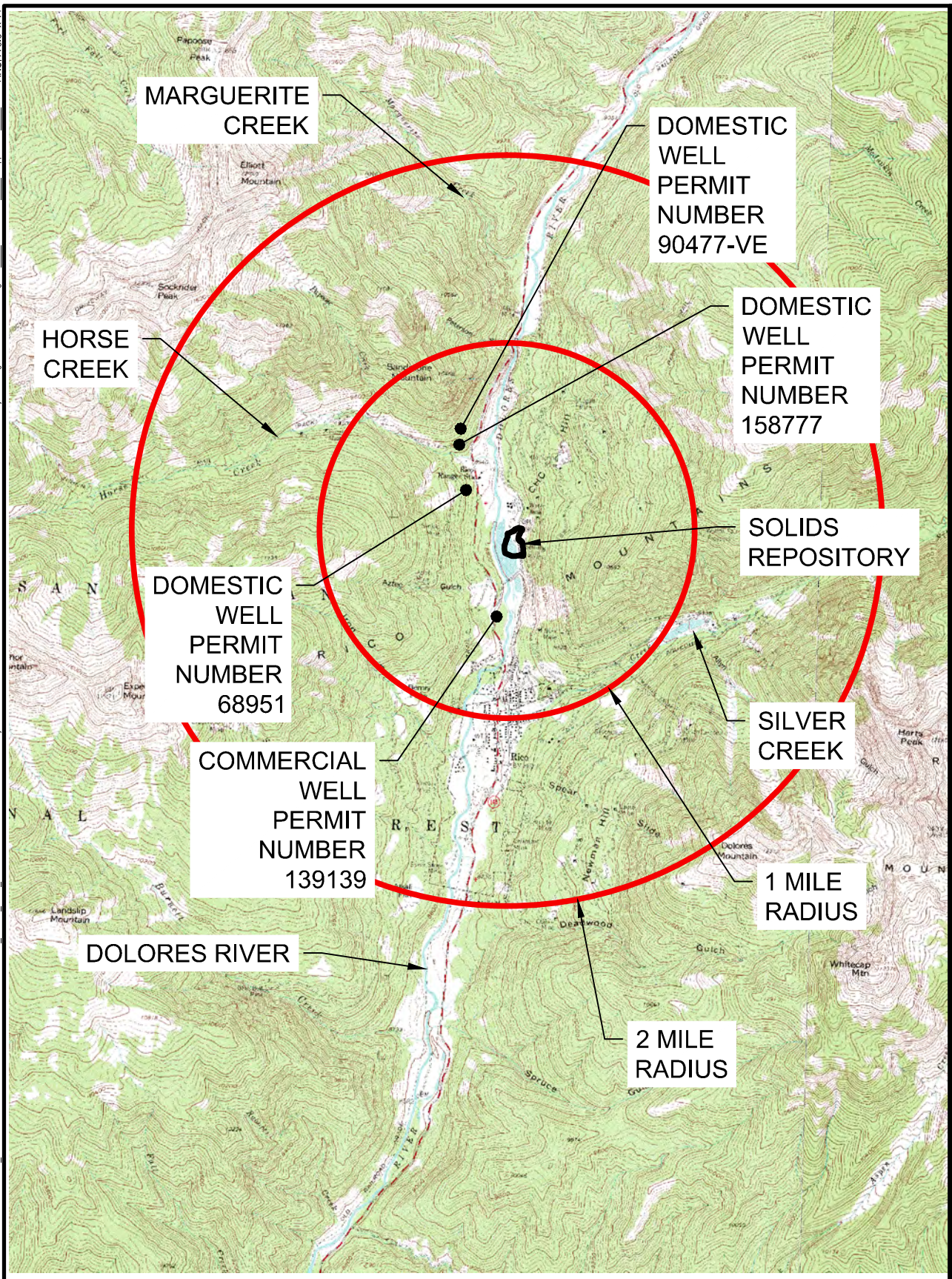



## GROUNDWATER WELLS & HYDROLOGIC FEATURES

Scale: 1'=4000'

0 4000'

N

AECOM

# RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

FIGURE 6 - GROUNDWATER WELLS & HYDROLOGIC FEATURES IN THE VICINITY OF THE SOLIDS REPOSITORY 60306858

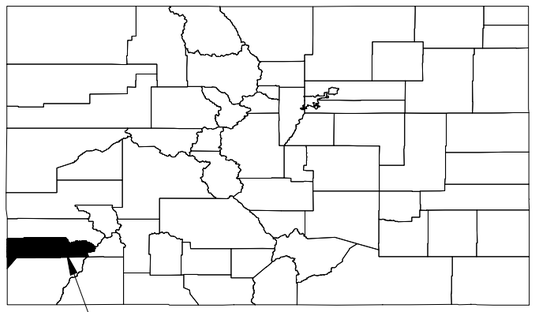
Filename: Z:_CURRENT_PROJECTS\ATLANTIC RICHFIELD\60157757 RICO\000_CADD\06-EXHIBITS\40-2013 SR ED&OP FIGURES\2013-SR_ED&OP_FIG-6_WATER-FEATURES.DWG Last saved by: RODDENA Last Plotted: 12/5/2013 2:11 PM Project Management Initials: Designer: Checked: Approved: ANSI A 8.5" x 11"

# Appendix A

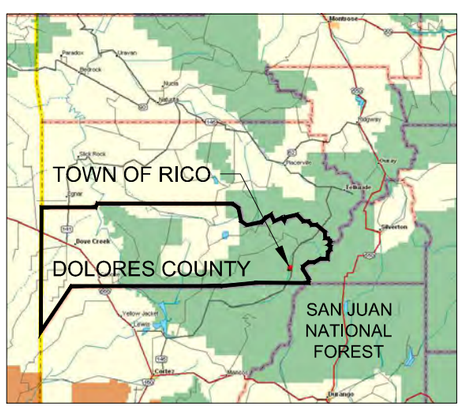
# Construction Drawings

# RICO-ARGENTINE SITE-OU01

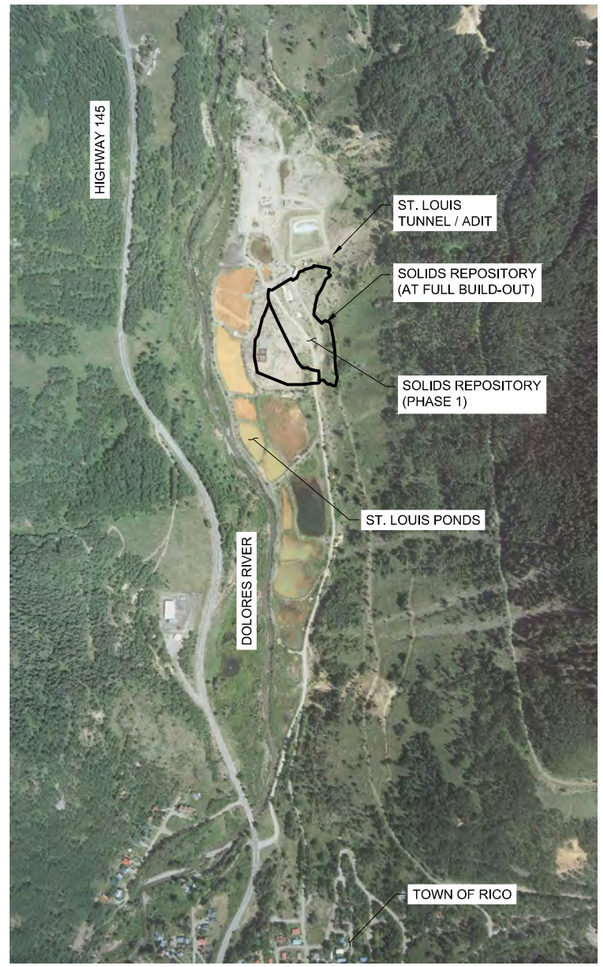
## SOLIDS REPOSITORY




**STATE OF COLORADO**
NOT TO SCALE




**DOLORES COUNTY**
NOT TO SCALE




**VICINITY MAP**
SCALE: 1" = 500'

0 500' 1000'
1" = 500'

N

**SHEET INDEX**


| | | |
|---|---|---|
| 1 | G-100 | COVER SHEET |
| 2 | G-110 | PROPERTY BOUNDARY PLAN |
| 3 | G-120 | SIMULTANEOUS OPERATIONS (SIMOPS) PLAN |
| 4 | G-130 | TOPOGRAPHIC SITE PLAN |
| 5 | G-140 | UTILITY & EXPLORATION PLAN |
| 6 | D-100 | PHASE 1 DEMOLITION & UTILITY RELOCATION PLAN |
| 7 | C-100 | PHASE 1 EROSION CONTROL PLAN |
| 8 | C-110 | PHASE 1 EXCAVATION PLAN & SECTION |
| 9 | C-120 | PHASE 1 ACCESS ROAD PLAN & SECTION |
| 10 | C-130 | PHASE 1 INITIAL FILL PLAN & SECTION |
| 11 | C-140 | PHASE 1 DRAINAGE LAYER PIPING PLAN |
| 12 | C-150 | PHASE 1 FINAL FILL PLAN |
| 13 | C-160 | PHASE 1 LINER PROFILE & SECTIONS |
| 14 | C-170 | PHASE 1 FILTER DIAPHRAGM DETAILS & SECTIONS |
| 15 | C-180 | FULL BUILD-OUT OF SOLIDS REPOSITORY |


AECOM

60306858

RICO-ARGENTINE SITE-OU01
SOLIDS REPOSITORY

FOR PERMITTING ONLY

ISSUED FOR REGULATORY REVIEW - DECEMBER 13, 2013


Project Management Initials: Designer: ACR Checked: EED Approved: DY ANSI D 22" x 34"
Last saved by: RODDENA
Filename: Z:_CURRENT_PROJECTS\ATLANTIC RICHFIELD\60157757 RICO\000_CADD\02-SHEETS\02-SOLIDS-REPOSITORY-2013\G\G100_COVER_RICO_SR_PH-1_30%.DWG
Last Plotted: 2013-12-13

ANSI D 22" x 34"

## PROPERTY BOUNDARY PLAN

Scale: 1:200
(on ANSI D 22"x34")

0 200' 400' 800'

N

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

AECOM
717 17th STREET
SUITE 2600
DENVER, CO 80202
303 228 3000 tel 303 228 3001 fax
www.aecom.com

**CONSULTANTS**

ANDERSON ENGINEERING COMPANY, INC.

**REGISTRATION**

**ISSUE/REVISION**

| I/R | DATE | DESCRIPTION |
|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

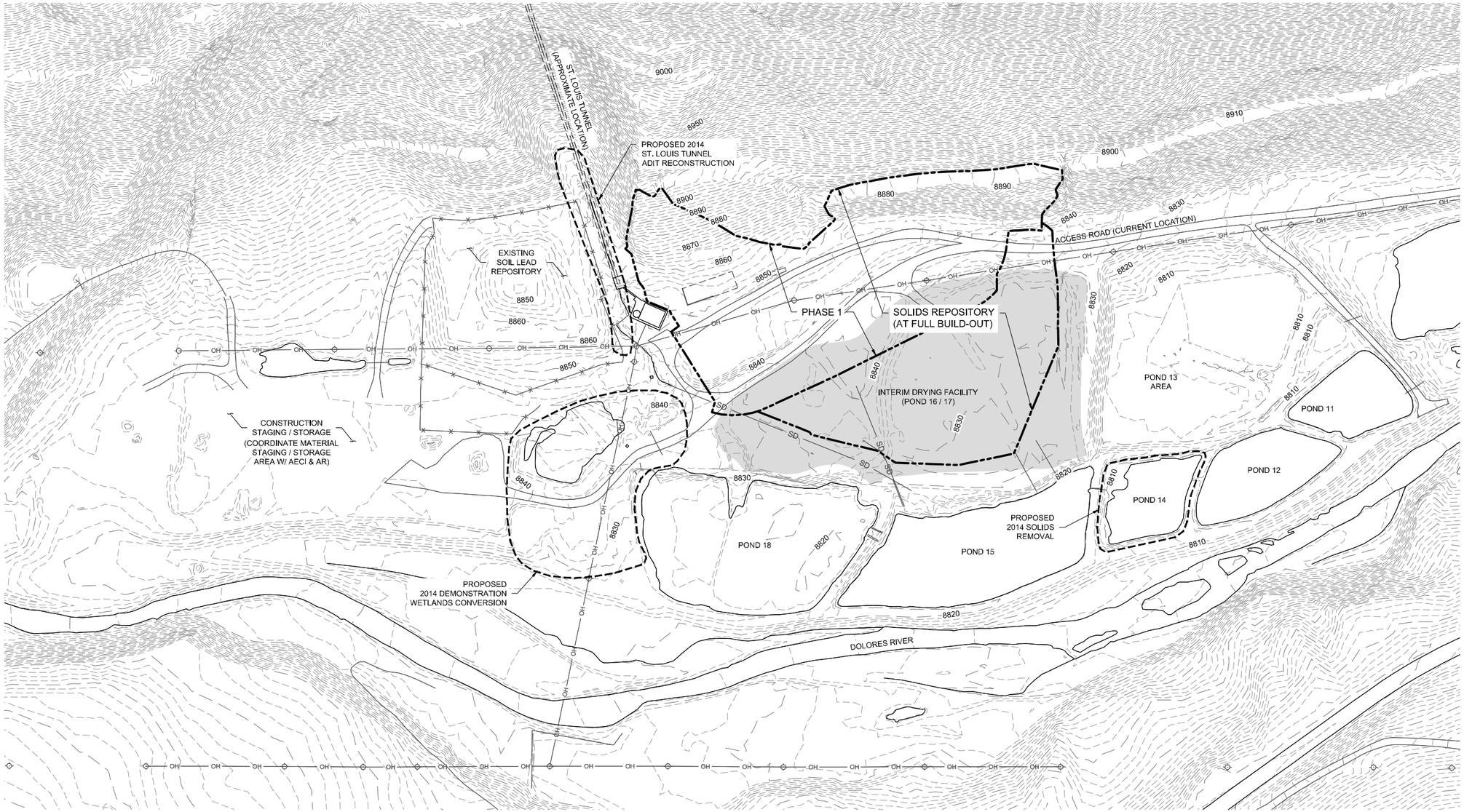
**SHEET TITLE**

PROPERTY BOUNDARY PLAN

**SHEET NUMBER**

G-110 2 OF 15

ANSI D 22" x 34"




## SIMULTANEOUS OPERATIONS (SIMOPS) PLAN

Scale: 1:100
(on ANSI D 22"x34")

0 100' 200' 400'

N

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

AECOM
717 17th STREET
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303 228 3000 tel 303 228 3001 fax
www.aecom.com

**CONSULTANTS**

ANDERSON ENGINEERING COMPANY, INC.

**REGISTRATION**

**ISSUE/REVISION**

| I/R | DATE | DESCRIPTION |
|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

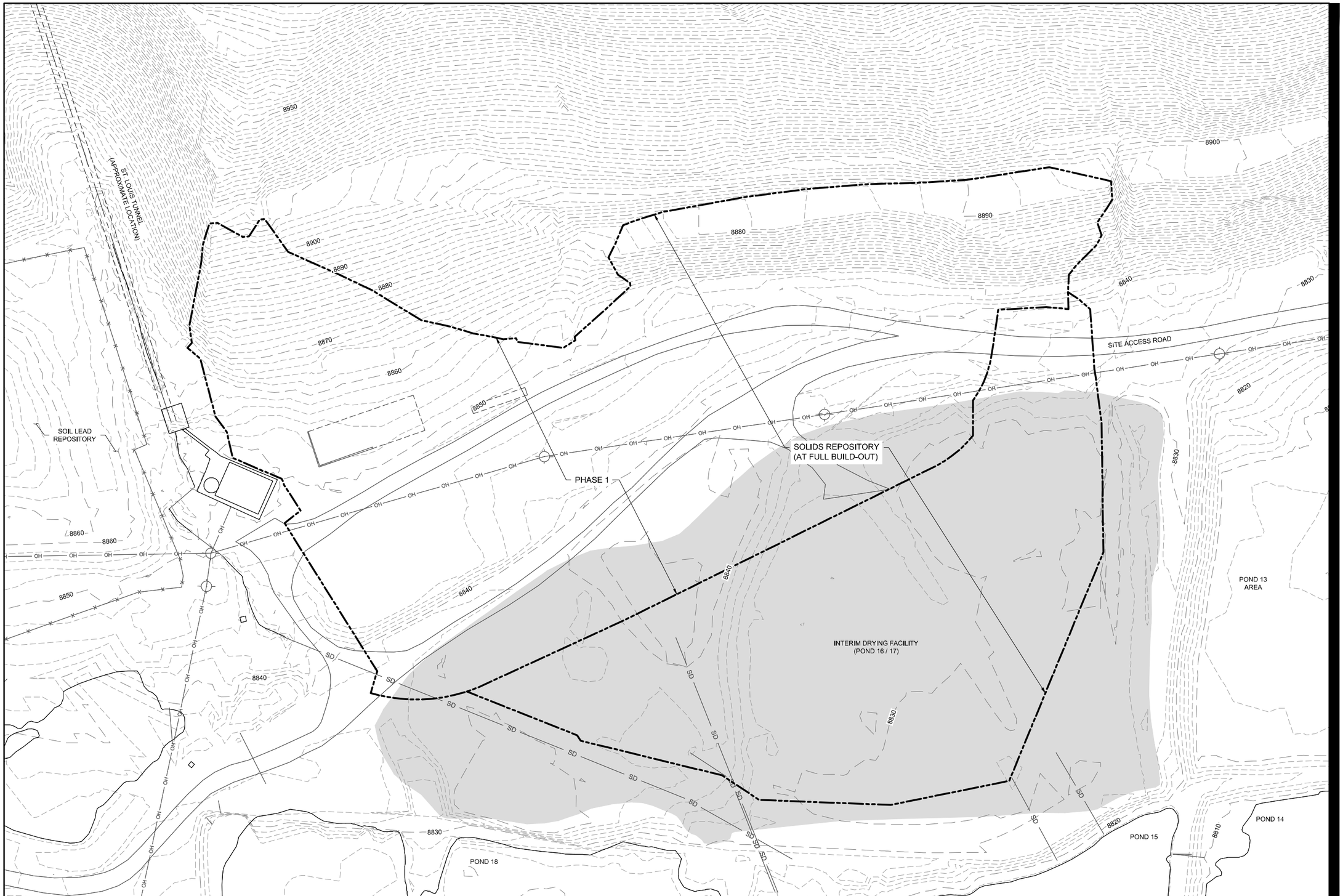
**SHEET TITLE**

SIMULTANEOUS OPERATIONS (SIMOPS) PLAN

**SHEET NUMBER**

G-120 3 OF 15

ANSI D 22" x 34"




## TOPOGRAPHIC SITE PLAN

(2' CONTOUR INTERVAL)

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

AECOM

**PROJECT**

RICO-ARGENTINE
SITE-OU01

SOLIDS
REPOSITORY

**CLIENT**

ATLANTIC
RICHFIELD
COMPANY

**CONSULTANT**


AECOM
717 17th STREET
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www.aecom.com


**CONSULTANTS**

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ENGINEERING
COMPANY, INC.

**REGISTRATION**

**ISSUE/REVISION**

| I/R | DATE | DESCRIPTION |
|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

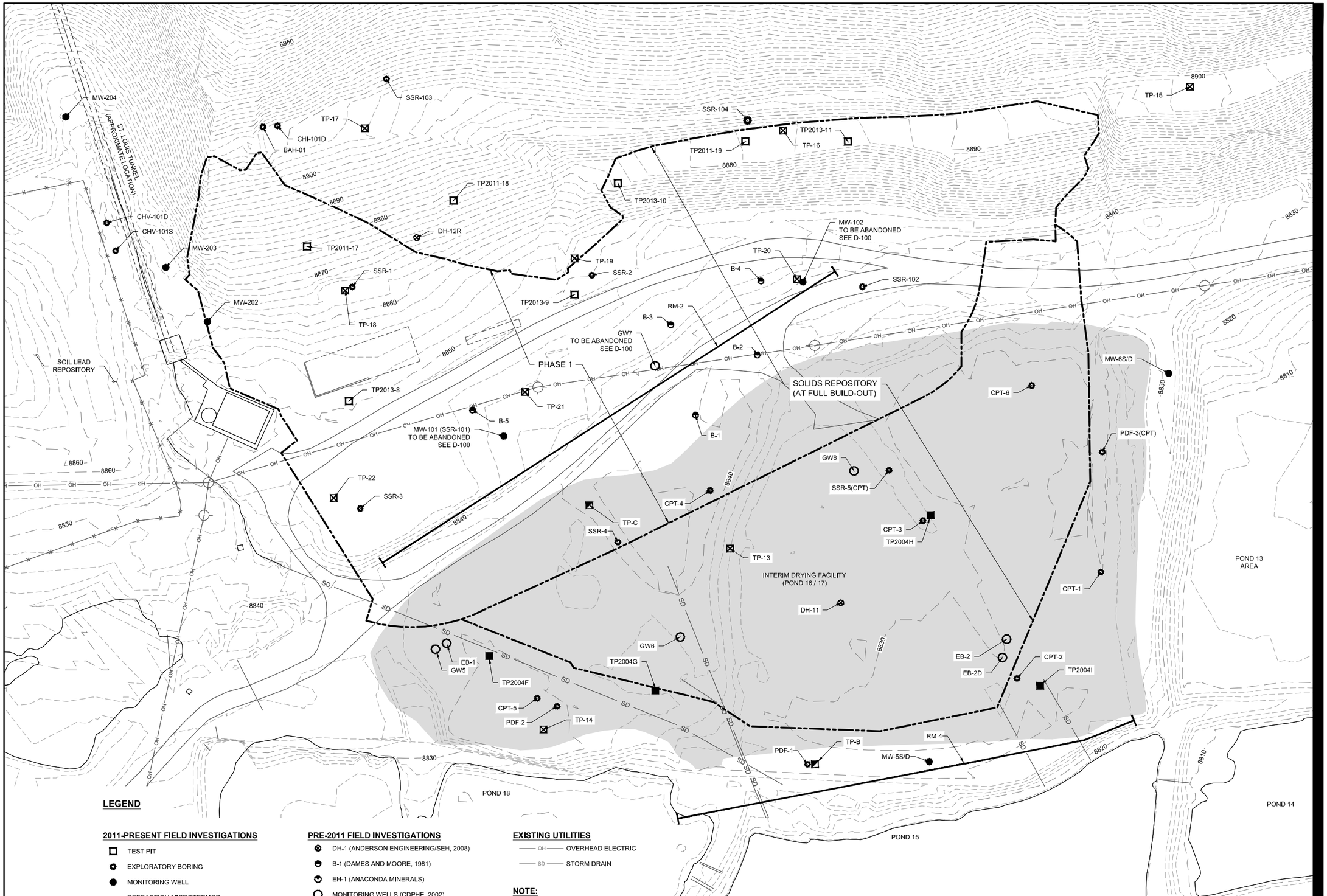
**SHEET TITLE**

TOPOGRAPHIC SITE PLAN

**SHEET NUMBER**

G-130 4 OF 15

ANSI D 22" x 34"




## LEGEND

**2011-PRESENT FIELD INVESTIGATIONS**

- TEST PIT
- EXPLORATORY BORING
- MONITORING WELL
- REFRACTION MICROTREMOR GEOPHYSICAL PROFILES
- (CPT) CPT PERFORMED ADJACENT TO BORING
- * APPROXIMATE LOCATION

**PRE-2011 FIELD INVESTIGATIONS**

- DH-1 (ANDERSON ENGINEERING/SEH, 2008)
- B-1 (DAMES AND MOORE, 1981)
- EH-1 (ANACONDA MINERALS)
- MONITORING WELLS (CDPHE, 2002)
- TP-1 (ANDERSON ENGINEERING/SEH, 2008)
- TP-2004A (SEH, 2004)
- TP-A (SEH, 2001)

**EXISTING UTILITIES**

- OH — OVERHEAD ELECTRIC
- SD — STORM DRAIN

**NOTE:**

ALL WELLS TO REMAIN UNLESS OTHERWISE NOTED.

## UTILITY & EXPLORATION PLAN

(2' CONTOUR INTERVAL)

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

AECOM
717 17th STREET
SUITE 2600
DENVER, CO 80202
303 228 3000 tel 303 228 3001 fax
www.aecom.com

**CONSULTANTS**

ANDERSON ENGINEERING COMPANY, INC.

**REGISTRATION**

**ISSUE/REVISION**

| I/R | DATE | DESCRIPTION |
|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

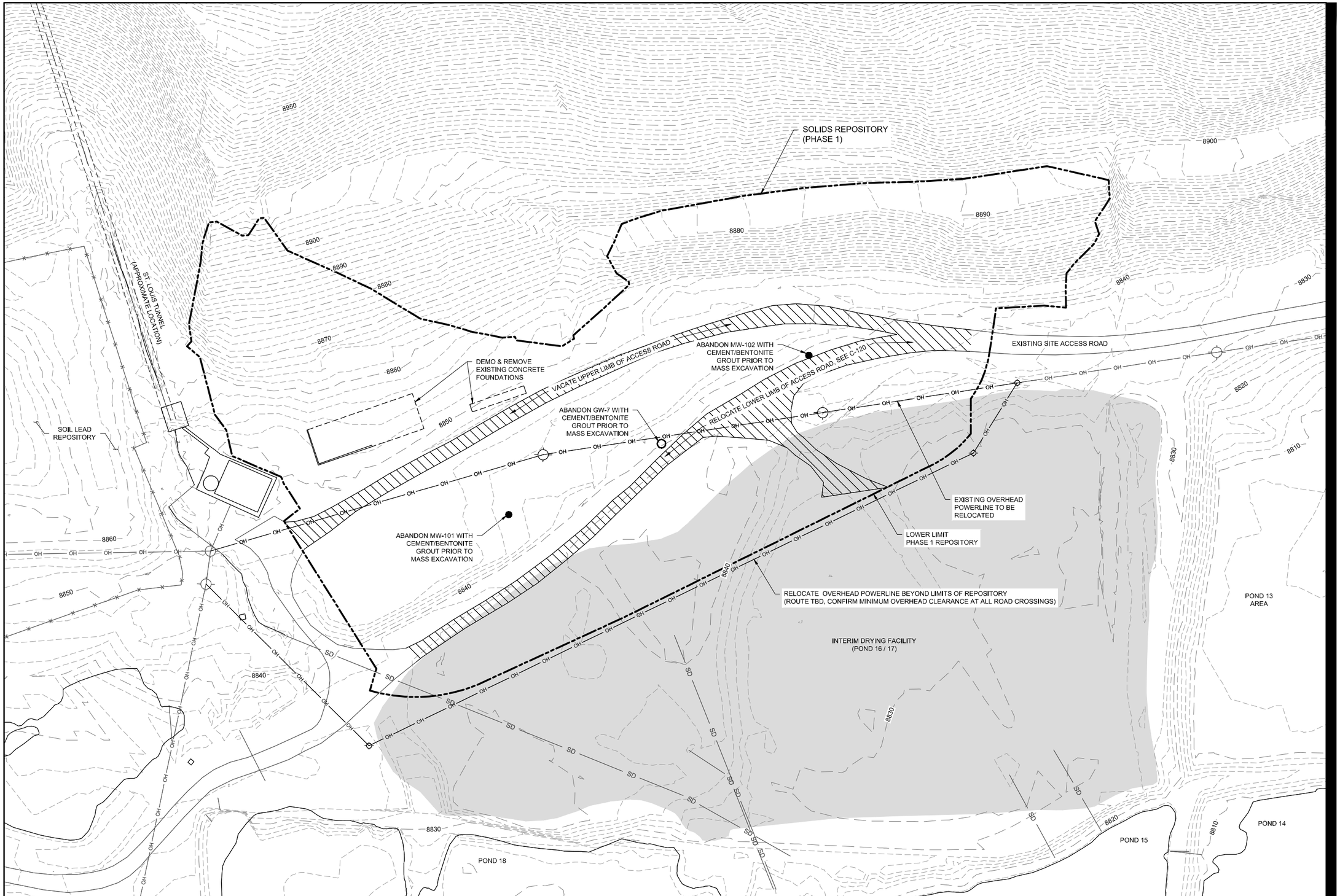
**SHEET TITLE**

UTILITY & EXPLORATION PLAN

**SHEET NUMBER**

G-140 5 OF 15

ANSI D 22" x 34"




**NOTE:**

OLD FACILITIES KNOWN TO HAVE EXISTED IN VICINITY.
BURIED FOUNDATIONS OR DEBRIS MAY EXIST.

## PHASE 1 DEMOLITION & UTILITY RELOCATION PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

AECOM

**PROJECT**

RICO-ARGENTINE
SITE-OU01

SOLIDS
REPOSITORY

**CLIENT**

ATLANTIC
RICHFIELD
COMPANY

**CONSULTANT**

AECOM
717 17th STREET
SUITE 2600
DENVER, CO 80202
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**CONSULTANTS**

ANDERSON
ENGINEERING
COMPANY, INC.

**REGISTRATION**

**ISSUE/REVISION**

| I/R | DATE | DESCRIPTION |
|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

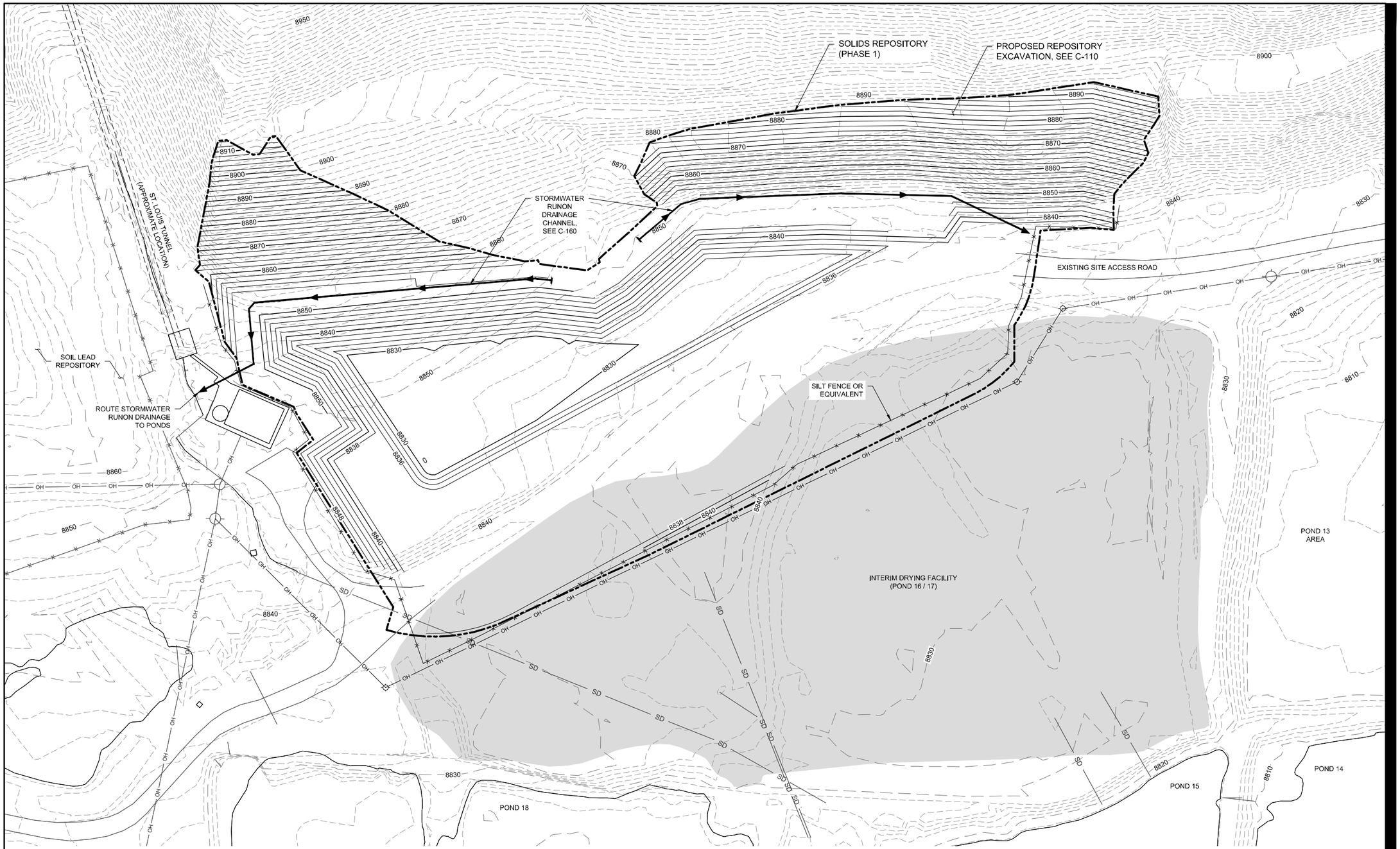
**SHEET TITLE**

PHASE 1 DEMOLITION &
UTILITY RELOCATION PLAN

**SHEET NUMBER**

D-100 6 OF 15

ANSI D 22" x 34"




## PHASE 1 EROSION CONTROL PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**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60306858

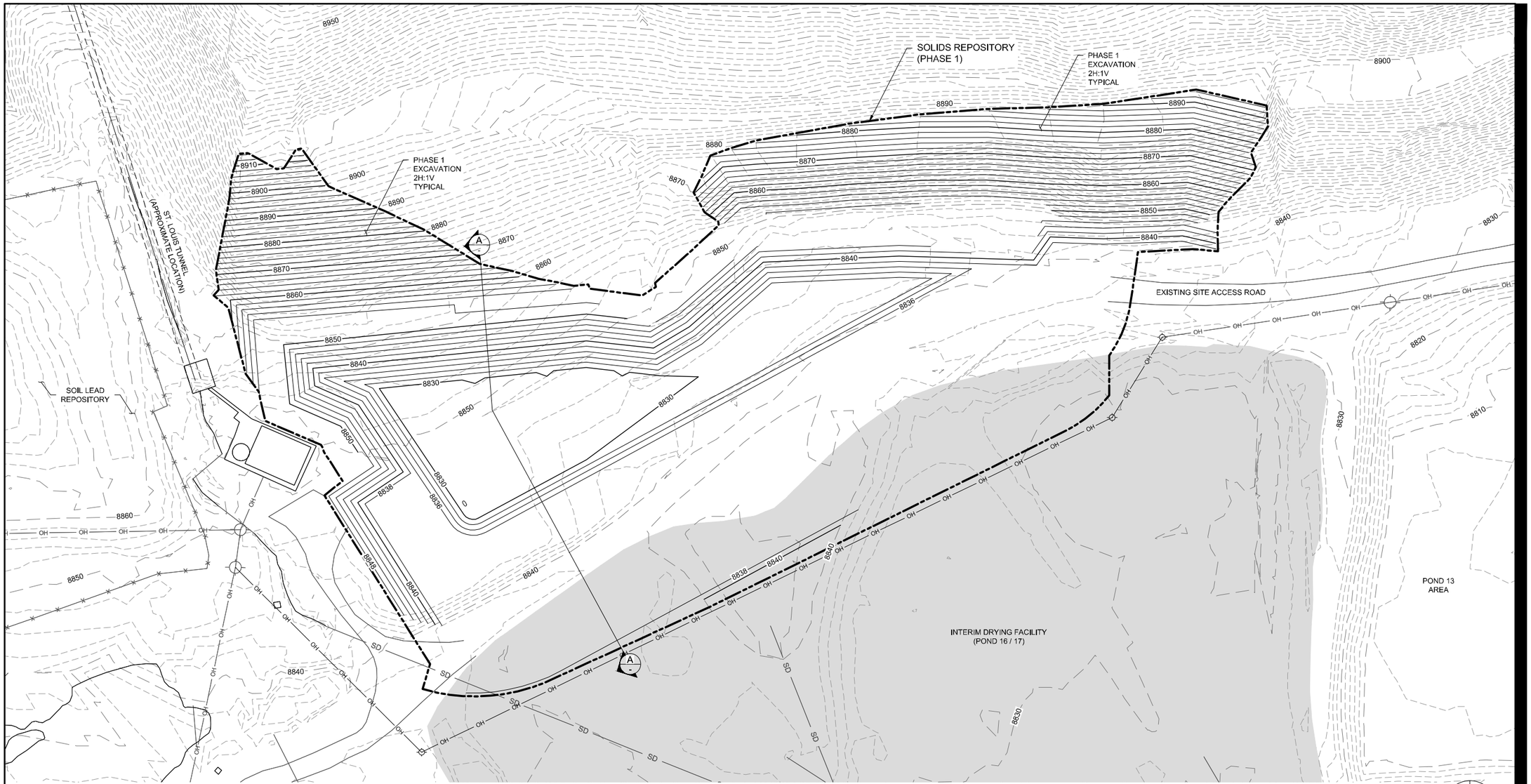
**SHEET TITLE**

PHASE 1 EROSION CONTROL PLAN

**SHEET NUMBER**

C-100 7 OF 15

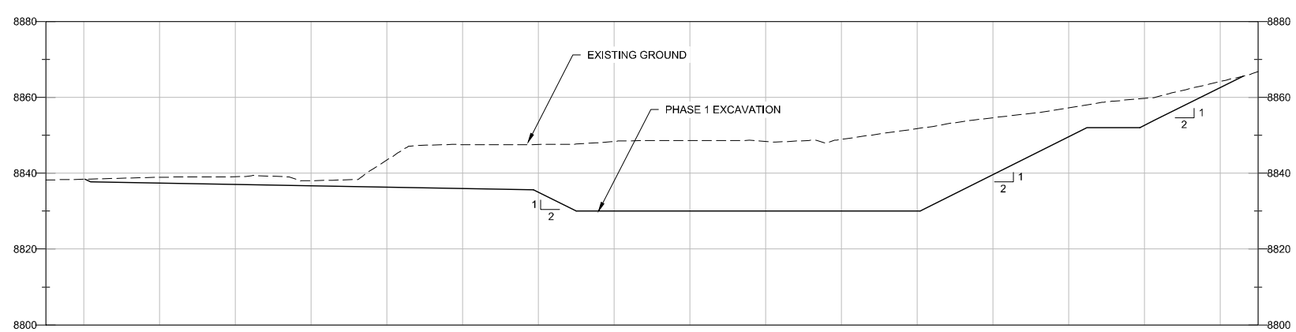
ANSI D 22" x 34"




## PHASE 1 EXCAVATION PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'




## A PHASE 1 EXCAVATION SECTION

Scale: 1:20
(on ANSI D 22"x34")

0 20' 40' 80'

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

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**PROJECT NUMBER**

60306858

**SHEET TITLE**

PHASE 1 EXCAVATION PLAN & SECTION

**SHEET NUMBER**

C-110 8 OF 15

ANSI D 22" x 34"

SOLIDS REPOSITORY (PHASE 1)

ST. LOUIS TUNNEL (APPROXIMATE LOCATION)

SOIL LEAD REPOSITORY

EXISTING SITE ACCESS ROAD

APPROXIMATE FILL FOR ACCESS ROAD RELOCATION

ACCESS ROAD RELOCATION

DRAINAGE DIVIDE FOR ACCESS ROAD DITCH FLOW

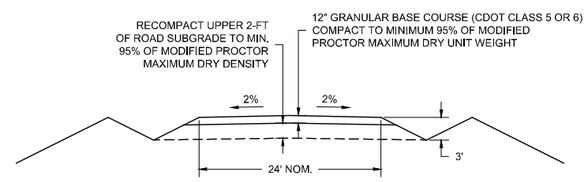
INTERIM DRYING FACILITY (POND 16 / 17)

POND 13 AREA

## PHASE 1 ACCESS ROAD PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'




## B PHASE 1 ACCESS ROAD SECTION

Scale: 1:10
(on ANSI D 22"x34")

0 10' 20' 40'

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

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|---|---|---|

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**PROJECT NUMBER**

60306858

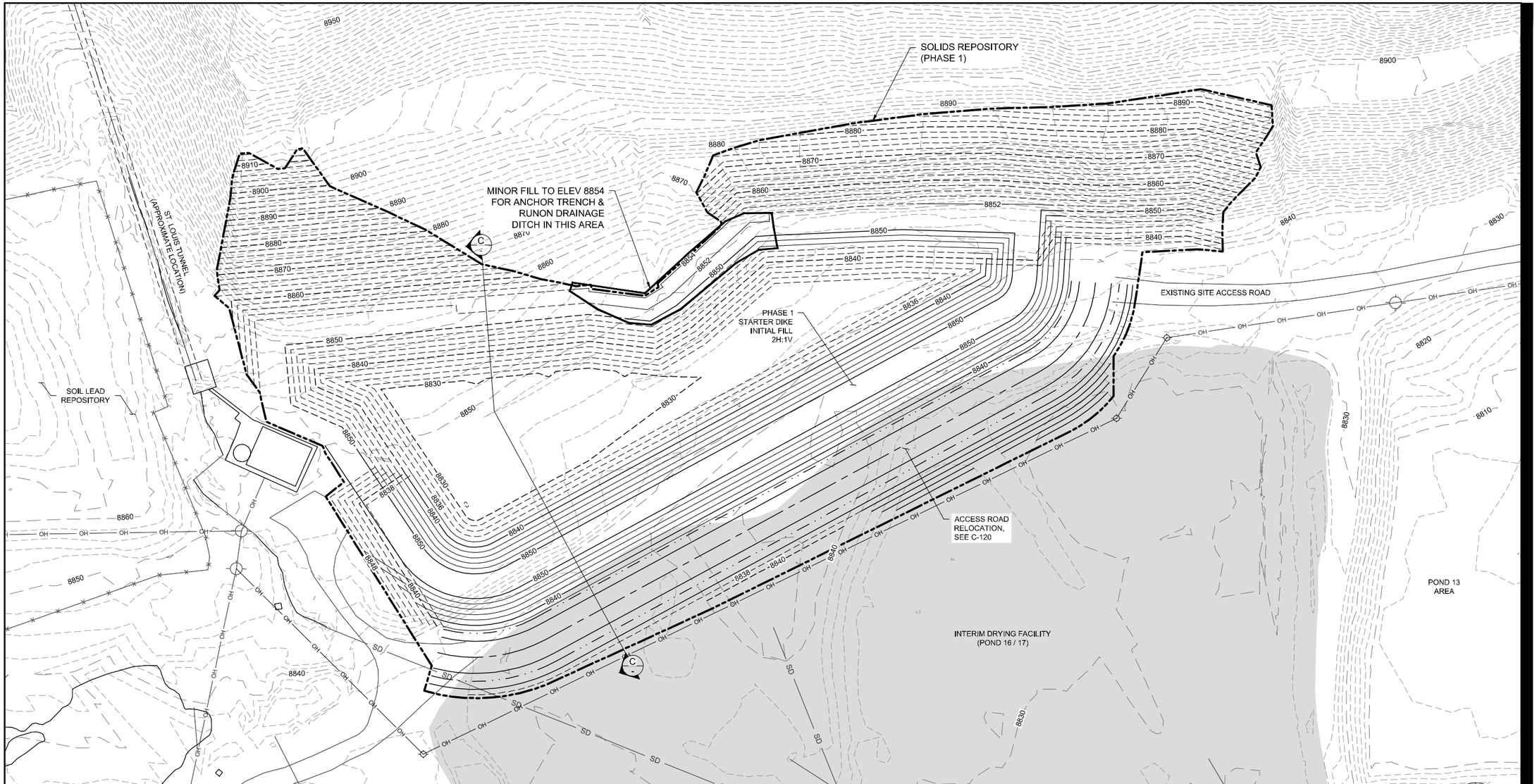
**SHEET TITLE**

PHASE 1 ACCESS ROAD PLAN & SECTION

**SHEET NUMBER**

C-120 9 OF 15

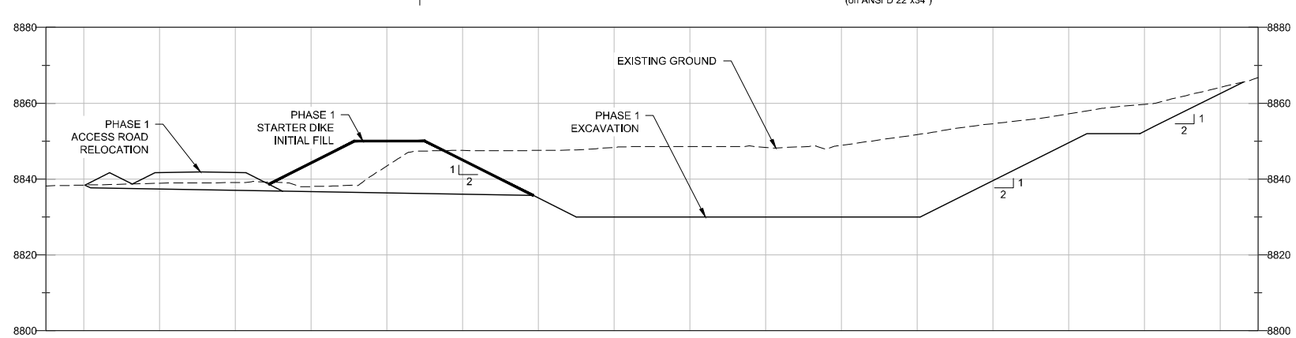
ANSI D 22" x 34"




## PHASE 1 INITIAL FILL PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'




## C PHASE 1 INITIAL FILL SECTION

Scale: 1:20
(on ANSI D 22"x34")

0 20' 40' 80'

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

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|---|---|---|

FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

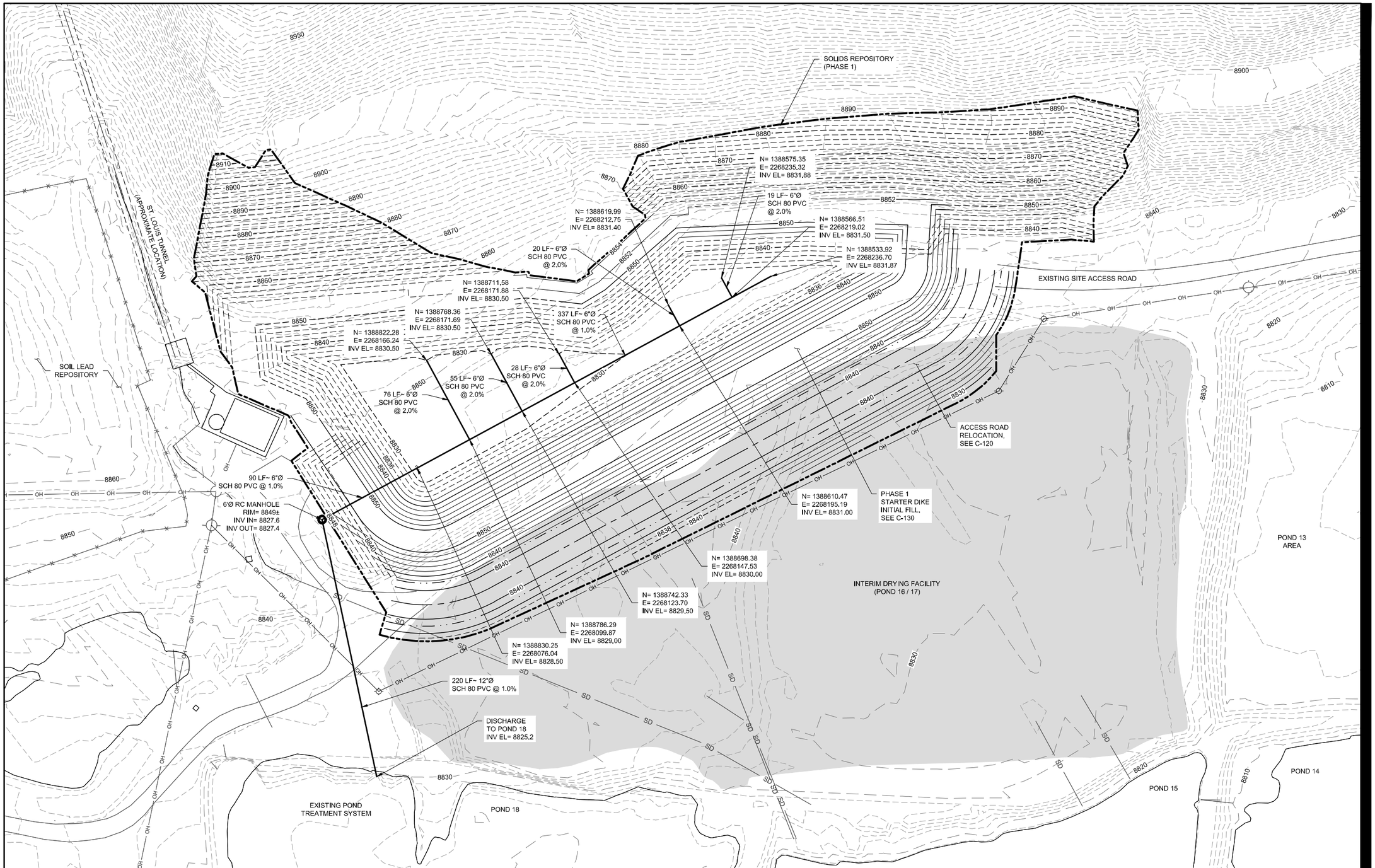
**SHEET TITLE**

PHASE 1 INITIAL FILL PLAN & SECTION

**SHEET NUMBER**

C-130 10 OF 15

ANSI D 22" x 34"




## PHASE 1 DRAINAGE LAYER PIPING PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

**AECOM**

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**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|---|---|---|

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**PROJECT NUMBER**

60306858

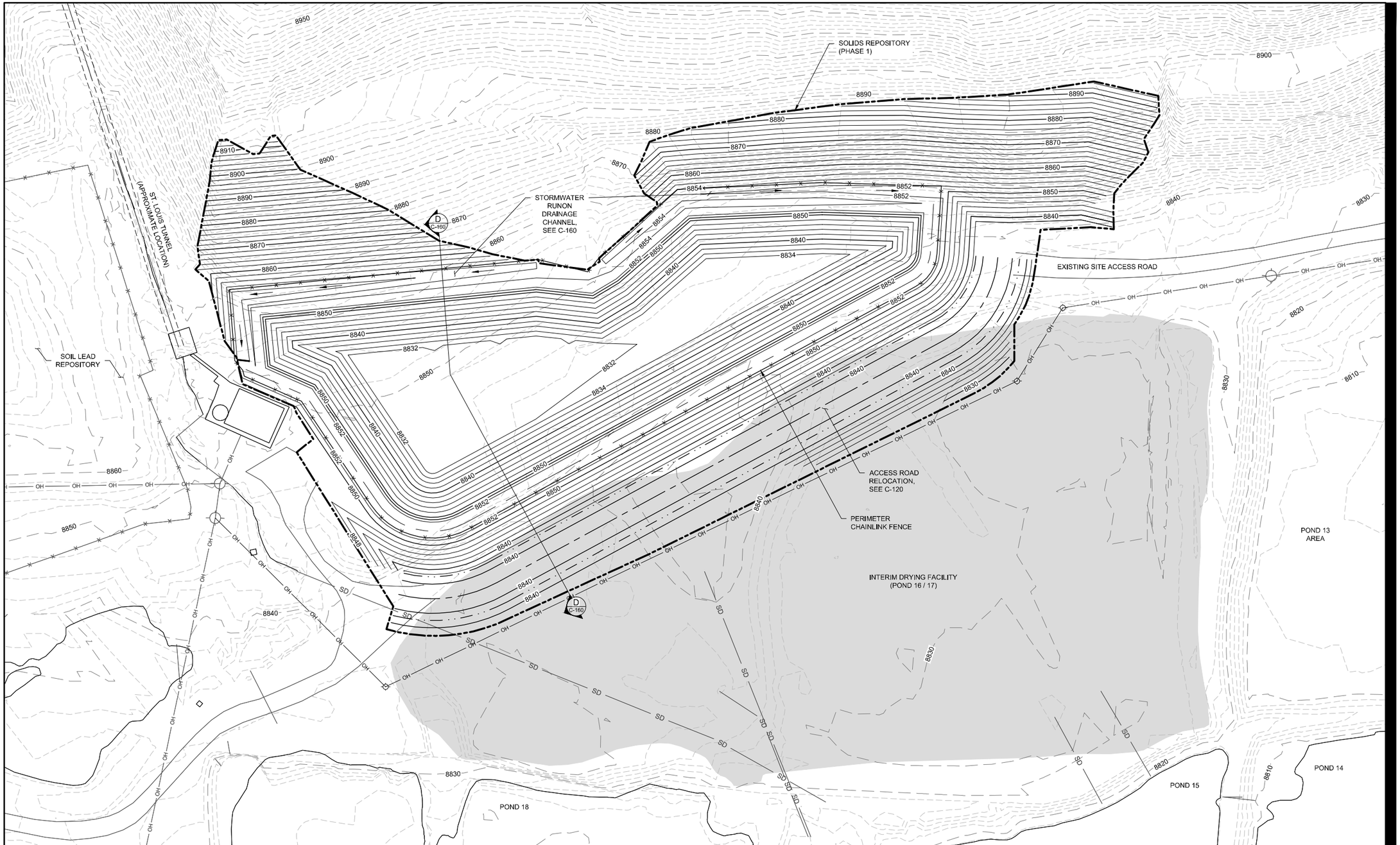
**SHEET TITLE**

PHASE 1 DRAINAGE LAYER PIPING PLAN

**SHEET NUMBER**

C-140

ANSI D 22" x 34"




## PHASE 1 FINAL FILL PLAN

Scale: 1:40
(on ANSI D 22"x34")

0 40' 80' 160'

N

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**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**PROJECT NUMBER**

60306858

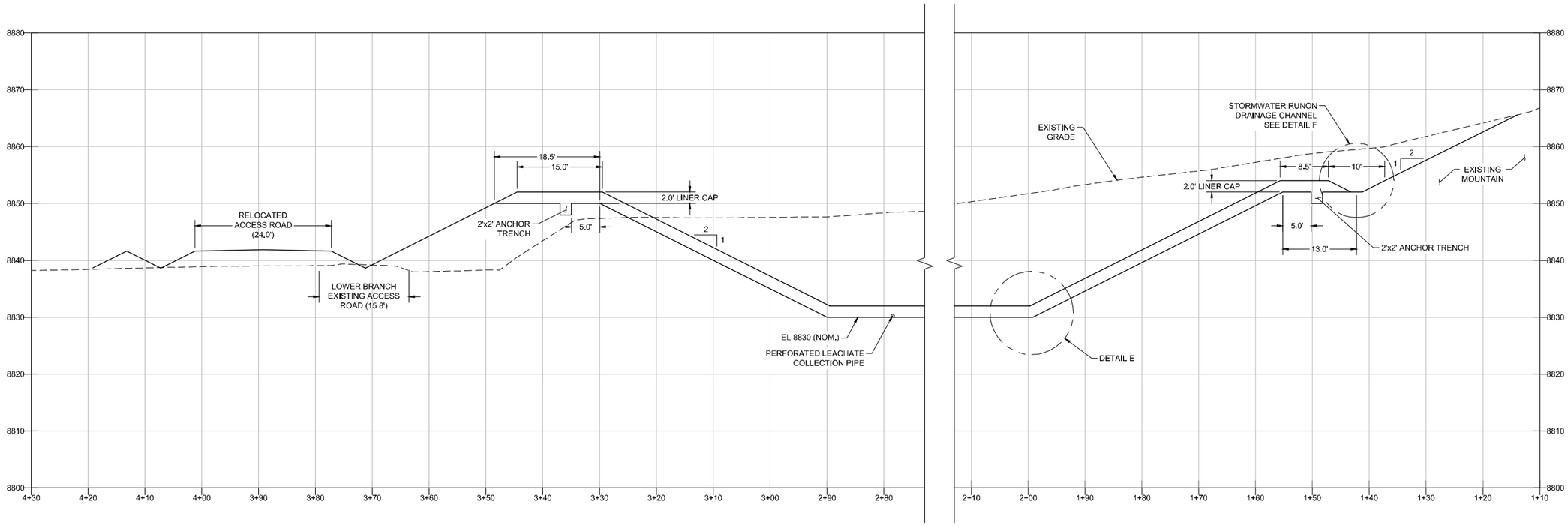
**SHEET TITLE**

PHASE 1 FINAL FILL PLAN

**SHEET NUMBER**

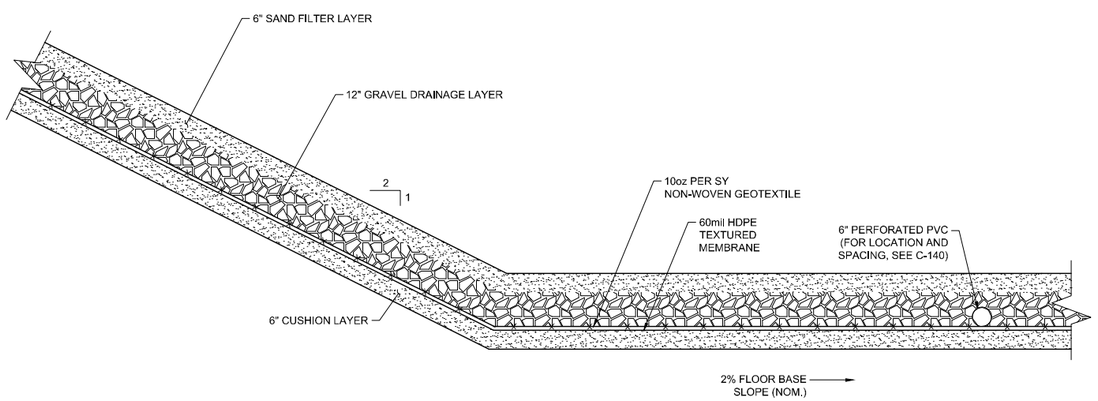
C-150 12 OF 15

ANSI D 22" x 34"



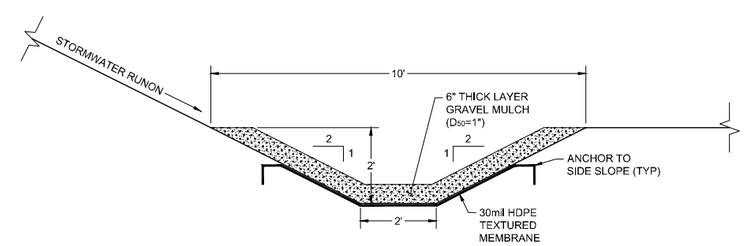

## D | LINER PROFILE

Scale: 1:10
(on ANSI D 22"x34")




## E | LINER SECTION

Scale: 1:2
(on ANSI D 22"x34")




## F | STORMWATER RUNON DRAINAGE CHANNEL SECTION

Scale: 1:2
(on ANSI D 22"x34")

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

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**PROJECT NUMBER**

60306858

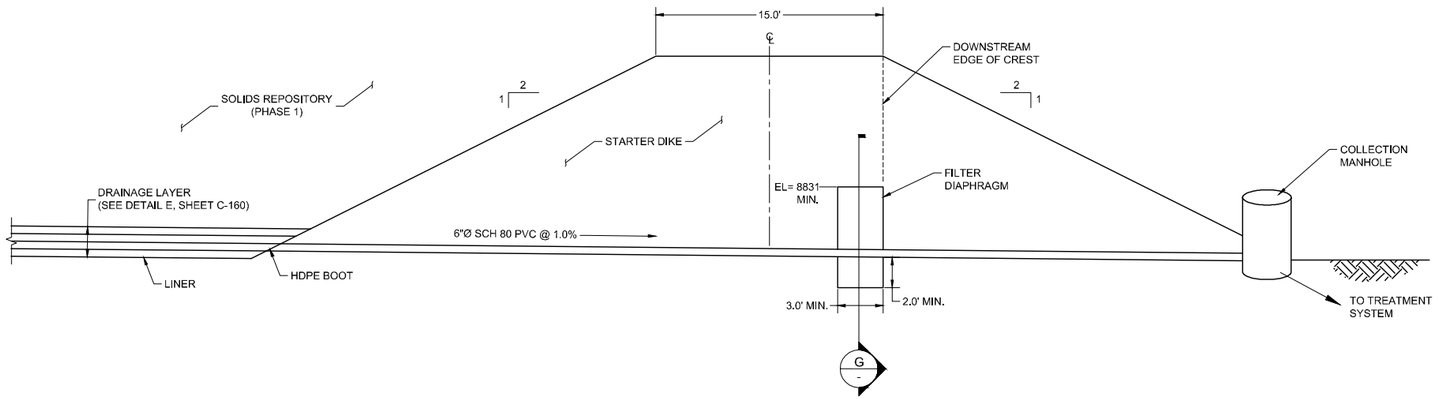
**SHEET TITLE**

PHASE 1 LINER PROFILE & SECTIONS

**SHEET NUMBER**

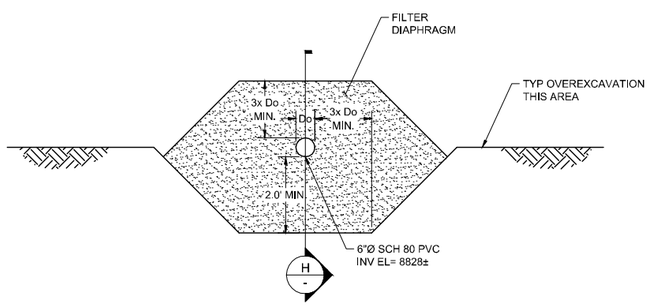
C-160 13 OF 15

ANSI D 22" x 34"



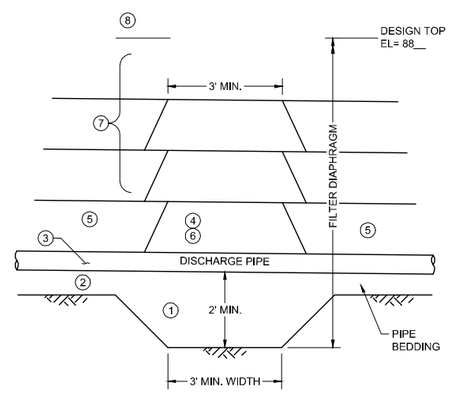

## OUTLET PIPE PROFILE

Scale: 1:5
(on ANSI D 22"x34")




## G | SECTION @ FILTER DIAPHRAGM

Scale: 1:2
(on ANSI D 22"x34")




1. OVER EXCAVATE & COMPACT LOWER SECTION OF THE FILTER DIAPHRAGM SAND FILL
2. PLACE SAND BEDDING
3. INSTALL PIPE TO DESIGN GRADE
4. LOOSE PLACE DIAPHRAGM SAND FILL (1st LIFT)
5. PLACE & COMPACT EMBANKMENT SIDE FILL (1st LIFT)
6. COMPACT DIAPHRAGM FILL (1st LIFT)
7. REPEAT FILL SEQUENCE TO TOP OF FILTER DIAPHRAGM (EL= 8831 MIN.)
8. PLACE AND COMPACT EMBANKMENT FILL TO PRE-LINER CAP CREST (EL= 8850)

## H | FILTER DIAPHRAGM CONSTRUCTION SEQUENCE

Not To Scale
(on ANSI D 22"x34")

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

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FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

**SHEET TITLE**

PHASE 1 FILTER DIAPHRAGM DETAILS & SECTIONS

**SHEET NUMBER**

C-170 14 OF 15

ANSI D 22" x 34"

## FINAL COVER SECTION

Scale: 1:2
(on ANSI D 22"x34")

## FULL BUILD-OUT OF SOLIDS REPOSITORY

Scale: 1:40
(on ANSI D 22"x34")

AECOM

**PROJECT**

RICO-ARGENTINE SITE-OU01

SOLIDS REPOSITORY

**CLIENT**

ATLANTIC RICHFIELD COMPANY

**CONSULTANT**

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FOR PERMITTING ONLY

**PROJECT NUMBER**

60306858

**SHEET TITLE**

FULL BUILD-OUT OF SOLIDS REPOSITORY

**SHEET NUMBER**

C-180 15 OF 15

# Appendix B

# Geotechnical Investigation Logs

# Boring and Monitoring Well Logs

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: AR-104 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

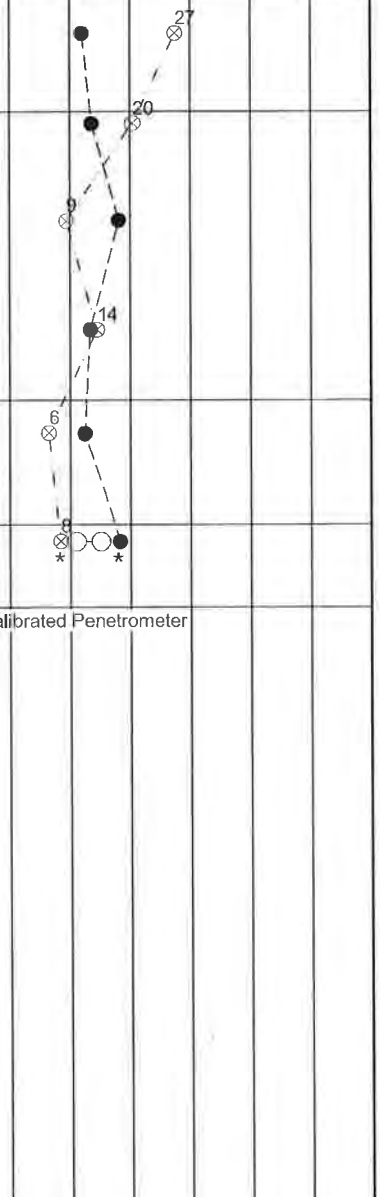
SITE LOCATION: Rico-Argentine

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1, 2, 3, 4, 5)

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % (10, 20, 30, 40, 50)

STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL (SURFACE ELEVATION Feet) | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | RB | | | | |
| | | 1 | SS | | | FILL: Well graded gravel with sand - 50% gravel sub angular to sub rounded, 30% sand, 20% fines - 7.5YR4/3 - medium dense (FILL: GC) | |
| | | | RB | | | 3.0 | |
| | | 2 | SS | | | FILL: Well graded sand with gravel - 60% sand, 35% angular to sub rounded gravel, 5% clay/silt - 10YR4/3 - loose to medium dense (FILL: SW) | |
| 5.0 | | | RB | | | | |
| | | 3 | SS | | | | |
| | | | RB | | | | |
| | | 4 | SS | | | | |
| 10.0 | | | RB | | | 10.0 | |
| | | 5 | SS | | | FILL: Well graded gravel with sand oxidized waste rock - 60% gravel, angular to well rounded, 30% sand, 10% fines - 10YR4/2 - loose (FILL: GW-GC) | |
| | | | RB | | | 13.0 | |
| | | 6 | SS | | | FILL: Well graded gravel with sand and clay and oxidized/weathered waste rock - 50% gravel angular to subangular, 25% sand, 25% clay - 10YR5/6 (FILL: GC) | |
| 15.0 | | | | | | 15.0 | |
| | | | | | | End of boring at 15.0'. Boring advanced with roller bit and HQ casing. Borings performed by Cascade Drilling and logged by Anderson Engineering Company, Inc. AECOM is not responsible for the soil classifications. | |




* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING | BORING STARTED 10/30/12 | AECOM OFFICE Denver | |
| EASTING | BORING COMPLETED 10/30/12 | ENTERED BY AMH | SHEET NO. 1 OF 1 |
| WL None Observed | RIG/FOREMAN Modified Ditchwitch/Cory Watson | APP'D BY | AECOM JOB NO. 60239818 |

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

# BORING B-1

SURFACE ELEVATION 8833

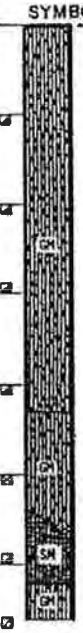
COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 18 | SPT |
| | | | | | | | | | | 9 | SPT |
| | | | | | | | | | | 7 | SPT |
| | | | | 14 | | | | | | 13 | SPT |
| | | | | | | | | | | 28 | D |
| | | | | | | | | | | 27 | SPT |
| | | | | | | | | | | 50/5" | SPT |

DEPTH IN FEET: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70

SAMPLING

SYMBOLS




DESCRIPTION

BROWN FINE TO COARSE SANDY GRAVEL WITH SILT MEDIUM DENSE

GRADES WITH LENSES OF SILTY SAND AND SANDY SILT

COLORS GREY AND GRADES WITH SOME CLAY GRADES LOOSE TO MEDIUM DENSE

GRADES LOOSE

GRADES WITH MORE GRAVEL AND MEDIUM DENSE

DARK BROWN TO BLACK SILTY GRAVEL WITH SAND, MEDIUM DENSE

BROWN SILTY FINE TO COARSE SAND WITH SOME GRAVEL MEDIUM DENSE

BROWN SANDY GRAVEL, DENSE TO VERY DENSE

AUGER REFUSAL AT 33 FEET

BORING COMPLETED AT 33.5 FEET ON 6/3/81

WATER ENCOUNTERED AT 21.8 FEET ON 6/3/81

FILL

KEY

- INDICATES UNDISTURBED SAMPLE
- INDICATES DISTURBED SAMPLE
- INDICATES SAMPLING ATTEMPT WITH NO RECOVERY
- INDICATES STANDARD PENETRATION TEST SAMPLE
- P - IN BLOW COUNT COLUMN INDICATES SAMPLER HYDRAULICALLY PUSHED

SAMPLE TYPE

- U - DAMES & MOORE "U" BIT
- T - DAMES & MOORE THIN-WALL
- P - DAMES & MOORE PISTON
- SPT - STANDARD SPLIT-SPOON
- D - DAMES & MOORE "D" SAMPLER

NOTE:

1. THE SOIL CONDITIONS ARE DESCRIBED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM, PLATE A-3.
2. BLOW COUNT HAS BEEN TAKEN AS THE NUMBER OF BLOWS REQUIRED TO DRIVE A SAMPLER TO ONE-FOOT PENETRATION USING A 140 POUND WEIGHT FALLING 30 INCHES.

# LOG OF BORING

DAMES & MOORE

PLATE A-1A

FILE ANACONDA RICO 05010-002-1008

# BORING B-2

SURFACE ELEVATION 8834

COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO. 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE | DEPTH IN FEET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 26 | SPT | 5 |
| GRADATION | | | | 22 | | | 32 | 17 | 15 | 8 | SPT | 10 |
| | | | | | | | | | | 12 | SPT | 15 |
| | | | | | | | | | | 21 | SPT | 20 |
| | | | | | | 67 | 67 | 51 | 16 | 5 | SPT | 25 |
| | | | | | | 66 | | | | 11 | SPT | |
| | | | | | | | | | | 50 for 1/4" | SPT | 30 |

SAMPLING

SYMBOLS

DESCRIPTION

SC — BROWN CLAYEY SAND WITH GRAVEL MEDIUM DENSE

SM — BROWN AND GREY GRAVELLY SAND WITH SOME CLAY

SC — YELLOW AND BROWN FINE TO COARSE CLAYEY SAND WITH GRAVEL LOOSE

LUMBER FRAGMENTS AT 15 FEET GRADES MEDIUM DENSE

GW — GREY & BROWN SANDY GRAVEL WITH SOME SILT MEDIUM DENSE

MH — DARK BROWN AND BLACK FINE SANDY SILT SOFT TO MEDIUM STIFF

AUGER REFUSAL AT 30.5 FEET
BORING COMPLETED AT 30.5 FEET ON 6/4/81
WATER ENCOUNTERED AT 20.7 FEET ON 6/3/81

FILL

35 40 45 50 55 60 65 70

KEY

- ■ INDICATES UNDISTURBED SAMPLE
- ⊠ INDICATES DISTURBED SAMPLE
- □ INDICATES SAMPLING ATTEMPT WITH NO RECOVERY
- ◪ INDICATES STANDARD PENETRATION TEST SAMPLE
- P - IN BLOW COUNT COLUMN INDICATES SAMPLER HYDRAULICALLY PUSHED

SAMPLE TYPE

- U - DAMES & MOORE "U" BIT
- T - DAMES & MOORE THIN-WALL
- P - DAMES & MOORE PISTON
- SPT - STANDARD SPLIT-SPOON
- D - DAMES & MOORE "D" SAMPLER

NOTE:
SEE PLATE A - 1A.

# LOG OF BORING

DAMES & MOORE



FILE ANACONDA RICO CHOIO-082-1WOD

## BORING B-3

SURFACE ELEVATION 8836
COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO. 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 42 | | | | | | 6 | SPT |
| | | | | | | | | | | 32 | SPT |
| | | | | | | | | | | 7 | SPT |
| | | | | | | | | | | 23 | SPT |

DEPTH IN FEET: 0, 5, 10, 15, 20, 25, 30

SAMPLING — SYMBOLS — DESCRIPTION

BROWN SANDY CLAYEY GRAVEL WITH SAND. LOOSE

SAMPLER DRIVEN THROUGH COBBLE

GRADES MEDIUM DENSE

FILL

AUGER REFUSAL AT 20'
BORING COMPLETED AT 20 FEET
ON 6/5/81
NO WATER ENCOUNTERED

## BORING B-4

SURFACE ELEVATION 8835
COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO. 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 8 | SPT |
| GRADATION | | | | 22 | | 15 | 27 | 21 | 6 | 5 | SPT |
| | | | | | | | | | | 1 | SPT |

DEPTH IN FEET: 0, 5, 10, 15, 20, 25, 30

SAMPLING — SYMBOLS — DESCRIPTION

BROWN CLAYEY SAND AND GRAVEL WITH COBBLES LOOSE

SC-GC

FILL

DARK BROWN SILTY AND SANDY CLAY WITH ORGANIC MATERIAL

CL

AUGER REFUSAL AT 24.5 FEET
BORING COMPLETED AT 24.5 FEET
ON 6/5/81
NO WATER ENCOUNTERED

KEY

- ■ INDICATES UNDISTURBED SAMPLE
- ⊠ INDICATES DISTURBED SAMPLE
- ☐ INDICATES SAMPLING ATTEMPT WITH NO RECOVERY
- ◪ INDICATES STANDARD PENETRATION TEST SAMPLE
- P - IN BLOW COUNT COLUMN INDICATES SAMPLER HYDRAULICALLY PUSHED

SAMPLE TYPE

- U - DAMES & MOORE "U" BIT
- T - DAMES & MOORE THIN-WALL
- P - DAMES & MOORE PISTON
- SPT - STANDARD SPLIT-SPOON
- D - DAMES & MOORE "D" SAMPLER

NOTE:
SEE PLATE A - 1A.

# LOG OF BORING

DAMES & MOORE



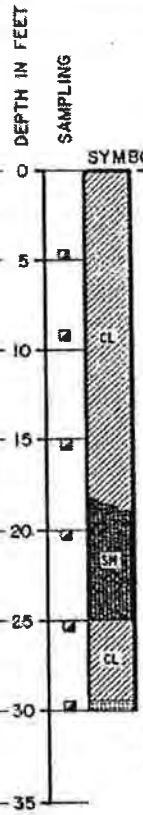
FILE ANACONDA RICO 04010-082-1808

## BORING B-5

SURFACE ELEVATION 8839

COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO. 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH, SULFATES | | | | | | 5 | 31 | 20 | 11 | 11 | SPT |
| | | | | | | | | | | 11 | SPT |
| | | | | | | | | | | 32 | SPT |
| | | | | 43 | | | | | | 11 | SPT |
| | | | | | | 13 | 44 | 23 | 21 | 38 | SPT |
| | | | | | | | | | | 50 for 4 1/2" | SPT |




DESCRIPTION

BROWN SANDY CLAY WITH SOME GRAVEL STIFF

GRADES WITH MORE GRAVEL

YELLOW-BROWN GRAVELLY SAND WITH SOME CLAY AND WOOD FRAGMENTS LOOSE TO MEDIUM DENSE

DARK BROWN SANDY CLAY

AUGER REFUSAL AT 29.5 FEET
WEATHERED SANDSTONE BEDROCK
BORING COMPLETED AT 30.25 FEET ON 6/5/81
WATER ENCOUNTERED AT 25.5 FEET ON 6/6/81

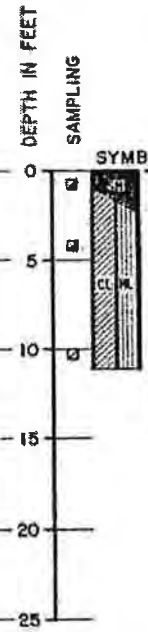
FILL

## BORING B-6

SURFACE ELEVATION 8793

COORDINATES

| OTHER TESTS | STRENGTH TEST RESULTS: TYPE OF TEST | CONFINING PRESSURE (psf) | PEAK SHEAR STRENGTH (psf) | % PASSING NO. 200 SIEVE | DRY DENSITY (pcf) | MOISTURE CONTENT (%) | ATTERBERG LIMITS: LL (%) | PL (%) | PI (%) | SAMPLING: BLOW COUNT | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 2/4" | SPT |
| | | | | 25 | | | 28 | 19 | 7 | 5 | SPT |
| | | | | | | | | | | 50/0" | SPT |




DESCRIPTION

DARK BROWN SILTY SAND WITH GRAVEL AND COBBLES MEDIUM DENSE

DARK BROWN CLAYEY SILT AND SILTY CLAY WITH GRAVEL AND COBBLES MEDIUM STIFF

AUGER REFUSAL AT 10 FEET
BORING COMPLETED AT 11 FEET ON 6/7/81
WATER ENCOUNTERED AT 5 FEET ON 6/7/81

KEY

- ■ INDICATES UNDISTURBED SAMPLE
- ⊠ INDICATES DISTURBED SAMPLE
- □ INDICATES SAMPLING ATTEMPT WITH NO RECOVERY
- ◪ INDICATES STANDARD PENETRATION TEST SAMPLE
- P - IN BLOW COUNT COLUMN INDICATES SAMPLER HYDRAULICALLY PUSHED

SAMPLE TYPE

- U - DAMES & MOORE "U" BIT
- T - DAMES & MOORE THIN-WALL
- P - DAMES & MOORE PISTON
- SPT - STANDARD SPLIT-SPOON
- D - DAMES & MOORE "D" SAMPLER

NOTE:

SEE PLATE A - 1A.

# LOG OF BORING

DAMES & MOORE



FILE ANACONDA RICO 09010-062-1605

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **BAH-01** |
|---|---|---|
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,912.6 Feet | |
| | | | | | | Cobbles, silt, sand - drilling mud: brown-red brown<br>Angle boring at 13 degrees from horizontal | |
| 5.0 | | | | | | | |
| 10.0 | | | | | | Easy drilling - drill mud brown | |
| 15.0 | | | | | | | |
| | | | | | 17.0 | | |
| | | | | | | Cobbles, boulders - drill mud brown with multiple rock type fragments | |
| 20.0 | | | | | | | |
| 25.0 | | | | | | Easy drilling - drill mud brown with red ss, gray ls and others. | |
| 30.0 | | | | | 30.0 | | |
| | | | | | | Boulder | |
| | | | | | 34.0 | | |
| 35.0 | | | | | | Cobbles, boulders - easy drill - drill mud brown<br>Moderate drill - drill mud brown | |
| 40.0 | | | | | 40.0 | | |
| | | | | | | . . . continued | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. **60157757** SHEET NO. **1** OF **4**

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **BAH-01** |
|---|---|---|
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,912.6 Feet (Continued) | |
| | | | | | | 41.0 Boulder - moderate drill - drill mud brown | |
| | | | | | | Cobbles, boulders | |
| 45.0 | | | | | | | |
| 50.0 | | | | | | 50.0 Boulder - drill mud brown-red brown - multiple rock fragment types | |
| | | | | | | 53.0 Cobbles, boulders - easy drill | |
| 55.0 | | | | | | 55.0 Boulder | |
| | | | | | | 56.0 Cobbles, boulders - easy drill | |
| 60.0 | | | | | | 60.0 Boulder - drill mud brown - multiple rock fragment types | |
| | | | | | | 64.0 Cobbles, boulders | |
| 65.0 | | | | | | Lost circulation at 65.0' | |
| | | | | | | Easy drill - some cobbles | |
| 70.0 | | | | | | | |
| 75.0 | | | | | | | |
| 80.0 | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 SHEET NO. 2 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **BAH-01** |
|---|---|---|
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) / ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL<br>SURFACE ELEVATION +8,912.6 Feet (Continued) | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|
| | 1 | | | | Cobbles, boulders | |
| 85.0 | | | | | 85.0 | |
| | | | | | Hard boulder - drill mud brown-red brown - multiple rock type fragments | |
| | | | | | 88.0 | |
| | | | | | Cobbles, boulders - moderate drilling | |
| 90.0 | | | | | | |
| 95.0 | | | | | | |
| 100.0 | | | | | Circulation 100.0-104.0' - drill mud brown-red brown | |
| 105.0 | | | | | Relatively easy drilling | |
| 110.0 | | | | | | |
| | 2 | | | | | |
| 115.0 | | | | | | |
| 120.0 | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. **60157757** SHEET NO. **3** OF **4**

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: BAH-01 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,912.6 Feet (Continued) | |
| | | | | | | Cobbles, boulders - moderate drilling | |
| | | | | | | 124.0 | |
| 125.0 | | | | | | Boulder - circulation restored - drill mud brown-red brown - multiple rock types in mud | |
| | | | | | | 127.0 | |
| | | | | | | Cobbles, boulders - easy drilling | |
| 130.0 | | 3 | | | | | |
| 135.0 | | | | | | 137.0 | |
| 140.0 | | | | | | Boulder - circulation returns drill mud brown-red brown - multiple rock types in mud | |
| 145.0 | | | | | | 145.0 | |
| | | | | | | Drill mud changed to gray-green - mineralogy appears consistent with latite, no other rock fragments present. | |
| | | | | | | 147.0 | |
| 150.0 | | | | | | Drill mast and front of rig lift off the ground, driller backed off down pressure, rig sets back to original location. Driller notes possible bedrock at 147.0'. Drill mud appears to contain latite fragments, no others. Drilled about 6.0" into rock | |
| | | | | | | Remove drill string 10/31/2011 (broken roller bit) | |
| | | | | | | Replace HWT with core bit and redrill to 147.0' | |
| 155.0 | | | | | | Over burden logged by L. Beem. | |
| | | | | | | Continued as rock core log below 147.0'. | |
| 160.0 | | | | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388951 | BORING STARTED 10/26/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268365 | BORING COMPLETED 11/9/11 | ENTERED BY SJH | SHEET NO. 4 OF 4 |
| WL | RIG/FOREMAN / | APP'D BY EED | AECOM JOB NO. 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| | | |
|---|---|---|
| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **BAH-01** |
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |
| SITE LOCATION | | SURFACE ELEVATION **+8,912.6 Feet** |

| DEPTH(FT) / ELEVATION(FT) | DRILLING: RUN NO. | CORING TIME, MIN/FT (AVG) | RECOVERY, % | RQD, % | LITHOLOGY: GRAPHIC | VISUAL DESCRIPTION AND REMARKS | DISCONTINUITY: FRACTURE FREQUENCY (BREAK/FT) | DEPTH, FT | DIP, DEG | TYPE | APERTURE | INFILL | AMOUNT | SHAPE | ROUGHNESS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 145.0 | Run No. | | | | | Rock core log continued from soil boring log at 147.0' | | | | | | | | | |
| | | | | | | 147 | | | | | | | | | |
| 150.0 | Run No. | | | | | Cored to 153.0' - recovered few rock fragments of colluvial material. Switch back to HWT casing. No drill fluid return. | | | | | | | | | |
| | | | | | | 153 | | | | | | | | | |
| 155.0 | | | | | | Fragments of sandstone, shale and latite porphyry (Colluvium)<br>156.0' - Fluid returns - medium green gray | | | | | | | | | |
| 160.0 | | | | | | 160 | | | | | | | | | |
| | Run No. | | 37 | 20 | | Fragments of greenstone, quartz vein, sandstone (Colluvium) - hard - largest clast 0.8' - switch to HQ3 to sample/drill through block - angle of rods 15 degrees - core barrel stuck tripped drill string | | | | | | | | | |
| | | | | | | 163 | | | | | | | | | |
| 165.0 | Run No. | | | | | Variable hard and soft drilling - advanced HWT casing with shoe bit - medium brown drill fluid returns | | | | | | | | | |
| 170.0 | | | | | | | | | | | | | | | |
| 175.0 | | | | | | 174.0' - Add 10.0' feet of casing - reem/no sample<br>177.0' - Quartzite, light gray, unfractured, hard, strong - possible boulder | | | | | | | | | |
| | | | | | | 178 | | | | | | | | | |
| 180.0 | Run No. | | 62 | 32 | | 177.17' - Drilling hard - return fluids change color to dark gray - switch to coring<br>Fines (matrix) wash out during drilling - cored 178.0-183.0' - hard and soft zones - returns varied light gray (hard drilling) to dark dirty | | | | | | | | | |
| | | | | | | 183 | | | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil/rock types: in situ, the transition may be gradual.

AECOM JOB NO. **60157757** SHEET NO. **1** OF **3**

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: BAH-01 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |
| SITE LOCATION | | SURFACE ELEVATION: +8,912.6 Feet |

| DEPTH(FT) / ELEVATION(FT) | DRILLING: RUN NO. | CORING TIME, MIN/FT (AVG) | RECOVERY, % | RQD, % | GRAPHIC | LITHOLOGY: VISUAL DESCRIPTION AND REMARKS | DISCONTINUITY: FRACTURE FREQUENCY (BREAK/FT) | DEPTH, FT | DIP, DEG | TYPE | APERTURE | INFILL | AMOUNT | SHAPE | ROUGHNESS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 185.0 | Run No. | | | | | brown (soft drilling) | | | | | | | | | |
| | Run No. | | 98 | 60 | | 186 "Soft" smooth drilling no cuttings/fluid return - trip HQ rods advance HWT casing through colluvium, no returns<br>185.42' - Drilling becomes hard, switch to HQ3 core | | | | | | | | | |
| 190.0 | Run No. | | 80 | 40 | | 190 190.5 Sandstone, light green gray, massive, hard, moderately strong, fine grained<br>189.17' - Dark gray siltstone, closely fractured, moderately hard, weak, grades to s.s. | | | | | | | | | |
| 195.0 | Run No. | | 41 | 12 | | Medium dark gray limestone closely fractured<br><br>Drill/core to 193.0' and pull drill string | | | | | | | | | |
| 200.0 | Run No. | | 78 | 20 | | 200 Sandstone and siltstone with medium brown sandy clay matrix - variable hard to soft drilling - most fines (matrix) washing out<br>193.42' - Drilling becomes variably hard, soft zones encountered<br>198-58' - Latite porphyry - light green gray, medium grained with pyrite stringers to veinlets | | | | | | | | | |
| 205.0 | Run No. | | 76 | 0 | | 205 No circulation<br>Wash out from 200.0-202.33'<br>202.33' - Latite porphyry, medium bluish gray (5B 5/1), hard, moderately strong with feldspars to 0.25"<br>204.5' - Shale, medium to dark gray (N3.5), hard, weak, closely fractured. | | | | | | | | | |
| 210.0 | Run No. | | 82 | 20 | | 209.58 Colluvium consists of mixture of sandstone, shale, arkose with red siltstone<br>Fine grained matrix wash out - clast range from 0.4'-0.5" | | | | | | | | | |
| 215.0 | Run No. | | 67 | 0 | | Altered sandstone - medium greenish gray, fine grained, with apparent relic beds or cross bed at 25 degrees to axis of core - moderately fractured, moderately hard, weak with pyrite and quartz along fracture surfaces (up to 0.25")<br>214.5' - Small fault zone | | | | | | | | | |
| 220.0 | Run No. | | 77 | 0 | | 220.5 Possible bedrock at 215.0'<br>Closely fractured | | | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil/rock types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 2 OF 3

| | | |
|---|---|---|
| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **BAH-01** |
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |
| SITE LOCATION | | SURFACE ELEVATION **+8,912.6 Feet** |

| DEPTH(FT) / ELEVATION(FT) | DRILLING: RUN NO. | CORING TIME, MIN/FT (AVG) | RECOVERY, % | RQD, % | LITHOLOGY: GRAPHIC | VISUAL DESCRIPTION AND REMARKS | DISCONTINUITY: FRACTURE FREQUENCY (BREAK/FT) | DEPTH, FT | DIP, DEG | TYPE | APERTURE | INFILL | AMOUNT | SHAPE | ROUGHNESS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 225.0 | Run No. | | 100 | 38 | | 224.25 Shear zone - siltstone dark green gray, closely fractured with light gray gouge along fractures. Loss circulation, core blocked, stop trip at 220.5' - switch back to 5.0' core barrel for recovery Good circulation through 5.0' run - NQ rods at 15.5 to horizontal degrees at surface | | | | | | | | |
| 230.0 | Run No. | | 34 | 0 | | 230 / 231 Siltstone, medium dark gray (N3.5), hydrothermally alt., finely dissim. pyrite, closely fractured with quartz veins and veinlets 0.063-.125" , moderately hard, weak to moderate;y strong. | | | | | | | | |
| 235.0 | Run No. | | 96 | 0 | | 235.2 Quartz vein, white to light gray (N9-N7), with vugs Lost circulation<br>Shear zone with fault gouge, intensely fractured | | | | | | | | |
| 240.0 | Run No. | | 20 | 0 | | 240 Sandstone/siltstone, medium dark gray (N4/5), sandstone very fine grained grades at 238.0' to siltstone, closely fractured, moderately hard, weak with pockets of pyrite and quartz to 0.25" | | | | | | | | |
| 245.0 | Run No. | | | | | 240.0-252.0' - VOID - pushed rods with no resistance except for apparent slough zone when lowered rods to 244.0' to advance another 5.0'. Pushed back through void from 246.0-252.0'. Assume one continuous void (St. Louis Tunnel) | | | | | | | | |
| 250.0 | Run No. | | | | | 252 | | | | | | | | | |
| 255.0 | Run No. | | | | | Drill stem appeared to be following tunnel; at risk of losing core barrel terminated drilling hole after 12.0' of void. | | | | | | | | |
| 260.0 | | | | | | | | | | | | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING **1388951** | BORING STARTED **10/26/11** | AECOM OFFICE **Denver** | |
| EASTING **2268365** | BORING COMPLETED **11/9/11** | ENTERED BY **SJH** | SHEET NO. **3** OF **3** |
| WL (DEPTH) | RIG/FOREMAN **/** | APP'D BY **EED** | AECOM JOB NO. **60157757** |

# AECOM Boring and Well Construction Log

**BORING #: CHI-101**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** J. Reidell, PE |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Troy |
| **Drilling Date:** 10/17/2013 - 10/25/2013 | **Drilling Equipment:** Boart/Longyear | **Total Depth (ft):** 113.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | GC | | Surface Meterials, Clayey Gravel, Gravel (Angular and variable rock types), Sand and Clay - Medium Plasticity, Maximum Grain Size = 1.5 (GC) | | Advance to 40' with PQ core and PW casing without triple tube. At 1:15 PM, Advance PW casing slowly with low down pressure to ensure casing is at 12.2 degree angle<br>(3-5) Drill through clayey gravel with cobbles, casing jerks around when contacting cobbles and boulders<br>(5-10) Driller states 'Soft drilling, did not hit any rocks, still gravelly'<br>No return fluid<br>Check casing angle 2.2 degrees<br><br>Driller states 'Soft drilling, did not hit any rocks, still gravelly'<br>No return fluid | | |
| 2 | | | | | | | | | |
| 4 | | | | | | | | | |
| 6 | | | | | | | | | |
| 8 | | | | | | | | | |
| 10 | | | | | | | | | |
| 12 | | | | | | | | | |
| 14 | | | | | 14.5 | | | | |
| | | | | | 15.0 4 Diameter Cobble | | Rock in end of PW shoe, hit other rock at end of string making casing jump. Mix batch of mud @ 3:00, begin advance @3:15 | | |
| 16 | | | GC | | | | (15-20) Driller states 'Intermittent cobbles, nothing very big (6-8)'<br>No return fluid<br>Check casing angle 12.2 degrees, re-adjust blocking<br>Soft drilling | | |
| 18 | | | | | | | | | |
| 20 | | | | | | | | | |
| 22 | | | | | 22.0 | | | | |
| | | | | | 11 Cobble/Boulder<br>23.3 | | Rock<br>Soft Drilling, no return fluid | | |
| 24 | | | GC | | | | | | |
| 26 | | | | | | | Check casing angle 12.2 degrees | | |
| | | | | | 27.0 | | Soft drilling | | |
| | | | | | 27.5 6 Cobble | | | | |
| 28 | | | GC | | | | No fluid return | | |
| 30 | | | | | 30.0 | | | | |

**Remarks:** Boring Terminated (ft): 113.0

Entered by: AKC

Notes:

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: CHI-101**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** J. Reidell, PE |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Troy |
| **Drilling Date:** 10/17/2013 - 10/25/2013 | **Drilling Equipment:** Boart/Longyear | **Total Depth (ft):** 113.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 30 | | | | | | | | | |
| | | CH-4 | | | 30.5 5 Cobble | | Check casing angle 12.2 degrees | | |
| | | | GC | | | | | | |
| 32 | | | | | 32.0 | | | | |
| | | | | | 32.8 8 Cobble | | No fluid return | | |
| | | | GC | | | | | | |
| 34 | | | | | | | | | |
| 36 | | CH-1 | | | | | Check casing angle 12.2 degrees, re-adjust blocking | | |
| 38 | | | | | | | Soft Drilling, no return fluid | | |
| 40 | | | | | 40.0 | | Switch from PW casing to PQ casing | | |
| | | | GC | | Clayey Gravel, Gravel (Arkose Sandstone) and Clay - Low-Plasticity, Orange-Tan (GC) | | | | |
| 42 | | CH-2 | | | 42.0 | | Stop drilling for day 3:10 PM 10/21/13 | | |
| | 30 | | GC | | Clayey Gravel, Gravel (1/2 to 4, black slate and dark red siltstone) and Fines - medium to low plasticity, Orangish-Tan with Olive Greenish Black Intrusive (GC) | | Thru casing, cuttings return is tan in color | | |
| 44 | | | | | | | Cuttings: tannish brown in color | | |
| | | | GC | | 45.0 Clayey Gravel with Sand, Gravel (black shale and medium grained Arkose Sandstone, moderately decomposed porphyry) and Fines - low plasticity, Orangish-Tan (GC) | | End of Day 4:45 PM, 10/21/13 | | |
| 46 | 90 | CH-3 | | | | | Begin drilling 11:20 AM 10/22/13; sensor repair, resume at 1:00 | | |
| 48 | | | | | | | | | |
| 50 | 80 | CH-4 | GC | | 49.5 Clayey Gravel, Gravel and Cobbles (Arkose Sandstone, Black Shale and Porphyry) and Fines - medium plasticity, max grain size = 5, Grayish-Tan (GC) | | | | |
| 52 | | | | | | | | | |
| 54 | | | | | | | Color change in cuttings at 52 - 52.5' (drilled through boulder) (53.5') Lost circulation, 20% circulation back at 54', circulation back at 55' 100% Circulation | | |
| 56 | 100 | CH-5 | GC | | 55.5 Clayey Gravel, Gravel and Cobbles (Arkose Medium to Coarse Sandstone, Latite and Monzonite) and Fines - medium plasticity, max grain size = 8, Orangish-Tan (GC) | | | | |
| 58 | | | | | | | | | |
| 60 | | CH-6 | GC | | 59.0 Clayey Gravel, Gravel and Fines - medium plasticity, Tan (GC) | | 59% Lost circulation | | |

**Remarks:** Boring Terminated (ft): 113.0

Entered by: AKC

Notes:

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*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: CHI-101**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** J. Reidell, PE |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Troy |
| **Drilling Date:** 10/17/2013 - 10/25/2013 | **Drilling Equipment:** Boart/Longyear | **Total Depth (ft):** 113.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 60 | | | | | | | | | |
| | | | GC | | Clayey Gravel, Gravel and Fines - medium plasticity, Tan (GC) *(continued)* | | | | |
| 62 | | | | | 62.0 | | (61-62') Muddy, soft drilling | | |
| | | | | | Boulder, Dark Blueish-Gray Sandstone (62-65') | | (62') 20% Circulation, tube sanded in pull rods | | |
| 64 | | | | | | | | | |
| | | | | | 65.0 | | Pull rods, empty mud step drill at 4:15, look down PW, very straight. Resume drilling 10-23-13 11:00 | | |
| 66 | | CH-7 | GC | | 65.5 Clayey Gravel, Gravel and Fines - medium plasticity, Tan (GC) | | | | |
| | | | | | 66.3 Boulders (Lithified Greenish-Gray Sandstone, 9 in length) | | | | |
| | | | GC | | Clayey Gravel, Gravel and Fines - medium plasticity, Tan (GC) | | | | |
| | | | | | 67.5 | | | | |
| 68 | | | | | 68.0 Boulders (Lithified Greenish-Gray Sandstone, 9 in length) | | | | |
| | 100 | CH-8 | GC | | Clayey Gravel with Sand, Gravel (Decomposed Latite, Black Shale, and Greenish-Gray Lithified Sandstone) and Fines - medium plasticity, Black Shale reacts to acid, Orangish-Tan (GC) | | Some of recovery is likely caved hole from pulling rods and re-insterting 10% Circulation | | |
| 70 | | | | | | | Mud is grayish brown | | |
| | | | | | 71.5 | | | | |
| 72 | 36 | CH-9 | GC | | Clayey Gravel with Sand, Gravel and Cobbles (Latite and Black Shale) and Fines - medium plasticity, Black Shale Reacts with Acid, Max Grain Size = 5, Orangish-Tan (GC) | | (72.5') 10-20% Circulation | | |
| 74 | | | | | | | (74') Increase circulation 40% | | |
| | | | | | 75.5 | | | | |
| 76 | | | GC | | Clayey Gravel with Sand, Gravel (Black Shale and Latite) and Fines - medium plasticity, Black Shale Reacts with Acid, Max Grain Size = 6, Orangish-Tan (GC) | | (75.5') 5% Circulation (76.5') 5% Circulation | | |
| | 46 | CH-10 | | | | | | | |
| 78 | | | | | | | | | |
| 80 | | | | | | | | | |
| 82 | | | | | | | (80.5') No circulation, very soft drilling | | |
| | | | | | 83.0 | | | | |
| 84 | 80 | CH-11 | GC | | Clayey Gravel with Sand, Gravel, Sand and Fines - medium plasticity, Max Grain Size = 3, Tan (GC) | | Mixed mud | | |
| | | | | | 85.0 | | | | |
| 86 | | | GC-CH | | Clayey Gravel, Gravel (Highly decomposed Latite and Black Shale) and Fines - high plasticity, Max Grain Size = 3, Tan (GC) | | Bit clogged, needed to pull rods to retreive tube | | |
| 88 | | | | | | | | | |
| | | | | | 88.5 | | | | |
| 90 | 96 | CH-12 | GC | | Clayey Gravel, Gravel (Monzonite, Volcanics, Black Shale and Latite, some are highly decomposed) and Fines - medium plasticity, Black shale reacts to acid, Max Grain Size = 6, Orangish-Tan (GC) | | Trip rods, 50 ft ?? Rods into 38' | | |

**Remarks:** Boring Terminated (ft): 113.0

Entered by: AKC

Notes:

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# AECOM Boring and Well Construction Log

**BORING #: CHI-101**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** J. Reidell, PE |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Troy |
| **Drilling Date:** 10/17/2013 - 10/25/2013 | **Drilling Equipment:** Boart/Longyear | **Total Depth (ft):** 113.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 90 | | | | | | | | | |
| 92 | | | GC | | Clayey Gravel, Gravel (Monzonite, Volcanics, Black Shale and Latite, some are highly decomposed) and Fines - medium plasticity, Black shale reacts to acid, Max Grain Size = 6, Orangish-Tan (GC) *(continued)* | | | | |
| 94 | | | GC | | 93.5 Clayey Gravel, Gravel and Cobbles (Black Shale and Monzonite) and Fines - medium plasticity, Black shale reacts to acid, Max Grain Size = 4, Orangish-Tan (GC) | | Stop for day 10-23-13, Continue 10/24/13 11:45 AM Hole caved at 52' on insertion of rods back into hole (95') No circulation Clay is making rod tripping difficult, driller says it is ?? Off hole (10/25/13) | | |
| | 200 | CH-13 | | | | | | | |
| 96 | 80 | CH-14 | | | 96.0 Cobbles and Boulders, spaces between filled with Gravelly Fat Clay | | | | |
| | | | CH | | 96.8 Gravelly Fat Clay | | | | |
| 98 | | | CH | | 97.0 Cobbles and Boulders, spaces between filled with Gravelly Fat Clay | | | | |
| | | | | | 97.8 Gravelly Fat Clay | | | | |
| | | | | | 98.0 20 Boulder | | Mix mud | | |
| 100 | | | CH | | 99.8 Gravelly Fat Clay | | | | |
| | | | | | 100.0 Cobble | | | | |
| | 100 | CH-15 | GC | | 101.0 Clayey Gravel, Gravel and Cobbles (Black Shale, Decomposed Latite and Green/Gray Fine Grained Sand/Siltstone) and Fines - medium to high plasticity, Orangish-Tan (GC) | | (100.6') No circulation | | |
| 102 | | | | | | | | | |
| 104 | | | | | 104.3 17 Boulder | | | | |
| 106 | | | | | 106.0 Clayey Gravel, Gravel and Cobbles (Lithified Sandstone and Black Sahle) and Fines (CL/CH), Maximum Grain Size 5, Orangish-Tan (GC) | | | | |
| | 50 | | GC | | | | | | |
| 108 | | | | | | | | | |
| 110 | | | | | | | (109-110.5') Very soft drilling | | |
| 112 | | | | | | | | | |
| | | | | | 113.0 End of boring at 113.0 ft. bgs. | | (113') Stop for day 10/24/13, end of hole End of boring at 113.0 ft. bgs. | | |

**Remarks:** Boring Terminated (ft): 113.0

Entered by: AKC

Notes:

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# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | |
| 2 | 60 SON | 1 | GW-GM | | (0-33') COLLUVIUM: Well Graded Gravel with Silt, 5% Cobbles, 55% Gravel (Angular to Subrounded), 30% Sand, 10% Fines (8% Silt, 2% Clay) - Low Plasticity, Max Grain Size = 4+, HCL=Strong - 5YR4/3 (Reddish Brown) (GW-GM) | Slightly Moist | Advance casing bit in 10' increments unless otherwise noted | | |
| 4 | | | | | 4.0 | | | | 3 Bags 4Quaguard bentonite grout, 1 bag bentonite chips on top |
| | | | GW-GM | | Cobbles 4'-5' | Dry | | | |
| | | | | | 5.0 | | | | |
| 6 | 30 SON | | GW-GM | | | Slightly Moist | | | |
| 8 | | | | | 8.0 | | | | |
| | | 2A | GC | | Clayey Gravel, 2% Cobbles, 50% Gravel (Very Angular to Subrounded), 33% Sand, 15% Fines (7.5% Silt, 7.5% Clay) - Medium Plasticity, Max Grain Size = 4+, HCL=Weak - 10YR4/3 (Brown) (GC) | | | | |
| 10 | | | | | | Wet perched water @ 9' | | | |
| | 80 SON | | | | | | | | |
| 12 | | | | | | | | | |
| 14 | | | | | | | | | |
| 16 | | | | | | Moist | | | |
| 18 | | | | | | | | | |
| 20 | | | | | | | | | |
| | 80 SON | 2B | | | | | | | |
| | | | | | 21.5 | | | | |
| 22 | | | GC | | Color becomes 10YR4/4 (Dark Yellowish Brown) at 21.5' | | | | |
| | | | | | 23.0 | | | | |
| 24 | | | GC | | cobbles 23'-27' | | | | |
| 26 | 80 SON | | | | | | | | |
| | | | | | 27.0 | | | | |
| 28 | | | GC | | | | | | |
| 30 | | | | | | Wet perched water @ | | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

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# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 32 | | | GC | | | 29' | | | |
| | | | | | 33.0 | Slightly Moist | | | |
| 34 | | 3 | GW-GM | | (33-61') ALLUVIUM/COLLUVIUM MIXTURE: Well Graded Gravel with Silt, 2% Cobbles, 50% Gravel (Angular to Subrounded), 40% Sand, 8% Fines (6.4% Silt, 1.6% Clay), Trace Organics - Non-plastic, Max Grain Size = 3+, HCL=None - 5YR4/4 (Reddish Brown) (GW-GM) | | | | |
| 36 | 60 SON | | | | | Wet perched water @ 35' | | | |
| 38 | | | GW-GM | | At 37' color becomes 7.5YR2.5/2 (very dark brown), fines drop to 5%, significant black carbon content | | | | 1.5 Bags 3/8 Hole Plug |
| 40 | | | | | | Moist | | | |
| | 80 SON | | | | 41.0 | | | | |
| 42 | | 4 | GW-GM | | Well Graded Gravel with Silt, 5% Cobbles, 50% Gravel (Angular to Rounded), 40% Sand, 8% Fines (6.4% Silt, 1.6% Clay) - Non-plastic, Max Grain Size = 4+, HCL=None - 10YR4/4 (Dark Yellowish Brown) (GW-GM) | | | | Colorado silica 20/40 |
| 44 | | | | | | | | | |
| 46 | | | | | | Wet saturated zone at 44' | | | 2 0.010 slot PVC |
| 48 | | | | | | | | | |
| 50 | | | | | 50.0 | | | | |
| 52 | 80 SON | 5 | GM | | Silty Gravel, 2% Cobbles, 50% Gravel (Subangular to Rounded), 36% Sand, 12% Fines (9.6% Silt, 2.4% Clay) - Low Plasticity, Max Grain Size = 3+, HCL=Weak - 10YR4/4 (Dark Yellowish Brown) (GM); severely weathered cobbles | | | | |
| 54 | | | | | | | | | |
| 56 | | | | | | | | | |
| 58 | | | | | | | | | 9 Bags 3/8 Hole Plug, probably collapse during casing reset |
| 60 | | | | | | | | | |
| | 70 SON | | | | 61.0 | Saturation not | | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

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# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 62 | | 6 | GW-GM | | (61-97') ALLUVIUM: Well Graded Gravel with Silt, 2% Cobbles, 50% Gravel (Subangular to Rounded), 40% Sand, 8% Fines (6.4% Silt, 1.6% Clay) - Low Plasticity, Max Grain Size = 4+, HCL=None - 5YR4/4 (Reddish Brown) (GW-GM); severely weathered cobbles | recorded | | | |
| 64 | | | | | | | | | |
| 66 | | | | | | | | | |
| 68 | | 7 | SW | | Well Graded Sand, 20% Gravel (Angular to Well Rounded), 75% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 3/4+, HCL=None - 5YR4/3 (Reddish Brown) (SW) | | | | |
| 70 | 80 SON | | | | | | | | |
| 72 | | | | | | | | | |
| 74 | | | | | | | | | |
| | | | | | 75.0 | | | | |
| 76 | | 8 | SP | | Poorly Graded Sand, 5% Gravel (Subangular to Well Rounded), 90% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 3/4+, HCL=None - 2.5YR4/3 (Reddish Brown) (SP) | | | | |
| 78 | | | | | | | | | |
| 80 | 80 SON | | | | | | | | |
| 82 | | | | | | Wet | | | |
| 84 | | | | | | | | | |
| | | | | | 85.0 | | | | |
| 86 | | 9 | SP | | Poorly Graded Sand, 5% Cobbles (Subangular to Well Rounded), 90% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 4+, HCL=None - 5YR3/3 (Dark Reddish Brown) (SP) | | | | |
| 88 | | | | | | | | | |
| 90 | | | | | 90.0 | | | | |
| | 75 SON | 7B | SW | | Well Graded Sand, 20% Gravel (Angular to Well Rounded), 75% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 3/4+, HCL=None - 5YR4/3 (Reddish Brown) (SW) | | | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

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*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 92 | | | SW | | 92.5 | Moist | | | |
| 94 | | 8B | SP | | Poorly Graded Sand, 5% Gravel (Subangular to Well Rounded), 90% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 3/4+, HCL=None - 2.5YR4/3 (Reddish Brown) (SP) | | | | |
| 96 | | | SP | | 94.5 Poorly Graded Sand, 5% Cobbles (Subangular to Well Rounded), 90% Sand, 5% Fines (Silt) - Non-plastic, Max Grain Size = 4+, HCL=None - 5YR3/3 (Dark Reddish Brown) (SP) | | | | |
| 98 | | 10 | GW | | 97.0 (97-100') COLLUVIUM, ALLUVIUM: Well Graded Gravel, 60% Gravel (Angular to Well Rounded), 35% Sand, 5% Fines (2.5% Silt, 2.5% Clay) - Non-plastic, Max Grain Size = 3, HCL=Strong - 2.5YR4/1 (Dark Reddish Gray) (GW); weathered gray | | | | |
| 100 | | | | | 100.0 calc ss cobbles, rounded red ss | | | | |
| 102 | 80 SON | 11 | GW-GC | | (100-104') COLLUVIUM: Well Graded Gravel with Clay, 10% Cobbles, 40% Gravel (Subangular to Subrounded), 40% Sand, 10% Fines (6% Clay, 4% Silt) - Low Plasticity, Max Grain Size = 4+, HCL=Weak - 1GLEY4/1 (Dark Greenish Gray) (GW-GC) | | | | |
| 104 | | | | | 104.0 | | | | |
| 106 | | | | | (104-121.5') SEVERELY WEATHERED COBBLES AND BOULDERS: Limestone boulders pulverized by drilling process; Dark gray siltstone/mudstone boulders pulverized byt drilling process | Dry | | | |
| 108 | | | | | | | | | |
| 110 | | | | | | Slightly Moist | For water test - difficulty filling casng/rod due to water take 110-120: tough drilling, sample pulverized | | |
| 112 | 60 SON | | | | | | | | |
| 114 | | | | | Dark gray sandstone boulders pulverized by drilling process | | | | |
| 116 | | | | | Dark gray siltstone boulders pulverized by drilling process | | Note: sample depths on bags mis-labled in photo | | |
| 118 | | | | | | | | | |
| 120 | | | | | Dark gray sandstone boulders pulverized by drilling process | | | | |
| 122 | 50 SON | | GP | | Dark gray mudstone boulders pulverized by drilling process; residual low plasticity silt from weathered boulder 121.5 | Moist / Saturation | Switch to Sonic wet coring | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

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# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 122 | | | | | | | | | |
| 124 | | | GP | | POSSIBLE WEATHERED BEDROCK: Poorly Graded Gravel, 70% Gravel (Subangular to Subrounded, calcareous and non-calc sandstone), 20% Sand, 2% Fines, Max Grain size = 4+inches, HCL=None to strong - 1GLEY3/N (Very Dark Gray) (GP); weathered mudstone; scattered chunks of hard re-cemented fault gouge with pyrite mineralization; unoxidized *(continued)* | not recorded | | | |
| 126 | | | | | | | | | |
| 128 | | | | | | | | | |
| 130 | | | | | | | | | |
| 132 | 50 SON | | | | | Saturation not recorded | | | |
| | | | GP | | 132.0 No residual soils returned 132-135, could be due to wet core method | | | | |
| 134 | | | | | | | | | |
| 136 | | | | | 135.0 Very thin to thinly laminated dark gray sandstones and mudstones. Significant pyrite mineralization along bedding planes; bedding planes on intact core fragments oriented near horizontal | | | | |
| 138 | | | | | | | | | |
| 140 | | | | | | | Hole caved 10' after water test per driller | | |
| 142 | 70 SON | | | | Uncemented fault gouge with 1GLEY2.5N (black), non calc siltstone; chunks in low to moderete plasticity silt (ML), 1GLEY2.5N (black) | | | | |
| 144 | | | | | 143.5 Siltstone/Mudstone, laminated (unknown dip or inclination due to sample disturbance), intensly weathered to decomposed, very soft, very intensely fractured, HCL=None - 1GLEY2.5/N (Black) | | | | Hole collapse during casing pull |
| 146 | | | | | | | | | |
| 148 | 50 SON | | | | Uncemented fault gouge with 1GLEY2.5N, non calc siltstone, chunks in low to moderete plasticity; 1GLEY2.5N silt (ML) | Wet | | | |
| 150 | | | | | Siltstone/Mudstone, laminated (unknown dip or inclination due to sample disturbance), intensly weathered to decomposed, very soft, very intensely fractured, HCL=None - 1GLEY2.5/N (Black) | Dry | | | |
| 152 | | | | | | | | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 154<br>156<br>158 | | | | | Siltstone/Mudstone, laminated (unknown dip or inclination due to sample disturbance), intensly weathered to decomposed, very soft, very intensely fractured, HCL=None - 1GLEY2.5/N (Black) *(continued)* | Wet<br>Dry | | | |
| 160<br>162<br>164 | 50 SON | 13 | | | 159.5<br>(159.5-165') ALLUVIUM:<br>Poorly Graded Gravel, 60% Gravel (Subangular to Rounded), 35% Sand, 5% Fines - Non-plastic, Max Grain Size = 3+, HCL=None - 1GLEY2.5/N (Black) (GP) | Saturation not recorded | Driller reports 5' drop 159-165, very soft drilling | | |
| 166<br>168<br>170<br>172<br>174 | 50 SON | 14A | | | 165.0<br>(165-185') ALLUVIUM/TALUS:<br>Poorly Graded Gravel, 40% Cobbles, 40% Gravel (Subangular to Subrounded), 19% Sand, 1% Fines - Non-plastic, Max Grain Size = 4+, HCL=None to strong - 1GLEY3/1 (Very Dark Greenish Gray) (GP)<br>At 168' hard to very hard pieces of strongly cemented conglomerate or fault gouge; inclusions - very dark gray siltstone pieces, well rounded quartzite, veins of calcite, unoxidized pyrite. | | Retreive more casing<br>Driller reports lost circulation<br>Driller reports tough drilling | | |
| 176<br>178<br>180<br>182 | | 14B | | | 174.5<br>At 174.5' grades to mostly siltstone-sandstone, very hard.<br>At 179.5' grades to mostly 1GLAY4/10GY (Dark Greenish Gray), very hard to extremely hard sanstone with silicate and oxidized pyrite inclusions. | | Extremely tough casing advance<br>Drove casing to 169', very tough. Could not drive core past casing bit. Pulled casing after water test @ 185', casing bit coned and cracked. Hole caved to 144', | | |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: CHV-101D**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 10/2/2013 - 10/8/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 185.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 184 | | | | | At 179.5' grades to mostly 1GLAY4/10GY (Dark Greenish Gray), very hard to extremely hard sanstone with silicate and oxidized pyrite inclusions. *(continued)* | | redrove casing to 147' to set well. | | |
| | | | | | 185.0 End of boring at 185.0 ft. bgs. | | End of boring at 185.0 ft. bgs. | | End of boring at 185.0 ft. bgs. |

**Remarks:** Boring Terminated (ft): 185.0 Entered by: AKC

Notes: Drove casing to 167', very tough. Could not drive core past casing bit. Pulled casing after water test at 185'. Casing bit coned and cracked. Hole caved to 144', re-drove casing to 147' to set well

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: Rico Ponds<br>PROJECT NO.: | BORING NUMBER: DH-1 | COORDINATES OR LOCATION: |
| LOGGED BY: K. Casper<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH (ENCOUNTERED) 11'<br>GWL DEPTH (STATIC) NA |
| DRILLING METHOD: HSA | HOLE DIAMETER: / FLUID USED: NA | DATE STARTED: / DATE COMPLETED: 10/8/08 |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | Clayey silt with some sand and gravel; brown, moist | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | 50% | | | |
| 8 | | | | | | Silty Sand & gravel dk. brown, moist | |
| 9 | | | | | | | |
| 10 | | | | | | | |
| 11 | | X | 12 | 50% | | Water - Saturated | |
| 12 | | | 9 | | | | |
| 13 | | | 13 | | | Cobbles | |
| 14 | | | | | | | |
| 15 | | | | | | | |
| 16 | | X | 13 | 60% | | Saturated cobbles/boulders | |
| 17 | | | 33 | | | | |
| 18 | | X | 27 | 0 | | Refusal @ 17.5' | |
| 19 | | | 50/½" | | | | |

NOTES

TD= 17.5'

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: RICO PONDS<br>PROJECT NO.: | BORING NUMBER: DH-9 | COORDINATES OR LOCATION: |
| LOGGED BY: K. Cosper<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH (ENCOUNTERED) ~ 17<br>GWL DEPTH (STATIC) NA |
| DRILLING METHOD: HSA | HOLE DIAMETER: / FLUID USED: NA | DATE STARTED: 10/8/08<br>DATE COMPLETED: |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | Red Calcine tailings Silty Sand | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| 10 | | | | | | | |
| 11 | | | 4 | 70% | | Thin layer of gray saturated silt @ 11' | |
| 12 | | | 4 | | | | |
| 13 | | | | | | | |
| 14 | | | | | | Red silty sand Calcine Tailings | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | Sand & Gravel - Saturated Black | |
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | 12 | | | | |
| 22 | | | 24 30 | | | | |
| 23 | | | | | | Refusal @ 23.5' | |
| 24 | | | | | | | |
| 25 | | | | | | | |
| 26 | | | | | | | |
| 27 | | | | | | | |
| 28 | | | | | | | |
| 29 | | | | | | | |
| 30 | | | | | | | |

NOTES

TD= 23.5'

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: PROJECT NO.: Rico Ponds | BORING NUMBER: DH-11 | COORDINATES OR LOCATION: |
| LOGGED BY: K. Cosper<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH (ENCOUNTERED) ~20<br>GWL DEPTH (STATIC) NA |
| DRILLING METHOD: HSA | HOLE DIAMETER: / FLUID USED: NA | DATE STARTED: 10/8/08<br>DATE COMPLETED: |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S. | |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 1–4 | | | | | | Brown clayey silt, moist minor gravel | |
| 5–16 | | | | | | Red silty sand. Calcine tailings | |
| 17–20 | | | | | | Red silt - calcine tailings | |
| 21–22 | | | 27<br>50/1" | | | Sand + gravel, saturated red/brown w/ cobbles<br>Refusal @ 21' | |

TD= 21

NOTES: Attempted Shelby @ 10' but sample pulled out - 0 Recovery

ANDERSON

# BORING LOG



| | | |
|---|---|---|
| PROJECT NAME: RICO PONDS<br>PROJECT NO.: | BORING NUMBER: DH-12R | COORDINATES OR LOCATION: |
| LOGGED BY: K. COOPER<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH (ENCOUNTERED) 43'<br>GWL DEPTH (STATIC) NA |
| DRILLING METHOD: ODEX | HOLE DIAMETER: / FLUID USED: AIR | DATE STARTED: 10/13/08<br>DATE COMPLETED: |
| CASING TYPE AND SIZE: | | FROM _____ A.G.S TO _____ B.G.S. |
| SCREEN TYPE AND SIZE: NA | | FROM _____ TO _____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | Brown Sandy Silt with some clay and gravel | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | Brown Clayey Silt with some sand and small gravel | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| 10 | | | | | | Rock | |
| 11 | | | | | | | |
| 12 | | | | | | Red silty sand with gravel (Calcine) | |
| 13 | | | | | | | |
| 14 | | X | 4 4 5 | | | Brown Sandy Silt with some clay and gravel | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | | | | | |
| 22 | | | | | | | |
| 23 | | | | | | Brown Sandy Silt with Gravel | |
| 24 | | | | | | | |
| 25 | | | | | | | |
| 26 | | | | | | | |
| 27 | | | | | | | |
| 28 | | | | | | | |
| 29 | | | | | | | |
| 30 | | | | | | | |
| 31 | | | | | | | |
| 32 | | | | | | | |

NOTES

TD= _____

ANDERSON

# BORING LOG



| | | |
|---|---|---|
| PROJECT NAME:<br>PROJECT NO.: | BORING NUMBER: DH-12R | COORDINATES OR LOCATION: |
| LOGGED BY:<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH (ENCOUNTERED) 43<br>GWL DEPTH (STATIC) NA |
| DRILLING METHOD: ODEX | HOLE DIAMETER: / FLUID USED: AIR | DATE STARTED:<br>DATE COMPLETED: |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM _____ A.G.S TO _____ B.G.S.<br>FROM _____ TO _____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 33 | | | | | | | |
| 34 | | | | | | Sandy silt and gravel, minor clay | |
| 35 | | | | | | | |
| 36 | | | | | | | |
| 37 | | | | | | | |
| 38 | | | | | | Rock - [illegible] | |
| 39 | | | | | | | |
| 40 | | | | | | Sandy silt and gravel minor clay | |
| 41 | | | | | | | |
| 42 | | | | | | Red rock with some silt & sand | |
| 43 | | | | | | | |
| 44 | | | | | | gravel with some silt | Water @ 43' |
| 45 | | | | | | | |
| 46 | | | | | | Silty gravel | |
| 47 | | | | | | | |
| 48 | | | | | | Clayey silt w/ minor gravel moist - wet | out of water @ 48' |
| 49 | | | | | | | |
| 50 | | | | | | | |
| 51 | | | | | | Sandy gravel with some silt, moist | |
| 52 | | | | | | | |
| 53 | | | | | | harder drilling | |
| 54 | | | | | | | |
| 55 | | | | | | | |
| | | | | | | TD ↑ | |

NOTES

TD= 55'

Some gravel is crushed rock from ODEX hammer bit. Unknown original size.

State of Wisconsin
Department of Natural Resources

# SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 7-98

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| St. Louis Ponds Area, Rico, Colorado | AARCOE0105.00 | EB-1 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Jeff Pennell<br>Layne-Western | 11/15/2004 | 11/18/2004 | hsa/odex |

| WI Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | EB-1 | 8,820.9 Feet Site | 8,837.9 Feet Site | 8.0 inches |

Local Grid Origin ☒ (estimated: ☐ ) or Boring Location ☐
State Plane N. E S/C/N
NW 1/4 of NW 1/4 of Section 25, T 40 N, R 10 W

Lat ___° ___' ___"
Long ___° ___' ___"

Local Grid Location
☒ N ☒ E
1388792 Feet ☐ S 2267917 Feet ☐ W

| Facility ID | County | County Code | Civil Town/City/ or Village |
|---|---|---|---|
| | | | Rico, Colorado |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Compressive Strength | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 SS | 24 | 29-44<br>18-14 | | FILL: Gray, very dense, WASTE ROCK, igneous cobbles | | | | | 62 | | | | | Note: Compressive Strength = SPT N value Note: Length att. on split spoon = 24" |
| 2 SS | 24 | 5-8<br>8-12 | 2 | FILL ("Calcine Tailings"): Purple-maroon to gray, loose to medium dense, fine to very fine grained, SILTY SAND, rare gravel | | | | | 16 | | | | | |
| 3 SS | 24 | 4-9<br>8-11 | 4 | | | | | | 17 | | | | | |
| 4 SS | 24 | 5-5<br>7-7 | 6 | | | | | | 12 | | | | | |
| 1 SH | 24 | | 8 | | | | | | | | | | | |
| 2 SH | 24 | | 10 | | | | | | | | | | | |
| 4 SS | 24 | 5-4<br>4-3 | 12 | | SM | | | | 8 | | | | | |
| 3 SH | 24 | | 14 | | | | | | | | | | | |
| 5 SS | 24 | 2-2<br>6-16 | 16 | | | | | | 8 | | | | | |
| 4 SH | 24 | | 18 | | | | | | | | | | | |
| 6 SS | 24 | 12-7<br>9-7 | 20 | | | | | | 16 | | | | | |
| 5 SH | 24 | | 22 | | | | | | | | | | | |
| | | | 24 | | GP | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: Daniel R. Reed

Firm: **SEH Inc** 421 Frenette Drive, Chippewa Falls, WI 54729, www.sehinc.com

Tel: 715.720.6200
Fax: 715.720.6300

This form is authorized by Chapters 281, 283, 289, 291, 292, 293, 295, and 299, Wis. Stats. Completion of this form is mandatory. Failure to file this form may result in forfeiture of between $10 and $25,000, or imprisonment for up to one year, depending on the program and conduct involved. Personally identifiable information on this form is not intended to be be used for any other purpose. NOTE: See instructions for more information, including where the completed form should be sent.

State of Wisconsin
Department of Natural Resources

# SOIL BORING LOG INFORMATION SUPPLEMENT

Form 4400-122A

Boring Number EB-1 Use only as an attachment to Form 4400-122. 

| Sample | | | | | | | | | Soil Properties | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Compressive Strength | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
| | | | 26 | Brown, dense, fine to coarse GRAVEL (alluvium), much fine to coarse grained sand. | | | | | | | | | | |
| 7 SS | 24 | 22-20 24-50 | 28 | | GP | | | | 44 | | | | | |
| | | | 30 | | | | | | | | | | | |
| | | | 32 | | | | | | | | | | | |
| | | | | End of boring at 33' (refusal) | | | | | | | | | | |

State of Wisconsin
Department of Natural Resources

# SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 7-98

Route To: Watershed/Wastewater ☐ Waste Management ☐ Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| St. Louis Ponds Area, Rico, Colorado | AARCOE0105.00 | EB-2 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Jeff Pennell<br>Layne-Western | 11/19/2004 | 11/19/2004 | hollow stem auger |

| WI Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | EB-2 | 8,818.8 Feet Site | 8,826.8 Feet Site | 8.0 inches |

Local Grid Origin ☒ (estimated: ☐ ) or Boring Location ☐
State Plane N, E S/C/N
NW 1/4 of NW 1/4 of Section 25, T 40 N, R 10 W
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location ☐ N ☐ E Feet ☐ S Feet ☐ W

| Facility ID | County | County Code | Civil Town/City/ or Village |
|---|---|---|---|
| | | | Rico, Colorado |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth in Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Compressive Strength | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | FILL: Gray, very dense, WASTE ROCK, igneous cobbles | | | | | | | | | | |
| 1 SS | 24 | 4-6<br>4-7 | 2 | FILL("Calcine Tailings"): Purple-maroon to gray, loose to medium dense, fine to very fine grained, SILTY SAND, rare gravel | | | | | 10 | | | | | Note: Compressive Strength = SPT N value Note: Length att. on split spoon = 24" |
| 2 SS | 24 | 4-4<br>5-4 | 4 | | | | | | 9 | | | | | |
| 3 SS | 24 | 3-3<br>6-3 | 6 | | | | | | 9 | | | | | |
| 4 SS | 24 | 3-2<br>1-1 | 8 | | SM | | | | 3 | | | | | |
| | | | 10 | | | | | | | | | | | |
| | | | 12 | | | | | | | | | | | |
| 5 SS | 24 | 1-1<br>1-1 | 14 | | | | | | 2 | | | | | |
| | | | 16 | | | | | | | | | | | |
| | | | 18 | Brown, dense, fine to coarse GRAVEL (alluvium), much fine to coarse grained sand. | | | | | | | | | | |
| 6 SS | 24 | 12-24<br>50 | 20 | | GP | | | | 74 | | | | | |
| | | | 22 | | | | | | | | | | | |
| | | | 24 | End of boring at 24' | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature Daniel R. Reed

Firm SEH Inc 421 Frenette Drive Chippewa Falls, WI 54729 www.sehinc.com Tel: 715.720.6200 Fax: 715.720.6300

This form is authorized by Chapters 281, 283, 289, 291, 292, 293, 295, and 299, Wis. Stats. Completion of this form is mandatory. Failure to file this form may result in forfeiture of between $10 and $25,000, or imprisonment for up to one year, depending on the program and conduct involved. Personally identifiable information on this form is not intended to be be used for any other purpose. NOTE: See instructions for more information, including where the completed form should be sent.

State of Wisconsin
Department of Natural Resources

# SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 7-98

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| St. Louis Ponds Area, Rico, Colorado | AARCOE0105.00 | EB-2D |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Jeff Pennell<br>Layne-Western | 11/18/2004 | 11/19/2004 | odex |

| WI Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | | Feet Site | 8,826.0 Feet Site | 5.0 inches |

Local Grid Origin ☒ (estimated: ☐ ) or Boring Location ☐
State Plane N, E S/C/N
NW 1/4 of NW 1/4 of Section 25, T 40 N, R 10 W
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location ☒ N ☒ E
1388306 Feet ☐ S 2267920 Feet ☐ W

| Facility ID | County | County Code | Civil Town/City/ or Village |
|---|---|---|---|
| | | | Rico, Colorado |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Soil Properties: Compressive Strength | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | FILL: Gray, very dense, WASTE ROCK, igneous cobbles | | | | | | | | | | |
| | | | 2 | FILL ("Calcine Tailings"): Purple-maroon to gray, loose to medium dense, fine to very fine grained, SILTY SAND, rare gravel | | | | | | | | | | |
| 1 SH | 24 | | 4 | | | | | | | | | | | Note: Compressive Strength = SPT N value Note: Length att. on split spoon = 24" 3" diameter split spoon used (no shelby rec) |
| 2 SH | 24 | | 6 | | | | | | | | | | | |
| 1 SS | 24 | | 8 | | | | | | | | | | | |
| 3 SH | 24 | | 10 | | SM | | | | | | | | | |
| 4 SH | 24 | | 12 | | | | | | | | | | | |
| | | | 14 | | | | | | | | | | | |
| 2 SS | 24 | 4-1 1-4 | 16 | | | | | | 2 | | | | | |
| | | | 13 | Brown, dense, fine to coarse GRAVEL (alluvium), much fine to coarse grained sand. | | | | | | | | | | |
| | | | 20 | | GP | | | | | | | | | |
| | | | 22 | | | | | | | | | | | |
| | | | 24 | | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature Daniel R. Reed

Firm SEH Inc 421 Frenette Drive Chippewa Falls, WI 54729 www.sehinc.com
Tel: 715.720.6200
Fax: 715.720.6300

This form is authorized by Chapters 281, 283, 289, 291, 292, 293, 295, and 299, Wis. Stats. Completion of this form is mandatory. Failure to file this form may result in forfeiture of between $10 and $25,000, or imprisonment for up to one year, depending on the program and conduct involved. Personally identifiable information on this form is not intended to be be used for any other purpose. NOTE: See instructions for more information, including where the completed form should be sent.

State of Wisconsin
Department of Natural Resources

# SOIL BORING LOG INFORMATION SUPPLEMENT

Form 4400-122A

Boring Number EB-2D Use only as an attachment to Form 4400-122. 

| Sample | | | | | | | | | Soil Properties | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Compressive Strength | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
| | | | | End of boring at 24' (abandoned - moved to EB-2, approx. 10' to east) | | | | | | | | | | |

| CDPHE<br>Colorado Department of Public Health and Environment<br>4300 Cherry Creek Drive South<br>Denver, CO 80246 | WELL DEVELOPMENT DATA AND SAMPLE FORM SUMMARY | Records Management Data |
|---|---|---|

| | |
|---|---|
| Project Number: Rico Light Industrial Park | Project Name: Rico Light Industrial Park |
| Well Number: RLP-GW5 | Well Location: Rico Light Industrial Park |

GW
COMMON El. all wells
- datum UNKNOWN

| | | | |
|---|---|---|---|
| Time / Date: | 10/17/02 | Elevation: | 8,800 msl |
| Drilling Method: | 4-Inch Hollow Stem Auger | Weather: | Clear Skies, Partly Sunny 60°F |
| Development Company: | Kayenta Consulting | | Slight Breeze |
| Date Development Started: | 10/17/02 | Date Development Completed: | 10/17/02 |
| Screen Intervals: 18 ft. to 23 ft bgs | | Well Diameter: | 2 Inch |
| Depth of Well (L"): | 23 ft. | Depth to Water Before Development (L'): | 15 ft. |
| Height of Water Column (L" - L'): | 8 ft. | | |
| Depth to Top of Sediment (L') | 14ft. | Sediment Thickness (L" - L'): | Na ft. |
| Well Volume: | 1.28 gal. | | |
| Total Volume Pumped: | 46 gal. | | |
| Number of Well Volumes Pumped | (total volume pumped/well volume): | 46 gallons purged on 10/17/02 | 0.16 gallons per foot on a 2-Inch Well |

## Monitoring Well Sample Data : Well RLP-GW5

| Date | Temp | pH | Cond | Gallons Purged | Observations |
|---|---|---|---|---|---|
| 10/17/02 | 13.8 | 6.89 | 2620 | 45 | Slightly turbid |
| 10/17/02 | 13.4 | 6.90 | 2620 | 45.5 | Clear, Slightly turbid |
| | 13.7 | 6.91 | 2610 | 46 | Clear |

* Sample collection continued after well development includes well development purge volumes

10/17/02 @ 1145 — Sample Collected

## Lithology

| | |
|---|---|
| 0-2 feet bgs | Waste rock materials |
| 2-23 feet bgs | Purple roasted tailings, wet |

| Presented By | Date | Checked By | Date |
|---|---|---|---|
| | | | |

| CDPHE<br>Colorado Department of Public Health and Environment<br>4300 Cherry Creek Drive South<br>Denver, CO 80246 | WELL DEVELOPMENT DATA AND SAMPLE FORM SUMMARY | Records Management Data |
|---|---|---|

| | |
|---|---|
| Project Number: Rico Light Industrial Park | Project Name: Rico Light Industrial Park |
| Well Number: RLP-GW6 | Well Location: Rico Light Industrial Park |

| | | | |
|---|---|---|---|
| Time / Date: | 10/17/02 | Elevation : | 8,800 msl |
| Drilling Method: | 4-Inch Hollow Stem Auger | Weather: | Clear Skies, Partly Sunny 60°F |
| Development Company: | Kaventa Consulting | | Slight Breeze |
| Date Development Started: | 10/17/02 | Date Development Completed: | 10/17/02 |
| Screen Intervals: 12 ft. to 17 ft bgs | | Well Diameter: | 2 Inch |
| Depth of Well ($L^w$): | 30 ft. | Depth to Water Before Development ($L^i$): | 25 ft. |
| Height of Water Column ($L^w$ - $L^i$): | 5 ft. | | |
| Depth to Top of Sediment ($L^i$) | 30ft. | Sediment Thickness ($L^w$ - $L^i$): | Na ft. |
| Well Volume: | 0.8 gal. | | |
| Total Volume Pumped: | 8 gal. | | |
| Number of Well Volumes Pumped | (total volume pumped/well volume): | 8+ volumespurged on 10/17/02 | 0.16 gallons per foot on a 2-Inch Well |

## Monitoring Well Sample Data : Well RLP-GW6

| Date | Temp | pH | Cond | Gallons Purged | Observations |
|---|---|---|---|---|---|
| 10/17/02 | 13.1 | 6.49 | 4000 | 6 | Slightly turbid |
| 10/17/02 | 12.6 | 6.38 | 3970 | 7 | Clear, Slightly turbid |
| 10/17/02 | 13.1 | 6.42 | 4110 | 8 | Clear |
| | | | * Purged dry total of 8 times, Collected sample on 9th recharge | | |

* Sample collection continued after well development includes well development purge volumes

10/17/02 @ 1645 — Sample Collected

## Lithology

| | |
|---|---|
| 0-18 feet bgs | Purple roasted tailings mixed with waste rock and river cobble |
| 18-30 feet bgs | Native Rock, Cobble |

| Presented By | Date | Checked By | Date |
|---|---|---|---|

| CDPHE<br>Colorado Department of Public Health and Environment<br>4300 Cherry Creek Drive South<br>Denver, CO 80246 | WELL DEVELOPMENT DATA AND SAMPLE FORM SUMMARY | Records Management Data |
|---|---|---|

| | |
|---|---|
| Project Number: Rico Light Industrial Park | Project Name: Rico Light Industrial Park |
| Well Number: RLP-GW7 | Well Location: Rico Light Industrial Park |

| | | | |
|---|---|---|---|
| Time / Date: | 10/17/02 | Elevation : | 8,800 msl |
| Drilling Method: | 4-Inch Hollow Stem Auger | Weather: | Clear Skies, Partly Sunny 60°F |
| Development Company: | Kaventa Consulting | | Slight Breeze |
| Date Development Started: | 10/17/02 | Date Development Completed: | 10/17/02 |
| Screen Intervals: 19 ft. to 24 ft bgs | | Well Diameter: | 2 Inch |
| Depth of Well ($L^w$): | 24 ft. | Depth to Water Before Development ($L^i$): | 19 ft. |
| Height of Water Column ($L^w$ - $L^i$): | 5 ft. | | |
| Depth to Top of Sediment ($L^s$) | 24 ft. | Sediment Thickness ($L^w$ - $L^s$): | Na ft. |
| Well Volume: | 0.8 gal. | | |
| Total Volume Pumped: | 35 gal. | | |
| Number of Well Volumes Pumped | (total volume pumped/well volume): | 43+ volumes purged on 10/17/02 | 0.16 gallons per foot on a 2-Inch Well |

## Monitoring Well Sample Data : Well RLP-GW7

| Date | Temp | pH | Cond | Gallons Purged | Observations |
|---|---|---|---|---|---|
| 10/17/02 | 15.5 | 6.51 | 1679 | 26 | Slightly turbid |
| 10/17/02 | 15.7 | 6.51 | 1719 | 35 | Clear |

* Sample collection continued after well development includes well development purge volumes

10/17/02 @ 1550 — Sample Collected

## Lithology

0-24 feet bgs — Waste rock / river cobble

| Presented By | Date | Checked By | Date |
|---|---|---|---|
| | | | |

| CDPHE<br>Colorado Department of Public Health and Environment<br>4300 Cherry Creek Drive South<br>Denver, CO 80246 | WELL DEVELOPMENT DATA AND SAMPLE FORM SUMMARY | Records Management Data |
|---|---|---|

| | |
|---|---|
| Project Number: Rico Light Industrial Park | Project Name: Rico Light Industrial Park |
| Well Number: RLP-GW8 | Well Location: Rico Light Industrial Park |

| | | | |
|---|---|---|---|
| Time / Date: | 10/17/02 | Elevation : | 8,800 msl |
| Drilling Method: | 4-Inch Hollow Stem Auger | Weather: | Clear Skies, Partly Sunny 60°F |
| Development Company: | Kayenta Consultine | | Slight Breeze |
| Date Development Started: | 10/17/02 | Date Development Completed: | 10/17/02 |
| Screen Intervals: 25 ft. to 30 ft bgs | | Well Diameter: | 2 Inch |
| Depth of Well ($L^w$): | 30 ft. | Depth to Water Before Development ($L^l$): | 25 ft. |
| Height of Water Column ($L^w$ - $L^l$): | 5 ft. | | |
| Depth to Top of Sediment ($L^l$) | 30 ft. | Sediment Thickness ($L^w$ - $L^l$): | Na ft. |
| Well Volume: | 0.8 gal. | | |
| Total Volume Pumped: | 24 gal. | | |
| Number of Well Volumes Pumped | (total volume pumped/well volume): | 24+ volumes purged on 10/17/02 | 0.16 gallons per foot on a 2-Inch Well |

## Monitoring Well Sample Data : Well RLP-GW8

| Date | Temp | pH | Cond | Gallons Purged | Observations |
|---|---|---|---|---|---|
| 10/17/02 | 13.0 | 6.46 | 2510 | 22 | Clear, Slightly turbid |
| 10/17/02 | 12.9 | 6.58 | 2520 | 23 | Clear, Slightly turbid |
| 10/17/02 | 12.5 | 6.64 | 2520 | 24 | Clear, Slightly turbid |

* Sample collection continued after well development includes well development purge volumes

10/17/02 @ 1735 — Sample Collected

## Lithology

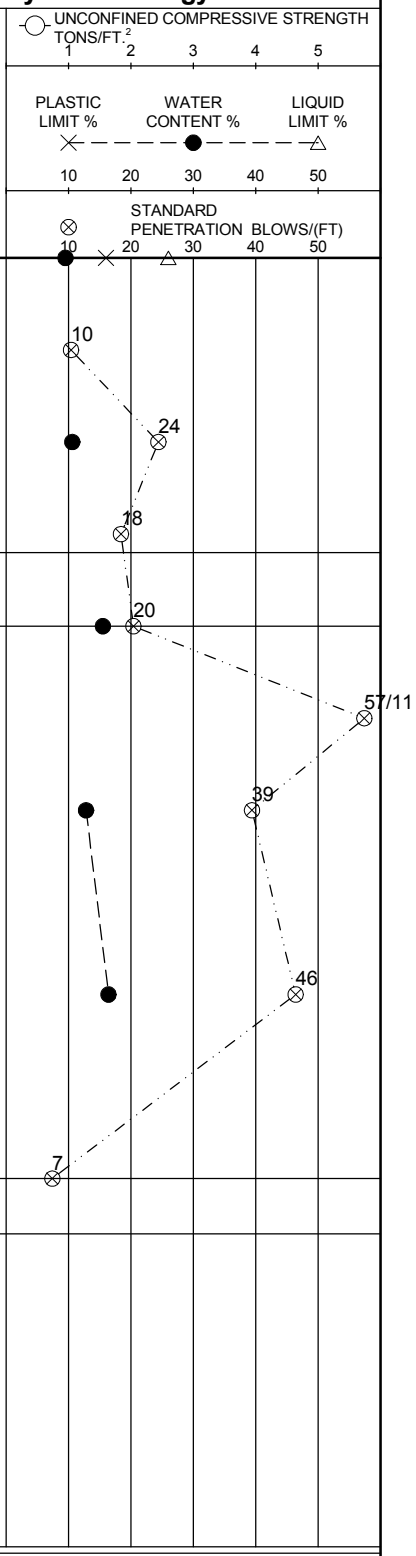
| | |
|---|---|
| 0-1 feet bgs | Fill material |
| 1-24 feet bgs | Red purple slimes, roasted tailings, saturated |
| 24 – 30 feet bgs | Native materials, river cobble |

| Presented By | Date | Checked By | Date |
|---|---|---|---|

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-3D |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,819.9 Feet | |
| | | | GB | | | FILL - Silty Cobbly Sandy Clayey GRAVEL (GM-GC) - approximately 5% cobbles, 40% gravel, 35 % sand and 20% fines - cobbles up to 4.5" or larger - predom. angular to subangular gravel - well graded - medium dense - moist | |
| | | 1 | GB | | | 0.0-1.5' - Mostly silt fines - low plasticity - black 5YR 2.5/1 | |
| 5.0 | | | GB | | | 1.5-2.0' - Calcines with above | |
| | | 2 | GB | | | 2.0-2.5' - Fines <10% - low plastic silt (GW) | |
| | | | GB | | | 2.5-6.5' - Predom clay fines - approx. 20% fines, moderate to high plasticity - dark brown 7.5YR 3/3 (GC) | |
| | | 3 | GB | | | 6.5-8.0' - <5% non-plastic silt fines - dark reddish brown 5YR 3/3 (GW) | |
| 10.0 | | | GB | | | FILL - Clayey Sandy Cobbly GRAVEL (GC) - approximately 40% gravel, 40% sand and 20% fines - fines clay with moderate to high plasticity - predom. subrounded to well rounded gravel - medium dense - moist to wet | |
| | | 4 | GB | | | Decayed roots and stems - black color with oxidized rock at 9.5-10.0' | |
| | | | GB | | | ALLUVIUM - Silty Clayey Cobbly GRAVEL (GC) - approximately 50% gravel and cobbles, 35% sand and 15% clay and silt fines - moderately plastic fines - predom. subrounded to rounded - black 5YR 2.5/1 - dense to loose - moist to wet | |
| | | 5 | GB | | | 11.5-12.5' - Grades to dark brown 7.5YR 3/3 - fines become predom. silt - low plasticity - <10% (GW) | |
| 15.0 | | | GB | | | 12.5-15.0' - reduction in cobble content and gravel to 40% in favor of sand (SW) | |
| | | 6 | GB | | | 15.0-16.0' - No cobbles - <5% silt fines - approx. 60% gravel and 40% sand (GW) | |
| 20.0 | | | GB | | | 16.0-17.5' - Increases fines - approx. 15% high plasticity clay - yellowish brown 10YR 5/8 (GW-GC) | |
| | | 7 | GB | | | 17.5-20.0' - Transitions to siltier fines - low plasticity - approx 15% fines content - grades to dark brown 7.5YR 3/3 (GW-GC) | |
| 25.0 | | | GB | | | 20.0-22.5' - Transitions back to strong brown color 7.5YR 4/4 | |
| 26.5 | | 8 | GB | | | 22.5-25.0' - Transitions to <5% fines - reduction in gravel to approx. 50% gravel and 45% sand (GW) | |
| | | | | | | Silty SAND (SM-SP) - predom. medium grained - subangular to subrounded with scattered well rounded gravels - strong brown 7.5YR 4/6 | |
| | | | | | | End of Boring<br>Boring logged by: A. Jewell<br>Boring completed as 2.0" diameter monitoring well: 0.010" PVC screen 13.0-23.0' with bottom plug and sand pack 12.0-25.5' - 13.0' SCH 40PVC riser with flush mounted cover. | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING | BORING STARTED | AECOM OFFICE | |
|---|---|---|---|
| 1388313 | 10/3/11 | Denver | |
| EASTING | BORING COMPLETED | ENTERED BY | SHEET NO. OF |
| 2267602 | 10/3/11 | SJH | 1 1 |
| WL | RIG/FOREMAN | APP'D BY | AECOM JOB NO. |
| 12.0' WD | MINI-SONIC C100/D. Cerventes | EED | 60157757 |

AECOM LOG RICO_GINT_DATABASE.GPJ FS_DATATEMPLATE.GDT 12/11/13

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **MW-3S** |
|---|---|---|
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,819.9 Feet | |
| | | | | | | No logging - No sampling<br><br>See MW-3D | |
| 5.0 | | | | | | | |
| 10.0 | | | | | | 10.0 | |
| | | | | | | Boring completed as 2.0" diameter monitoring well: Total depth 10.0' - 0.010" PVC screen 4.0-9.0' with bottom plug and sand pack 3.0-10.0' - 4.0' SCH 40 PVC riser with flush mounted cover. | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING **1388563** | BORING STARTED **10/3/11** | AECOM OFFICE **Denver** | |
|---|---|---|---|
| EASTING **2267604** | BORING COMPLETED **10/3/11** | ENTERED BY **SJH** | SHEET NO. **1** OF **1** |
| WL | RIG/FOREMAN **MINI-SONIC C100/D. Cerventes** | APP'D BY **EED** | AECOM JOB NO. **60157757** |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-5D |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.1 Feet | |
| | | | GB | | | PDF EMBANKMENT FILL - Silty Sandy GRAVEL (GW) - subangular to subrounded - medium dense - brown 7.5 YR 4/4 - moist | |
| | | 1 | GB | | | 3.5 | |
| 5.0 | | | GB | | | FILL - Oxidized material - Clayey SAND (SC) - low plasticity fines - dark reddish brown 2.5YR 2.5/3 - loose - moist | |
| | | 2 | GB | | | 6.0 | |
| | | | GB | | | FILL - Calcines - Silty fine SAND (SP) and silt sized - estimated <10% fines - reddish purple (no munsell) - medium dense to very loose - moist | |
| | | 3 | GB | | | | |
| 10.0 | | | GB | | | | |
| | | 4 | GB | | | | |
| | | | GB | | | | |
| 15.0 | | 5 | GB | | | Becoming wet and black/reddish purple below 15.0' | |
| | | | GB | | | Becomes silty with low plasticity fines at 17.0;' - estimated up to 30% silt | |
| 20.0 | | 6 | GB | | | 22.0 | |
| | | | GB | | | 23.0 Organic SILT (ML-OL) - probable overbank deposits - decayed plant fibers - trace fine sand and thin 1/8" calcine layers - low plasticity - greenish black - moist to wet | |
| 25.0 | | 7 | GB | | | ALLUVIUM - Silty Sandy Cobbly GRAVEL (GM) - color varies - dense - saturated | |
| | | | GB | | | Clayey sandy cobbly gravel (GC) - fines moderately plastic - very dark gray 7.5YR 3/1 - predom. subangular with some subrounded | |
| 30.0 | | 8 | GB | | | Transition to silt fines (GW-GM) - reddish brown 5YR 4/4 | |
| | | | GB | | | Very dark gray 7.5YR 3/1 - becomes predom. subrounded | |
| | | | | | | Lower fines content (<10%) (GW) - dark yellowish brown 10YR 4/6 | |
| | | | | | | Increased fines, approximately 15% (GW-GM) - yellowish brown 10YR 5/8 - medium dense | |
| | | | | | | 34.5 | |
| 35.0 | | | | | | | |

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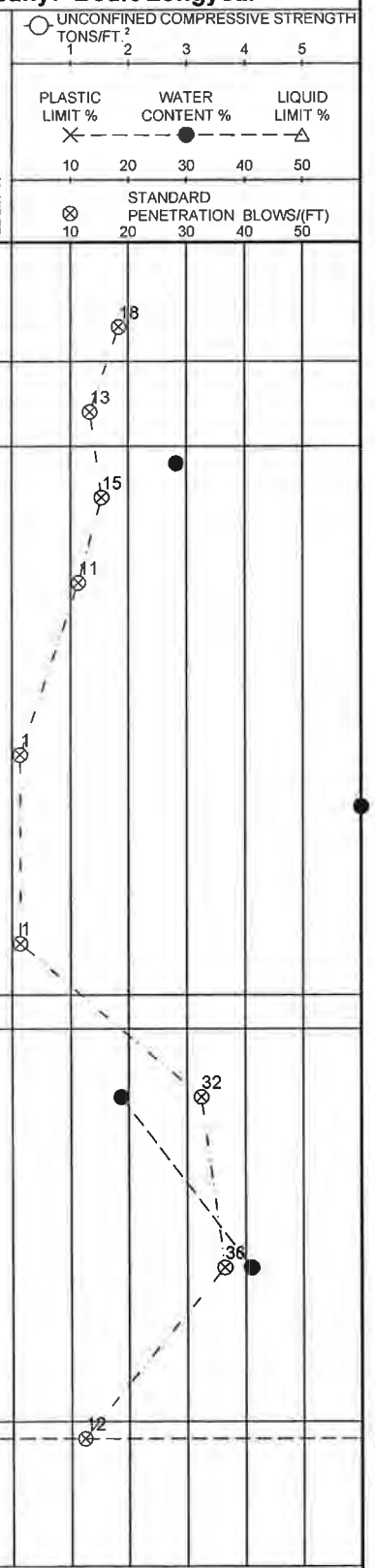



The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO 1 OF 2

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-5D |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.1 Feet (Continued) | | |
| 36.5 | | 9 | GB | | | ALLUVIUM - Gravelly Silty SAND (SM) - approximately 10% gravel, 15% silt and 75% sand - red 2.5YR 5/6 - wet - medium dense (36.5) | | |

End of Boring
Boring logged by: A. Jewell
Casing: 5.5" I.D.
Boring completed as 2.0" diameter monitoring well: 0.010" PVC screen 11.0-21.0' with bottom plug and sand pack 10.0-21.0' - 11.0' SCH 40PVC riser with flush mounted cover.

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING | BORING STARTED | AECOM OFFICE | |
|---|---|---|---|
| 1388375 | 10/9/11 | Denver | |
| EASTING | BORING COMPLETED | ENTERED BY | SHEET NO. OF |
| 2267814 | 10/9/11 | SJH | 2 2 |
| WL | RIG/FOREMAN | APP'D BY | AECOM JOB NO |
| 15.5' WD | MINI-SONIC C100/D. Cerventes | EED | 60157757 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-5S |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.1 Feet | | | | |
| | | | | | | No logging - No sampling<br>See MW-5D | | | | |
| 5.0 | | | | | | | | | | |
| 10.0 | | | | | | | | | | |
| 15.0 | | | | | | | | | | |
| 20.0 | | | | | | | | | | |
| 22.0 | | | | | | 22.0 | | | | |
| | | | | | | Boring completed as 2.0" diameter monitoring well: Total depth 22.0' - 0.010" PVC screen 11.0-21.0' with bottom plug and sand pack 10.0-22.0' - 11.0' SCH 40 PVC riser with flush mounted cover. | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388370 | BORING STARTED 10/9/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2267814 | BORING COMPLETED 10/10/11 | ENTERED BY SJH | SHEET NO 1 OF 1 |
| WL | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO 60157757 |

AECOM

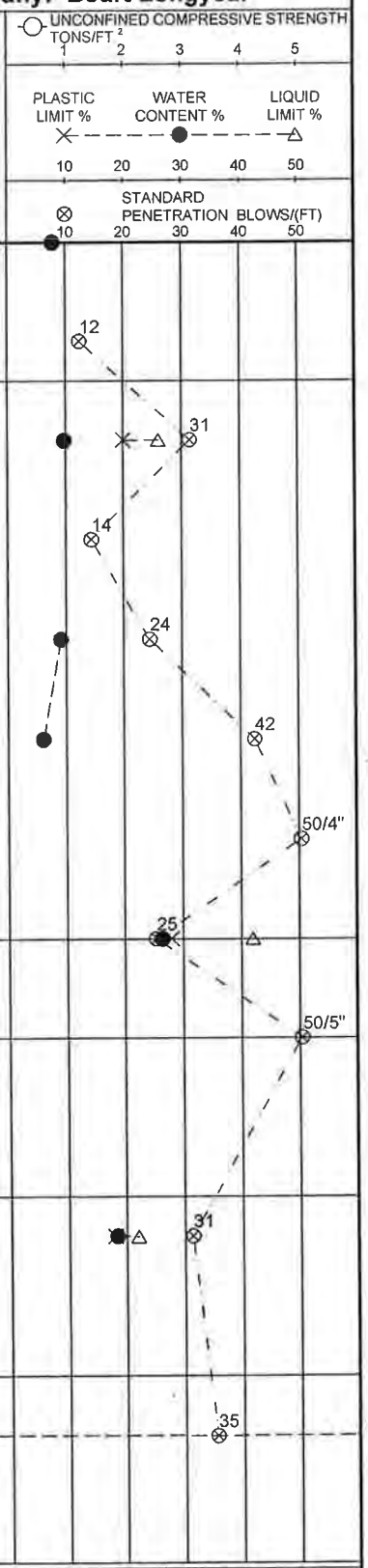
| CLIENT | LOG OF BORING NUMBER |
|---|---|
| **Atlantic Richfield Company** | **MW-6D** |
| PROJECT NAME | ARCHITECT-ENGINEER |
| **Rico-Argentine Site - OU01** | **Drilling Company: Boart Longyear** |

SITE LOCATION

SURFACE ELEVATION +8,830.6 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | GB | | | FILL - Dike - altered wasterock, Silty Cobbly Sandy GRAVEL (GW-GM) - approximately 45% gravel and cobbles, 40% sand and 15% silt - cobble to 4.0" or larger - predom subangular - strong brown 7.5YR 5/6 - medium dense - slightly moist | |
| | | 1 | GB | | | 3.5 | |
| 5.0 | | | GB | | | 0.0-0.66' - Highly altered wasterock - rock matrix evident - clays residual include greenish gray, yellow 5YR 8/6 and white | |
| | | 2 | GB | | | FILL - Dike - Clayey Cobbly Sandy GRAVEL (GC) - approximately 40% gravel and cobbles, 40% sand and 20% clay fines - cobbles to 4.0" or larger - predom. subangular to angular - dark brown 7.5YR 3/3 - dense to medium dense - moist - highly plastic clay fines - various colors, dark reddish brown 2.5YR 3/4 and dark brown 10YR 2/2 | |
| | | | GB | | | | |
| | | 3 | GB | | | | |
| 10.0 | | | GB | | | Cobbly layer - cobbles to 5.0" or larger, subround to subangular at 9.5-10.0' | |
| | | 4 | GB | | | | |
| | | | GB | | | | |
| | | 5 | GB | | | Cobbly layer - cobbles to 3.0" or larger, subangular at 13.0-13.5' - extremely dense | |
| 15.0 | | | GB | | | Possible colluvium from 13.0-17.0' | |
| | | 6 | GB | | | 13.5' - Changes to silt fines - approximately 15% fines - brown 7.5YR 4/2 - very cobbly (GW-GM) | |
| | | | GB | | | 15.0' - Becomes dark reddish brown 2.5YR 3/4 - gap graded - approximately 5% fines, 5% sand and rest gravel and cobbles - cobbles to 5.0" or larger (GP) | |
| | | 7 | GB | | | 17.5 | |
| 20.0 | | | GB | | | Significant increase in clay fines to 20% and tree stems to 3/8" relatively undecayed from 16.5-17.5' (GC) | |
| | | 8 | GB | | | 20.0 | |
| | | | GB | | | ALLUVIUM - Organic SILT (ML-OL) - decayed plant matter - scattered gravel to 1.0" or larger - medium dense - moist | |
| | | | | | | 18.0' - Significant increase in gravels - subangular to angular - up to 30% gravels - gap graded - decayed plant matter | |
| | | | | | | 24.0 | |
| 25.0 | | | | | | COLLUVIUM - Silty Sandy GRAVEL (GM) to 2.0" or larger - predom. angular to subangular - very dark gray 7.5YR 3/1 - extremely dense - slightly moist | |
| | | 9 | GB | | | ALLUVIUM - Clayey Gravelly Cobbly SAND (SC) - approximately 40% sand, 30% cobbles and gravel and 30% moderately plastic clay - cobbles to 6.0" or larger - predom. subangular to angular - dark gray 7.5YR 4/1 - dense - wet | |
| | | | GB | | | 28.5 | |
| 30.0 | | | | | | | |

. . . continued




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO. 60157757

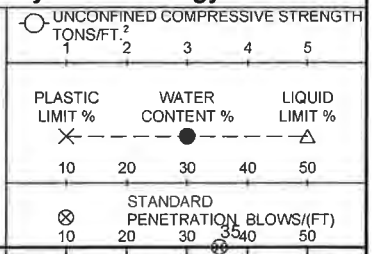
SHEET NO. 1 OF 2

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-6D |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,830.6 Feet (Continued) | |
| | | 10 | GB | | | ALLUVIUM - Clayey Gravelly Cobbly SAND (SC) - approximately 40% sand, 30% cobbles and gravel and 30% moderately plastic clay - cobbles to 6.0" or larger - predom. subrounded to angular - dark gray 7.5YR 4/1 - dense - wet | |
| | | | GB | | | 31.5' - Becomes Silty Sandy GRAVEL (GW) - approx. 60% gravel, 30% sand and 10% fines - predom. subrounded to subangular - dark brown Becomes strong brown 7.5YR 4/6 at 34.0' | |
| 35.0 | | 11 | GB | | | | |
| | | | | | | 36.5 ALLUVIUM - Silty fine SAND (SP) - <5% silt - medium grain sand - dark yellowish brown 10YR 4/4 - wet | |
| | | | GB | | | 37.5 ALLUVIUM - Sandy GRAVEL (GW) - subangular to subrounded - approximately 60% gravel, 40% sand and <3% silt - gravel to 3.0" - well graded - subangular to subrounded - wet | |
| 40.0 | | 12 | GB | | | 39.5 | |
| 41.5 | | | | | | 41.5 Core sample from 37.5-40.0' is probably loosened, mixed and sorted due to multiple attempts to clean hole (flapper bit) | |
| | | | | | | ALLUVIUM - Silty fine SAND (SM) - up to 20% silt - low plastic fines - strong brown 2.5YR 3/4 - loose | |
| | | | | | | Becomes dark reddish brown 12.5YR 3/4 at 41.0' | |
| | | | | | | End of Boring | |
| | | | | | | Boring logged by: A. Jewell | |
| | | | | | | Casing: 5.5" I.D. | |
| | | | | | | Boring completed as 2.0" diameter monitoring well: 0.010" PVC screen 30.0-40.0' with bottom plug and sand pack 29.0-41.5' - 30.0' SCH 40PVC riser with flush mounted cover. | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388166 | BORING STARTED 10/11/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268148 | BORING COMPLETED 10/11/11 | ENTERED BY SJH | SHEET NO. 2 OF 2 |
| WL 23.75' WD | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO. 60157757 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-6S |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,830.7 Feet | | | | |
| | | | | | | No logging - No sampling | | | | |
| | | | | | | See MW-6D | | | | |
| 5.0 | | | | | | | | | | |
| 10.0 | | | | | | | | | | |
| 15.0 | | | | | | | | | | |
| 20.0 | | | | | | | | | | |
| 25.0 | | | | | | | | | | |
| 28.0 | | | | | | | | | | |

Boring completed as 2.0" diameter monitoring well: Total depth 28.0' - 0.010" PVC screen 17.0-27.0' with bottom plug and sand pack 16.0-28.0' - 17.0' SCH 40 PVC riser with flush mounted cover.

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388166 | BORING STARTED 10/11/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268153 | BORING COMPLETED 10/11/11 | ENTERED BY SJH | SHEET NO. 1 OF 1 |
| WL | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO. 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **MW-102**<br>**DRAFT** |
|---|---|---|
| | PROJECT NAME<br>**Rico - Argentine Mine Site** | ARCHITECT-ENGINEER<br>**Anderson Engineering Company, Inc.** |

SITE LOCATION
**Rico-Argentine**

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1, 2, 3, 4, 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10, 20, 30, 40, 50) | STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,841.3 Feet | | | | |
| | | | | | | Note:<br>Offset boring 75' NNE from SSR-102<br>No soil samples obtained | | | | |
| 5.0 | | | | | | | | | | |
| 10.0 | | | | | | | | | | |
| 15.0 | | | | | | | | | | |
| 20.0 | | | | | | | | | | |
| 25.0 | | | | | | | | | | |
| 30.0 | | | | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818

SHEET NO. 1 OF 2

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **MW-102**<br>**DRAFT** |
|---|---|---|
| | PROJECT NAME<br>**Rico - Argentine Mine Site** | ARCHITECT-ENGINEER<br>**Anderson Engineering Company, Inc.** |

SITE LOCATION
**Rico-Argentine**

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,841.3 Feet (Continued) | | |
| | | | | | | Note:<br>Offset boring 75' NNE from SSR-102<br>No soil samples obtained | | |
| 32.0 | | | | | | 32.0 | | |
| | | | | | | Blank drilled with 4-1/4" ID HSA to 32 feet with wood plug in lead end of 4 1/4" ID HSA. Piezometer installed in borehole with tip at 31 feet.<br>No soil samples obtained. | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING **1388482.836** | BORING STARTED **11/11/12** | AECOM OFFICE **Denver** | |
| EASTING **2268230.492** | BORING COMPLETED **11/12/12** | ENTERED BY **DCJ** | SHEET NO. **2** OF **2** |
| WL **W.L. @ 23.5'** | RIG/FOREMAN **CME-85/Reggie Castro** | APP'D BY | AECOM JOB NO. **60239818** |

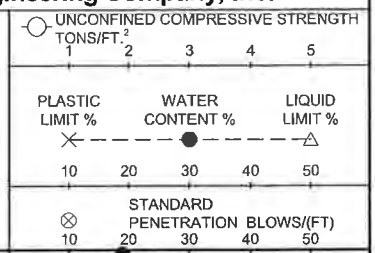
AECOM

| CLIENT | LOG OF BORING NUMBER |
|---|---|
| **Atlantic Richfield Company** | **DRAFT** **MW-202** |
| PROJECT NAME | ARCHITECT-ENGINEER |
| **Rico - Argentine Mine Site** | **Anderson Engineering Company, Inc.** |

SITE LOCATION
**Rico-Argentine**

SURFACE ELEVATION +8,859.2 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | 1 | SON | | | FILL: Well graded gravel, some sand, little silt - 57% gravel, 30% sand, 13% fines - 10YR3/2 - (FILL: GM) | |
| | | | | | | 2.0 | |
| | | 2,3 | SON | | | Clayey sand and gravel, some silt - 35% gravel, 40% fine to coarse sand, 25% fines - 7.5YR4/3 (SC) | |
| 5.0 | | | | | | | |
| | | | | | | 6.0 | |
| | | | | | | Well graded clayey gravel and sand, little silt - 7/5YR4/3 (GW-GC) | |
| | | | | | | 9.0 | |
| | | 3,4 | SON | | | Clayey sand and gravel, some silt - 35% gravel, 40% fine to coarse sand, 25% fines - 7.5YR4/3 (SC) | |
| 10.0 | | | | | | | |
| | | | | | | 13.0 | |
| | | 5 | SON | | | Well graded sand, some gravel, little silt - 20% gravel, 71% fine to coarse sand, 9.3% silt - 10YR4/3 (SW-SM) | |
| 15.0 | | | | | | | |
| 20.0 | | 6 | SON | | | | |
| | | | | | | 23.5 | |
| | | 7 | SON | | | Well graded sand, some gravel, little silt - 20% gravel, 71% fine to coarse sand, 9.3% silt - 10YR4/4 (SW-SM) | |
| 25.0 | | | | | | | |
| 30.0 | | | | | | | |

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The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 2

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: MW-202 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,859.2 Feet (Continued) | | |
| | | 8 | SON | | | Well graded sand, some gravel, little silt - 20% gravel, 71% fine to coarse sand, 9.3% silt - 10YR4/4 (SW-SM) | | |
| 35.0 | | | | | | 35.5 | | |
| | | | RB | | | Blind Drilling | | |
| 38.8 | | | | | | 38.8 | | |
| | | | | | | End of boring at 38.8 ft. Boring advanced to 35.5 feet with sonic drilling techniques, boring advanced to 38.8 feet using mud rotary techniques. Piezometer installed with tip at 38.8 feet. | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING 1388999.649 | BORING STARTED 11/8/12 | AECOM OFFICE Denver | |
| EASTING 2268195.978 | BORING COMPLETED 11/11/12 | ENTERED BY AMH | SHEET NO. 2 OF 2 |
| WL W.L. @ 22.5' W.D. | RIG/FOREMAN AMS Compact Sonic 10-C/Kyle King | APP'D BY | AECOM JOB NO. 60239818 |

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

# AECOM Boring and Well Construction Log

**BORING #: MW-203**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** Cascade Drilling | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 9/24/2013 - 9/24/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 62.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 60 SON | 1 | SW-SC | | (0-46.5') COLLUVIUM: Well Graded Sand with Clay, 40% Gravel (Very Angular to Subrounded), 45% Sand, 15% Fines (7.5% Clay, 7.5% Silt), Trace Organics - Low Plasticity, Max Grain Size = 2.5, HCL=None - 7.5YR3/2 (Dark Brown) (SW-SC); roots to 2' | Slightly Moist; Moist | | | 2 PVC |
| 2 | | | | | | | | | |
| 4 | | | | | | | | | |
| 6 | 60 SON | | | | 6.0 | | | | |
| | | 2 | SC | | Clayey Sand, 2% Cobbles, 35% Gravel (Very Angular to Subrounded), 43% Sand, 20% Fines (10% Clay, 10%Silt) - Low Plasticity, Max Grain Size = 3, HCL=Weak - 10YR4/3 (Brown) (SC) | | | | |
| 8 | | | | | | | | | |
| 10 | | | | | 10.0 | | | | |
| | 70 SON | 3 | SW-SM | | Well Graded Sand with Silt, 30% Gravel (Very Angular to Subrounded), 60% Sand, 10% Fines (2% Clay, 8%Silt) - Non-plastic, Max Grain Size = 2, HCL=None - 10YR4/4 (Dark Yellowish Brown) (SW-SM) | | | | |
| 12 | | 4 | SC | | 11.5 Clayey Sand, 40% Gravel (Very Angular to Subangular), 45% Sand, 15% Fines (7.5% Clay, 7.5% Silt) - Medium Plasticity, Max Grain Size = 2.5, HCL=Weak - 7.5YR3/2 (Dark Brown) (SC) | Wet | | | |
| 14 | | | | | | | | | |
| 16 | 70 SON | | | | | Slightly Moist | | | |
| 18 | | | | | 18.5 | | | | |
| | | | SC | | 4+ Cobble | | | | |
| 20 | 70 SON | | | | 21.0 | Moist | | | |
| 22 | | 5 | GC | | Clayey Gravel, 50% Gravel (Angular to Subrounded), 35% Sand, 15% Fines (10.5% Clay, 4.5% Silt) - Medium Plasticity, Max Grain Size = 2.5, HCL=Strong - 10YR4/3 (Brown) (GC) | | | | |
| 24 | | | | | | | | | |
| 26 | 70 SON | | | | 26.0 | | | | |
| | | 6A | GM | | Silty Gravel, 50% Gravel (Angular to Subrounded), 35% Sand, 15% Fines (7.5% Clay, 7.5% Silt) - Low Plasticity, Max Grain Size = 2, HCL=Strong - 10YR5/4 (Yellowish brown) (GM) | | | | |
| 28 | | | | | | | | | |
| 30 | | | | | | | | | |
| | 70 | | | | | | | | |

**Remarks:** Boring Terminated (ft): 62.0

Entered by: AKC

Notes:

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: MW-203**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** Cascade Drilling | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 9/24/2013 - 9/24/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 62.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 32 | SON | 6B | GM | | Silty Gravel, 50% Gravel (Angular to Subrounded), 35% Sand, 15% Fines (7.5% Clay, 7.5% Silt) - Low Plasticity, Max Grain Size = 2, HCL=Strong - 10YR5/4 (Yellowish brown) (GM) *(continued)* | | | | |
| | | | | | 32.5 | | | | |
| 34 | | | GM | | Severely weathered gray cobbles | | | | |
| | | | | | 35.0 | | | | |
| 36 | 80 SON | | GM | | Intact boulder | | | | |
| | | | | | 36.0 | | | | |
| 38 | | 7 | GW-GM | | Well Graded Gravel with Silt, 50% Gravel (Angular to Subrounded), 36% Sand, 14% Fines (11.2% Clay, 2.8% Silt) - Non-plastic, Max Grain Size = 1.5, HCL=Weak - 5YR4/3 (Reddish Brown) (GW-GM); residual red sandstone | Wet | | | |
| 40 | | | | | | Moist | | | 3/8 Hole Plug |
| | | | | | 40.0 | | | | |
| 42 | 70 SON | 8 | GC | | Clayey Gravel, 50% Gravel (Angular to Subrounded), 37% Sand, 15% Fines (12% Clay, 3% Silt) - Low Plasticity, Max Grain Size = 2, HCL=Weak - 2.5Y4/2 (Dark Grayish Brown) (GC); weathered and residual gray mudstone | | | | |
| 44 | | | | | | Wet | | | 20/40 Colorado Silica |
| 46 | 70 SON | | | | | | | | 2 0.010 slot Sch 40 PVC |
| | | | | | 46.5 | | | | |
| 48 | | 9 | GP-GM | | (46.5-52') ALLUVIUM/COLLUVIUM MIXTURE: Poorly Graded Gravel with Silt, 60% Gravel (Angular to Rounded), 30% Sand, 10% Fines (2% Clay, 8%Silt) - Non-plastic, Max Grain Size = 3, HCL=Weak - 5YR3/3 (Dark Reddish Brown) (GP-GM), Exact contact depth is unclear | | | | |
| 50 | 0 SON | LOST | | | | | | | |
| 52 | | | | | 52.0 | | | | |
| 54 | | | GC | | (52-57') COLLUVIUM: Clayey Gravel, 50% Gravel (Angular to Subrounded), 37% Sand, 15% Fines (12% Clay, 3% Silt) - Low Plasticity, Max Grain Size = 2, HCL=Weak - 2.5Y4/2 (Dark Grayish Brown) (GC); weathered and residual gray mudstone | | | | |
| 56 | 30 SON | 8 | | | | | | | |
| | | | | | 57.0 | | | | |
| 58 | 70 SON | 10 | GW-GM | | (57-62') ALLUVIUM/COLLUVIUM MIXTURE: Well Graded Gravel with Silt, 5% Cobbles, 50% Gravel (Angular to Subrounded), 33% Sand, 12% Fines (2.4% Clay, 9.6%Silt) - Non-plastic, Max Grain Size = 4+, HCL=Strong - 7.5YR4/3 (Brown) (GW-GM) | | | | |
| 60 | | | | | | | | | |

**Remarks:** Boring Terminated (ft): 62.0

Entered by: AKC

Notes:

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

*(Continued Next Page)*

# AECOM Boring and Well Construction Log

**BORING #: MW-203**



| | | |
|---|---|---|
| **Client:** Atlantic Richfield Company | **Location:** Rico-Argentine Mine / St. Louis Ponds | **Logged By:** A. Jewell |
| **Project #:** 60306687/60306858 | **Drilling Company:** Cascade Drilling | **Drilling Foreman:** Rick Mallet |
| **Drilling Date:** 9/24/2013 - 9/24/2013 | **Drilling Equipment:** Boart/Longyear Sonic 300 | **Total Depth (ft):** 62.0 |
| | **Sampling Method:** SON-Sonic Core; SPT-Standard Penetration Test; ST-Shelby Tube | |

| Depth (ft bgs) | Recovery % Sample Method | Lab Sample ID | USCS Code | Graphic | Soil and Rock Description Classification Scheme: USCS | Soil Saturation (field observation) | Notes | Well Diagram | Well Meterials |
|---|---|---|---|---|---|---|---|---|---|
| 62 | | | GW-GM | | 62.0 | | | | |
| | | | | | End of boring at 62.0 ft. bgs. | | | | End of boring at 62.0 ft. bgs. |

**Remarks:** Boring Terminated (ft): 62.0

Entered by: AKC

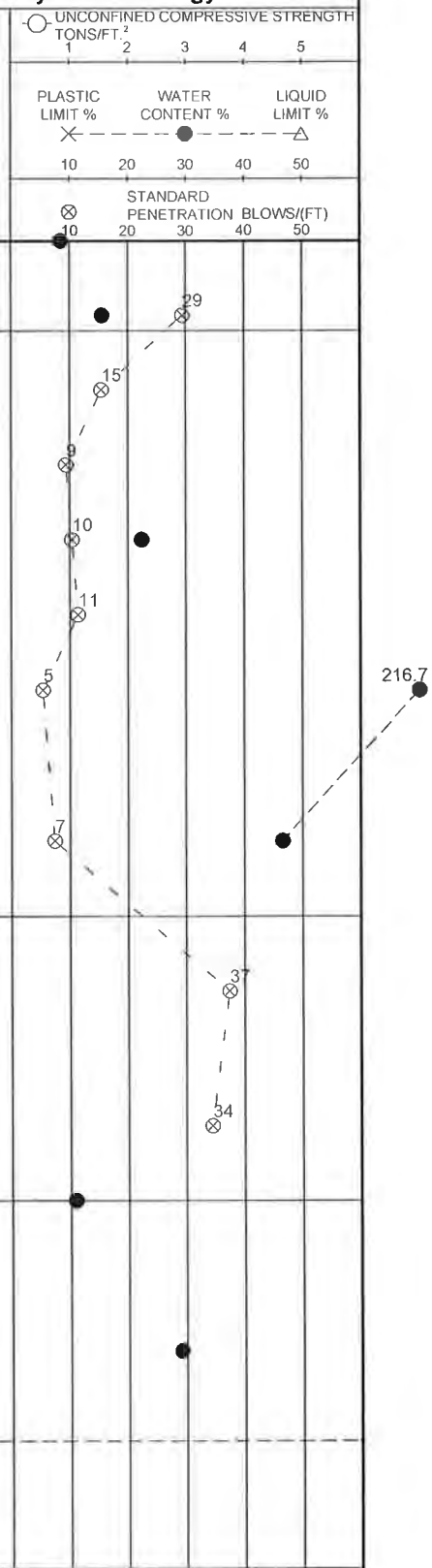
Notes:

**717 17th Street, Suite 2600**
**Denver CO 80202**
**(303)228-3000**

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS /FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.6 Feet | |
| | | | GB | | | PDF DIKE FILL - Silty Sandy GRAVEL (GW) - subrounded to rounded - medium dense - moist | |
| | | | | | | 3.0 | |
| | | 1 | GB | | | FILL - Calcines - Silty fine SAND (SM), sized est. <10% silt - reddish purple (no munsell color) - moist - medium dense to loose | |
| | | | GB | | | | |
| 5.0 | | | | | | | |
| | | 2 | GB | | | | |
| | | | GB | | | | |
| | | 3 | GB | | | | |
| 10.0 | | | GB | | | | |
| | | 4 | GB | | | | |
| | | | GB | | | | |
| | | 5 | GB | | | | |
| 15.0 | | | GB | | | Becoming wet at 14 5' | |
| | | 6 | GB | | | | |
| | | | GB | | | | |
| 20.0 | | | | | | | |
| | | 7 | GB | | | | |
| | | | | | | 22 5 | |
| | | | GB | | | ALLUVIUM - Silty Sandy Cobbly GRAVEL (GW) - approximately 5% cobbles to 4.5", 55% gravel, 30% sand and 10% silt fines - predom. subrounded to well-rounded gravel - bluish black 2 GLEY 2.5/5PB- black color does not appear to be organic, rather appears to be chem related to calcines - dense - wet | |
| 25.0 | | | | | | | |
| | | 8 | GB | | | | |
| | | | GB | | | 25.0-30.5' - Core sample appears to contain calcines from above - using water to prevent heaving in drill casing - sampling alluvial material only | |
| 30.0 | | | | | | | |
| | | 9 | GB | | | Becomes dark olive green 5Y 3/2 | |
| | | | GB | | | 32.0 Mix of units from 22.5-30.0' and 32.0'+ | |
| | | | | | | ALLUVIUM - Gravelly Silty SAND (SW) - subrounded to rounded gravels - gravels up to 1.5" - strong brown 7.5YR 5/8 - wet | |
| 35.0 | | | GB | | | 35 0': Becomes dark yellowish brown 10YR 4/6 | |
| | | | GB | | | | |
| 40.0 | | | | | | | |
| | | | | | | continued | |




The stratification lines represent the approximate boundary lines between soil types in situ, the transition may be gradual

AECOM JOB NO 60157757 | SHEET NO 1 OF 3

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.6 Feet (Continued) | |
| | | | | | | ALLUVIUM - Gravelly Silty SAND (SW) - subrounded to rounded gravels - gravels up to 1.5" - strong brown 7.5YR 5/8 - wet<br>40.0': Dark yellowish brown 10YR 4/6 | |
| | | | GB | | | | |
| 45.0 | | | | | | Mostly fine sand, gravels reduce to <5%, approximately 5% silt - yellowish red 5YR 4/6 (SP) | |
| | | | GB | | | Grades to silty fine sand with approximately 10% silt fines - reddish brown 2.5YR 4/8 (SP-SM) | |
| 50.0 | | | | | | Subangular to subrounded, medium and coarse sands - fines <5% (SP) | |
| 55.0 | | | GB | | | Transitions back to silty fine sand - approximately 10% fines (SP-SM) | |
| 60.0 | | | | | | | |
| | | | GB | | | | |
| 65.0 | | | | | | | |
| | | | | | | 68.0 | |
| | | | GB | | | Fine Sandy CLAY (CL) - dark reddish gray 2.5YR 4/1 - moderately plastic - moist | |
| 70.0 | | | | | | 70.0 | |
| | | | | | | Transitions to Silty fine SAND (SP) - weak red 2.5YR 4/2 - approximately <5% fines | |
| 75.0 | | | GB | | | | |
| | | | | | | Transitions to reddish brown 2.5YR 4/3 | |
| 80.0 | | | | | | | |
| | | | | | | continued | |

UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1, 2, 3, 4, 5)

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % (10, 20, 30, 40, 50)

STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50)

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO 60157757 | SHEET NO 2 OF 3

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

UNCONFINED COMPRESSIVE STRENGTH TONS/FT$^2$ (1, 2, 3, 4, 5)

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % (10, 20, 30, 40, 50)

STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS/FT$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,831.6 Feet (Continued) | |
| | | | | | | Transitions to Silty fine SAND (SP) - weak red 2.5YR 4/2 - approximately <5% fines | |
| 85.0 | | | GB | | | | |
| 90.0 | | | | | | | |
| | | | GB | | | 92.0 | |
| | | | | | | Silty fine SAND (SM) - predom. approximately 15% silt with 6.0" layer at 93.0' and 99.0' of 25% silt and dark reddish gray 2.5YR 4/1 - generally reddish brown 2.5YR 4/3 | |
| 95.0 | | | | | | | |
| | | | GB | | | | |
| 100.0 | | | | | | 100.0 | |
| | | | | | | End of Boring<br>Backfilled with bentonite (19 bags)<br>Boring logged by: A. Jewell<br>Casing: 5.5" I.D.<br>No water available - frozen pump | |

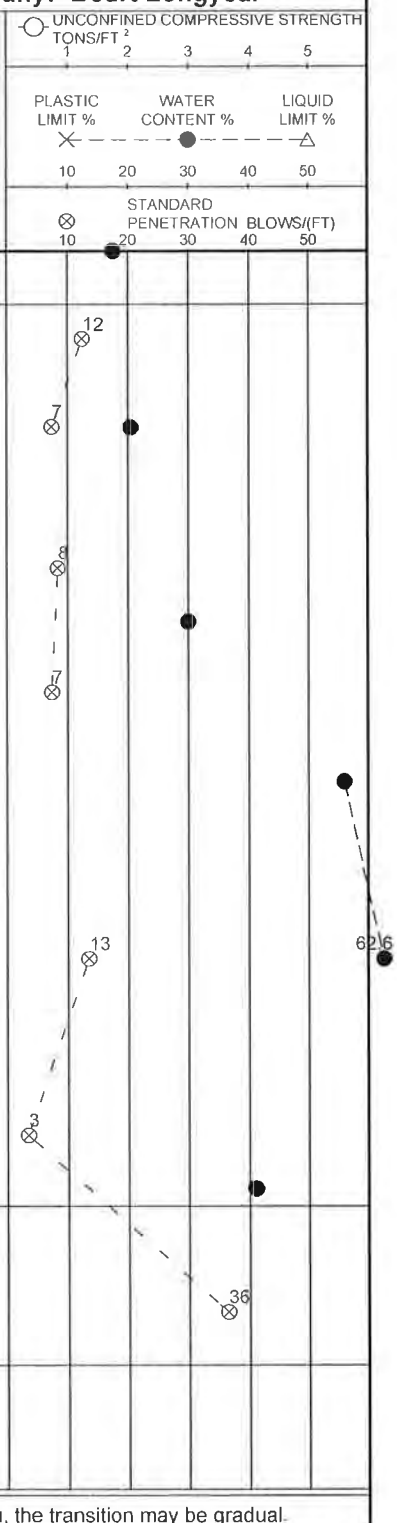
The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING 1388479 | BORING STARTED 10/6/11 | AECOM OFFICE Denver | |
| EASTING 2267812 | BORING COMPLETED 10/6/11 | ENTERED BY SJH | SHEET NO 3 OF 3 |
| WL 14.5' WD | RIG/FOREMAN MINI-SONIC C100/ | APP'D BY EED | AECOM JOB NO 60157757 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-2 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,838.9 Feet | |
| | | | GB | | | FILL - Wasterock/colluvium intermixed with calcines - COLLUVIUM FRACTION - Clayey Gravelly SAND (SP-SM) - gravels to 2.0" or larger - subangular - reddish purple (no munsell) | |
| | 1.5 | | | | | CALCINES - Silty fine SAND (SM) sized - black - medium dense to very dense - slightly moist to moist Alternating colors from black to reddish purple - color changes do not appear to be in clearly defined layers | |
| | | 1 | GB | | | | |
| 5.0 | | | GB | | | | |
| | | 2 | GB | | | | |
| | | 3 | ST | | | Becoming coarse grained at 6.5' | |
| 10.0 | | 4 | GB | | | | |
| | | | GB | | | | |
| | | 5 | GB | | | | |
| 15.0 | | | GB | | | | |
| | | 6 | ST | | | | |
| | | | GB | | ▼ | Becoming wet at 18.0' | |
| 20.0 | | | | | | Becoming slightly coarser grained | |
| | | 7 | GB | | | | |
| | | | GB | | | | |
| 25.0 | | | | | | | |
| | | 8 | GB | | | | |
| | 27.0 | | | | | ALLUVIUM OR CALCINE/ALLUVIUM MIX - Silty Sandy Cobbly GRAVEL (GW-GM) - approximately 50% gravel 35 % sand and 15% silt fines - cobbles to 3.0" or larger - subrounded to subangular - reddish purple color of calcines to approx. 28.0' - dense - becoming alluvium at approx. 28.0' very dark gray - wet | |
| | | | GB | | | | |
| 30.0 | | | | | | | |
| | | 9 | GB | | | | |
| 31.5 | 31.5 | | | | | End of Boring<br>Backfilled with bentonite (13 bags)<br>Boring logged by: A. Jewell<br>Casing: 5.5" I.D. | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388696 | BORING STARTED 10/10/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2267862 | BORING COMPLETED 10/10/11 | ENTERED BY SJH | SHEET NO 1 OF 1 |
| WL 18.0' WD | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

SURFACE ELEVATION +8,830.8 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS/FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1–5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10–50) | STANDARD PENETRATION BLOWS/(FT) (10–50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | GB | | | PDF EMBANKMENT FILL - Silty Sandy GRAVEL (GW) - approximately 50% gravel, 40% sand and 5-10% silt - subrounded to subangular - some scattered clumps with moderate plasticity | | | | 44 |
| | | 1 | GB | | | 3.5 | | | | |
| 5.0 | | | GB | | | FILL - Cobbly Sandy Clayey GRAVEL (GC) - man made debris - approximately 40% sand, 40% gravel and 20% fines - cobbles to 4.0" - dark reddish brown 5YR 3/3 - loose | | | | 7 |
| | | 2 | GB | | | Clumps with up to 40% clay at 6.0-6.5' | | | | |
| | | | GB | | | 7.5 Becomes mixed with calcines at 7.0' | | | | 7 |
| | | 3 | ST | | | FILL - CALCINES - fine sand and silt sized (SM) - approximately 10% fines - reddish purple (no munsell color) - very loose<br>8.0-8.5' - Wet saturated layer - up to 30% silt - low plasticity | | | | |
| 10.0 | | 4 | GB | | | General increase in silt content similar to 8.0-8.5' at 10-12.5' | | | | |
| | | | GB | | | | | | | 1 |
| | | 5 | GB | | ▼ | No representative core sample due to hole cave | | | | |
| 15.0 | | | GB | | | | | | | 2 |
| | | 6 | GB | | | | | | | |
| | | | GB | | | Attempted shelby tube - no recovery - hit rock at 24.0' | | | | |
| 20.0 | | 7 | ST | | | Attempted shelby tube - no recovery - moving to SPT at 25.0'<br>Core bag ripped - no recovery from 20.0-22.5' | | | | |
| | | | GB | | | 23.0<br>ALLUVIUM - Organic Silty SAND (ML-OL) - decayed plant fibers - some medium to coarse angular sand layers - organic smell - very loose to dense - wet | | | | |
| 25.0 | | 8 | GB | | | No core recovery from 25.0-30.0' | | | | 3 |
| | | | GB | | | | | | | |
| 30.0 | | | | | | | | | | 41 |

... continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO 60157757 | SHEET NO 1 OF 2

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: PDF-3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS/FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,830 8 Feet (Continued) | | |
| | | 9 | GB | | | | | |
| 31.5 | | | | | | 31.5 Possible silty sandy cobbly gravel alluvium contact at 31.0' - inferred rock - no rock in tip | | |
| | | | | | | End of Boring<br>Backfilled with bentonite (8 bags)<br>Boring logged by: A. Jewell<br>Casing: 5.5" I.D. | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388223 | BORING STARTED 10/10/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268083 | BORING COMPLETED 10/10/11 | ENTERED BY SJH | SHEET NO 2 OF 2 |
| WL 14.0' WD | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO. 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

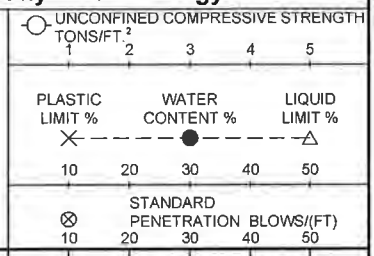
AECOM

| CLIENT | LOG OF BORING NUMBER |
|---|---|
| **Atlantic Richfield Company** | **SSR1** |
| PROJECT NAME | ARCHITECT-ENGINEER |
| **Rico-Argentine Site - OU01** | **Drilling Company: Boart Longyear** |

SITE LOCATION

SURFACE ELEVATION +8,863.5 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS/FT³ |
|---|---|---|---|---|---|---|---|
| | | 1 | SS | | | Gravelly lean CLAY (CL) - angular gravel, cobbles - medium dense - damp - brown (talus) | |
| | | | PA | | | | |
| 5.0 | | | | | | | |
| | | 2 | SS | | | Siltier - dark brown | |
| | | | PA | | | | |
| | | | | | | Flat talus chips | |
| 10.0 | | | | | | | |
| | | | | | | 10.5 Cobbles - boulders | |
| | | 3 | SS | | | Clayey GRAVEL (GC) - angular gravel to cobbles - medium dense - damp - brown | |
| | | | PA | | | | |
| | | | | | | 14.0 Subrounded gravel to cobbles | |
| 15.0 | | | | | | Very Gravelly SILT with Sand (ML) - subrounded gravel, 2" minus - dense - damp - brown | |
| | | 4 | SS | | | 16.0 | |
| | | | | | | Gravelly CLAY with Sand (CL) - subangular gravel, 3" minus - damp - brown (CL) | |
| | | | PA | | | | |
| | | | | | | Cobble/boulder | |
| 20.0 | | | | | | 20.0 Yellow staining | |
| | | 5 | SS | | | Silty GRAVEL with Sand (GM) - subrounded gravel to cobble/boulder - medium dense - damp - brown | |
| | | | | | | 22.0 | |
| | | | | | | ALLUVIUM - Gravelly lean CLAY with Sand (CL) - subrounded gravel to cobble - dense - damp - red-brown | |
| | | | PA | | | | |
| | | | | | | Yellow staining, black staining, angular gravel | |
| 25.0 | | | | | | | |
| | | 6 | SS | | | | |
| | | | | | | Fat clay, less yellow staining, no black staining, less gravel (CH) | |
| | | | PA | | | | |
| 30.0 | | | | | | 30.0 | |
| | | | | | | ..... continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757

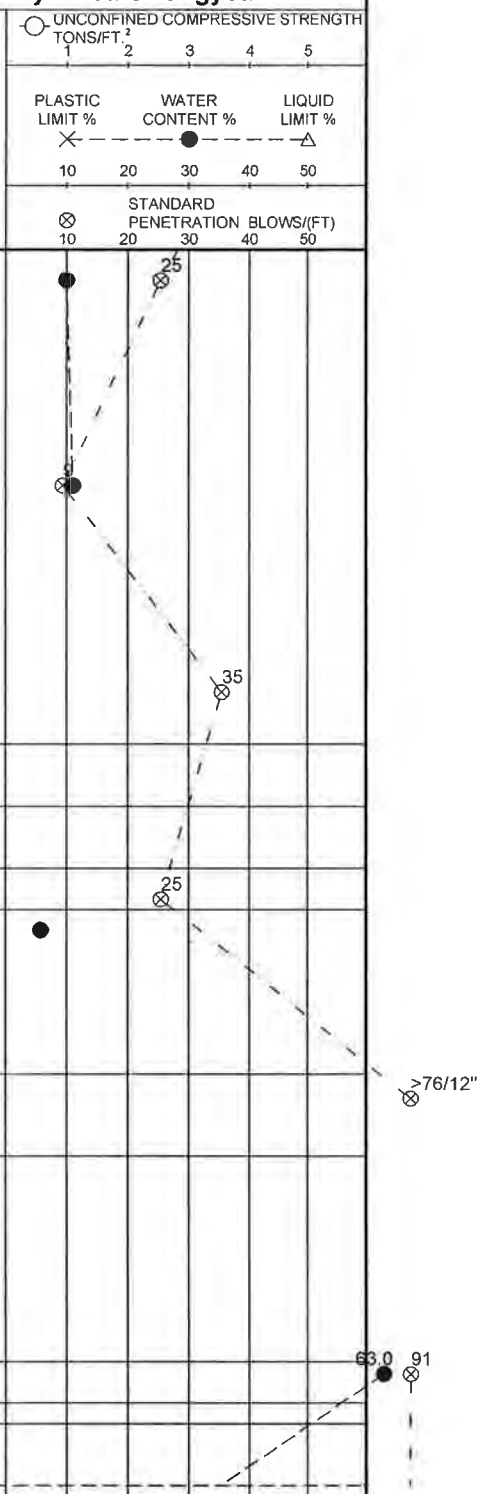
SHEET NO 1 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS/FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,863.5 Feet (Continued) | |
| | | 7 | SS | | | Gravelly CLAY with Sand (CL) - subangular gravel, 4" minus - wet - loose to dense - red-brown - yellow staining around 30.0', plastic (talus) | |
| | | | PA | | | Same with cobbles | |
| | | | | | | Less plastic with boulder | |
| 35.0 | | | | | | | |
| | | 8 | SS | | | | |
| | | | PA | | | Yellow staining | |
| | | | | | | Boulder | |
| 40.0 | | | | | | | |
| | | 9 | SS | | | | |
| | | | PA | | | 42.0 Clayey GRAVEL with coarse Sand (GC) - subangular gravel, few 4" minus cobbles - wet - red-brown - yellow staining | |
| | | | | | | 43.5 ALLUVIUM - Well graded GRAVEL with Sand (GW) - subrounded gravel, 3" minus - grades less sand with cobbles - wet - red-brown | |
| 45.0 | | | | | | 45.0 | |
| | | 10 | SS | | | 46.0 Well graded SAND with Gravel (SW) - subrounded gravel, 1" minus grades with cobbles - wet - medium dense - red-brown - upward fining sequence in shoe | |
| | | | PA | | | Gravelly fat CLAY, few coarse Sand, some angular Gravel (CL) - subrounded gravel and cobbles - wet - red-brown - cobbles are (hermosa SS) | |
| 50.0 | | | | | | 50.0 | |
| | | 11 | SS | | | Clayey GRAVEL with Sand (GC) - subrounded, 4" minus gravel with cobbles - extremely dense - wet - red-brown (talus) | |
| | | | | | | 52.0 Well graded GRAVEL with Sand (GW) - subrounded gravel, 2" minus grades to cobbles with less sand - wet - brown | |
| | | | PA | | | | |
| 55.0 | | | | | | More sand | |
| | | | | | | More cobbles | |
| | | | | | | 57.0 | |
| | | 12 | SS | | | 58.0 ALLUVIUM - Well graded SAND (SW) - extremely dense - wet - red-brown | |
| | | | | | | 58.5 Well graded GRAVEL (GW) - angular, 1" minus - wet - red-brown | |
| 60.0 | | | | | | | |

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The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO. 60157757 | SHEET NO. 2 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

SURFACE ELEVATION +8,863.5 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS /FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | PA | | | Clayey GRAVEL with Sand (GC) - subrounded gravel, 4" minus with cobbles - wet - red-brown With yellow staining | | |
| | | | | | | 62.0 | | |
| | | 13 | SS | | | Silty GRAVEL with Sand (GM) - subrounded gravel/cobbles - extremely dense - wet - red-brown | | >50/6" |
| 65.0 | | | PA | | | Cobble/boulder in bit - recovered 1.0' below cobble and 1.0' above from drill deck | | |
| | | | | | | 67.0 | | |
| | | 14 | SS | | | Poorly graded SAND (SP), very fine to fine - dense - wet - red-brown | | 36 |
| 70.0 | | | PA | | | Grades to medium sand | | |
| | | | | | | 70.5 Grades to coarse sand | | |
| | | | | | | 71.5 Well graded GRAVEL with Clay and Sand (GW-GC) - wet - red-brown - subrounded gravel 2" minus | | |
| | | | | | | Poorly graded SAND (SP) - wet - red brown - very fine to fine 73.0' - Grades to medium sand 73.5' - Grades to coarse sand | | |
| | | | | | | 74.0 | | |
| 75.0 | | 15 | SS | | | 75.0 Well graded GRAVEL with Sand, coarse Sand, trace Silt (GW) - subangular to subrounded gravel, 2" minus - medium dense - wet - red-brown | | 15 |
| | | | PA | | | 76.0 Well graded SAND with Gravel, trace Silt (SW-SM) - subrounded gravel, 3" minus - wet - red-brown | | |
| | | | | | | 77.0 Very fine Silty SAND (SM) - wet - red-brown | | |
| | | 16 | SS | | | Well graded SAND (SW) - grades fine to coarse - some rounded gravel, 1"minus - wet - red-brown - saturated - clean | | |
| | | | | | | 79.0 | | |
| 80.0 | | | PA | | | 80.0 Poorly graded coarse SAND (SP) - wet - red-brown | | |
| | | | | | | 81.0 Well graded Sandy GRAVEL, trace Silt (GW) - rounded, 2" minus - wet - red-brown (GW) | | |
| | | 17 | SS | | | Well graded SAND, minimal fine Sand (SW) - grades coarser with rounded gravel, 1" minus - wet - red-brown - clean | | |
| 85.0 | | | PA | | | Color change in matrix to dark gray brown | | |
| | | | | | | 87.0 | | >50/3" |
| | | 18 | SS | | | Poorly graded SAND (SP) - grades fine to coarse - wet - red-brown | | |
| | | | | | | 88.0 | | |
| | | | | | | 88.5 Well graded GRAVEL with Sand (GW) - 2" minus gravel - wet - red-brown (talus) | | |
| 90.0 | | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 3 OF 4

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR1 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,863.5 Feet (Continued) | | | | |
| | | | PA | | | Well graded SAND, minimal fine Sand (SW) - rounded grains - saturated - dark gray-brown<br>Fine sand, red-brown - saturated<br>Dark gray-brown with cobbles | | | | |
| | | 19 | SS | | | | | | | |
| | | | | | | 94.0 | | | | |
| 95.0 | | | | | | Well graded GRAVEL with Sand (GW) - subrounded gravel-cobble - wet - gray-brown | | | | |
| | | | | | | 95.5 | | | | |
| | | | | | | Poorly graded SAND with Silt, very fine Sand (SP-SM) - wet - gray-brown (SP-SM) | | | | |
| | | | | | | 97.5 | | | | |
| | | | | | | Poorly graded SAND, fine Sand (SP) - wet - gray-brown | | | | |
| 100.0 | | | | | | 100.0 | | | | |
| | | | | | | End of Boring.<br>Boring logged by: S. Johnston<br>Casing: 7.0" I.D. | | | | |

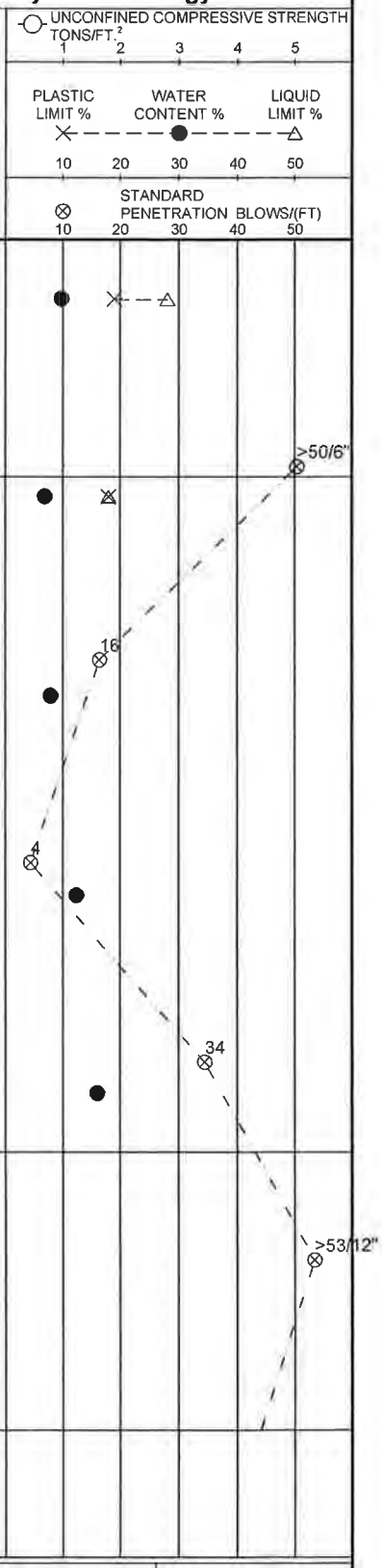
The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING 1388874 | BORING STARTED 10/9/11 | AECOM OFFICE Denver | |
| EASTING 2268226 | BORING COMPLETED 10/10/11 | ENTERED BY SJH | SHEET NO. 4 OF 4 |
| WL 44.0' WD | RIG/FOREMAN SONIC C600/ | APP'D BY EED | AECOM JOB NO 60157757 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR2 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS/FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,850.3 Feet | |
| | | 1 | SS | | | Clayey SILT with angular Gravel (ML) - extremely dense - dry - brown (talus) | |
| | | | PA | | | | |
| 5.0 | | | | | | | |
| | | 2 | SS | | | 6.0 Lean CLAY with angular Gravel and cobbles 5" minus (CL) - loose to dense - dry - brown | |
| | | | PA | | | | |
| 10.0 | | | | | | | |
| | | 3 | SS | | | | |
| | | | PA | | | | |
| 15.0 | | | | | | | |
| | | 4 | SS | | | Cobble/boulder | |
| | | | PA | | | | |
| 20.0 | | | | | | | |
| | | 5 | SS | | | | |
| | | | PA | | | SS cobble/boulder 23.0 POSSIBLE ALLUVIAL FAN DEPOSIT? - CLAY with Gravel (CL) - extremely dense - damp - red-brown with dark brown staining | |
| 25.0 | | | | | | | |
| | | 6 | SS | | | | |
| | | | PA | | | 12" boulder | |
| 30.0 | | | | | | Angular gravel/cobble 4" minus 30.0 | |
| | | | | | | ... continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO. 60157757 | SHEET NO 1 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR2 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS/FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,850.3 Feet (Continued) | | | | |
| | | 7 | SS | | | Gravelly CLAY (CL) - talus - very moist - brown - medium-high plasticity (possibly CH) | | | | 42 |
| | | | PA | | | Cobble/boulder | | | | |
| 35.0 | | | | | | 35.0 | | | | |
| | | 8 | SS | | | Clayey GRAVEL with Sand (GC) - extremely dense - wet - brown | | | | >50/6" |
| | | | | | | 36.5 | | | | |
| | | | PA | | | Silty GRAVEL with Sand (GM) - extremely dense - wet - brown | | | | |
| | | | | | | Cobble/boulder 6" plus | | | | |
| 40.0 | | | | | | Saturated | | | | |
| | | 9 | SS | | | | | | | >50/6" |
| | | | | | | 43.0 | | | | |
| | | | PA | | | ALLUVIUM - Well graded SAND with Gravel (SW) - subrounded gravel-cobble 4" minus - wet - red-brown | | | | |
| | | | | | | 44.0 | | | | |
| 45.0 | | | | | | Well graded Sandy GRAVEL (GW) - subrounded gravel-cobble 5" minus - wet - red-brown | | | | |
| | | | | | | 47.0 | | | | |
| | | 10 | SS | | | Gravelly CLAY with Sand (CL) - subangular to subrounded gravel 3" minus - extremely dense - wet - red-brown - trace silt | | | | >50/6" |
| | | | | | | 48.0 | | | | |
| 50.0 | | | PA | | | Well graded GRAVEL with Sand, trace Silt (GW) - subangular to subrounded gravel 3" minus - very dense - wet - red-brown | | | | |
| | | 11 | SS | | | | | | | |
| 55.0 | | | PA | | | Saturated | | | | |
| | | 12 | SS | | | | | | | 50 |
| 60.0 | | | | | | 60.0 | | | | |
| | | | | | | . . . continued | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 2 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR2 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,850.3 Feet (Continued) | | | | |
| | | | PA | | | Silty GRAVEL, with little Sand, trace Clay (GM) - subrounded gravel 3" minus - wet - red-brown - saturated | | | | |
| | | | | | | 62.0 | | | | |
| | | 13 | SS | | | Poorly graded SAND, trace Clay (SP) - very fine to fine - wet - red-brown (SP) | | | ● | |
| | | | | | | 64.0 | | | | |
| | | | | | | Well graded SAND with Gravel, trace Silt (SW) - subrounded gravel 2" minus - wet - red-brown | | | | |
| 65.0 | | | PA | | | 65.0 | | | | |
| | | | | | | Silty GRAVEL with Sand (GM) - subrounded gravel 2" minus - grades to clayey gravel - wet - red-brown | | | | |
| | | | | | | 67.0 | | | | |
| | | 14 | SS | | | Well graded GRAVEL with Silt and Sand (GW-GM) - rounded gravel-cobble 4" minus - very dense - wet - red-brown - saturated | | | | |
| 70.0 | | | PA | | | | | | | |
| | | | | | | 72.0 | | | | |
| | | 15 | SS | | | Poorly graded, fine SAND (SP) - very dense - wet - red-brown - saturated | | | | |
| | | | | | | 73.5 | | | | |
| | | | | | | 74.0 Well graded SAND with Gravel, trace Silt (SW) - wet - red-brown | | | | |
| 75.0 | | | PA | | | Silty GRAVEL with Sand (GM) - rounded gravel-cobble 4" minus - wet - red-brown | | | | |
| | | | | | | 77.0 | | | | |
| | | 16 | SS | | | 77.5 Well graded SAND with Gravel, trace Silt (SW) - subrounded gravel 1" minus - wet - red-brown | | | | |
| | | | | | | Silty GRAVEL with Sand (GM) - subrounded subangular gravel 2" minus - very dense - wet - red brown | | | | |
| 80.0 | | | PA | | | 80.5 | | | | |
| | | | | | | Well graded SAND, trace Gravel (SW) - wet - red-brown | | | | |
| | | | | | | 81.5 | | | | |
| | | | | | | 82.0 Well graded GRAVEL, trace fines or Sand (GW) - subrounded to subangular gravel 2" minus - wet - red-brown | | | | |
| | | 17 | SS | | | Well graded GRAVEL with Sand (GW) - subrounded to rounded gravel 2" minus - extremely dense - wet - red-brown - saturated | | | | |
| 85.0 | | | PA | | | 85.0 | | | | |
| | | | | | | Well graded GRAVEL with Silt and Sand (GW-SM) - rounded gravel-cobbles 4" minus - wet - red-brown - saturated | | | | |
| | | | | | | 87.0 | | | | |
| | | 18 | SS | | | Well graded SAND, few Gravel, trace Silt (SW) - round 1" minus gravel - wet - red-brown | | | | |
| 90.0 | | | | | | 90.0 | | | | |
| | | | | | | ... continued | | | | |

79

51

62

>95/12"

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual

AECOM JOB NO 60157757 | SHEET NO 3 OF 4

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR2 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,850.3 Feet (Continued) | |
| | | | PA | | | Well graded SAND with Gravel (SW) - rounded 2" minus gravel - wet - red-brown | |
| | | 19 | SS | | | | |
| | | | | | | 94.0 | |
| 95.0 | | | | | | Poorly graded fine SAND with Silt (SP-SM) - few .5" minus gravel - wet - red-brown | |
| | | | | | | 96.0 | |
| | | | PA | | | Poorly graded SAND (SP) - few .5" minus gravel - wet - red-brown | |
| 100.0 | | | | | | 100.0 | |
| | | | | | | End of Boring<br>Drilled from 87.0' to 100.0' with no SPT<br>Boring logged by: S. Johnston<br>Casing: 7.0" I.D. | |

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1, 2, 3, 4, 5)

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % (10, 20, 30, 40, 50)

STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50)

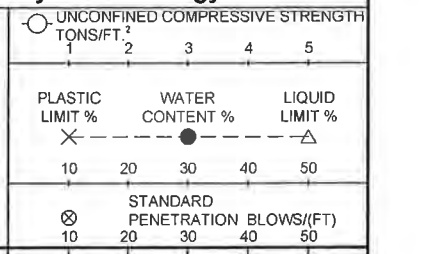
The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388666 | BORING STARTED 10/7/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268236 | BORING COMPLETED 10/9/11 | ENTERED BY SJH | SHEET NO. 4 OF 4 |
| WL 35.5' WD | RIG/FOREMAN SONIC C600/ | APP'D BY EED | AECOM JOB NO. 60157757 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS/FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,849.3 Feet | |
| | | 1 | SS | | | 0.5 CONCRETE pad<br>Well graded GRAVEL with Clay and Sand (GW-GC) - subangular to subrounded 3" minus gravel - wet - brown | |
| | | | PA | | | 2.5 Well graded GRAVEL with Sand (GW) - angular to rounded gravel-cobbles 6" minus - medium dense - dry - brown | |
| 5.0 | | 2 | SS | | | | |
| | | | PA | | | 7.0 Damp<br>Gravelly CLAY with Sand (GC) - subangular gravel - cobble 4" minus - damp - brown | |
| 10.0 | | 3 | SS | | | 10.0 Well graded GRAVEL with Sand (GW) - subangular to rounded - wet - brown - loose - saturated<br>11.0 Gravelly CLAY with Sand (CL) - gravel to cobbles - subangular to subrounded 5" minus - very dense to loose - damp - brown | |
| | | | PA | | | | |
| 15.0 | | 4 | SS | | | | |
| | | | PA | | | | |
| 20.0 | | 5 | SS | | | Less cobbles | |
| | | | PA | | | 23.0 Clayey GRAVEL with Sand (GC) - gravel to cobbles - subangular to subrounded 5" minus - very dense to medium dense - damp - brown | |
| 25.0 | | 6 | SS | | | | |
| | | | PA | | | | |
| 30.0 | | | | | | ... continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 1 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1–5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10–50) | STANDARD PENETRATION BLOWS/(FT) (10–50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,849.3 Feet (Continued) | | | | |
| | | 7 | SS | | | Clayey GRAVEL with Sand (GC) - gravel to cobbles - subangular to subrounded 5" minus - very dense to medium dense - damp - brown | | | | 26 |
| | | | PA | | | 32.0 Well graded GRAVEL with Sand (GW) - subangular to subrounded gravel 3" minus - wet - brown | | | | |
| 35.0 | | 8 | SS | | | Many cobbles | | | | |
| | | | PA | | | 37.0 | | | | |
| | | 9 | SS | | | Well graded GRAVEL with Clay and Sand (GW-GC) - subangular gravel/cobbles/boulders - extremely dense to very dense - wet - brown | | | | >106/12" |
| 40.0 | | | PA | | | *NOTE: 4" clast of fine grain well graded SAND (SW) damp, dark red (maroon), cohesive. Possibly spent ore. | | | | 50 |
| | | 10 | SS | | | Same from SPT without SW clast | | | | |
| 45.0 | | | PA | | | Saturated | | | | |
| | | 11 | SS | | | Color change to red-brown with cobble/boulder | | | | >50/4" |
| 50.0 | | | PA | | | | | | | |
| | | 12 | SS | | | Many cobbles | | | | |
| | | | PA | | | 52.0 | | | | |
| | | 13 | SS | | | Well graded GRAVEL with Sand (GW) - subangular to subrounded gravel to cobbles - wet - red-brown 53.0 | | | | |
| | | | | | | Poorly graded SAND (SP) - medium grain - wet - red-brown - saturated 54.5 | | | | |
| 55.0 | | | PA | | | Well graded GRAVEL with Sand, trace Silt (GW) - subrounded gravel - cobble 6" minus - wet - red-brown | | | | |
| | | | | | | Casing advanced with auger to 58.0' 58.0 | | | | |
| | | 14 | SS | | | Poorly graded very fine SAND (SP) - wet - red-brown - saturated Grades to medium | | | | 56 |
| 60.0 | | | | | | | | | | |

. . . continued

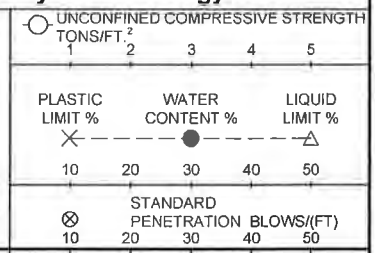
The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 2 OF 4

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,849.3 Feet (Continued) | |
| | | | PA | | | Poorly graded very fine SAND (SP) - wet - red-brown - saturated | |
| | | | | | | 61.5 Grades to coarse sand/gravel subrounded-rounded 1" minus gravel | |
| | | | | | | 62.5 Well graded SAND (SW), no fine sand, medium to coarse sand subrounded - very dense - wet - brown | |
| | | 15 | SS | | | 63.0 Well graded GRAVEL (GW) - subangular to subrounded - wet - brown - saturated | |
| | | | | | | 64.0 Clayey GRAVEL with Sand (GC) - subangular to subrounded 1" minus - damp - brown with yellow mottling | |
| 65.0 | | | PA | | | Poorly graded very fine SAND (SP) - wet - brown - saturated | |
| | | | | | | Grades to medium then coarse sand/gravel | |
| | | 16 | SS | | | 67.5 Grades fine to coarse in the SPT shoe | |
| | | | | | | 68.5 Well graded SAND with Gravel (SW) - gravel could be broken cobble in shoe - very dense - wet - brown | |
| | | | | | | 69.5 Poorly graded SAND (SP) - grades fine to coarse - wet - brown - saturated | |
| 70.0 | | | PA | | | 70.5 Well graded GRAVEL with Sand, trace Silt (GW) - subrounded 1" minus gravel - wet - brown | |
| | | | | | | Poorly graded SAND (SP) - grades fine to coarse to gravel - dense - wet - brown | |
| | | 17 | SS | | | 73.0 Well graded SAND with Gravel (SW) - rounded 2" minus - wet - brown with yellow mottling | |
| | | | | | | 74.0 Poorly graded SAND (SP) - grades medium to coarse to with gravel rounded 0.5" minus - wet - brown | |
| 75.0 | | | PA | | | 75.5 Well graded GRAVEL with Sand, trace Silt (GW) - subrounded to rounded 1" minus gravel - wet brown | |
| | | | | | | 77.0 Well graded SAND with Gravel, trace Silt (SW) - rounded 1 " minus - wet - brown - dense - saturated | |
| | | 18 | SS | | | | |
| 80.0 | | | PA | | | 80.0 Well graded SAND (SP) - medium grain - wet - brown | |
| | | | | | | 82.0 Well graded GRAVEL with Sand (GW), trace fines - subrounded to rounded gravel - grades 0.5" minus to 2" minus gravel - dense - wet - brown | |
| | | 19 | SS | | | 84.0 Well graded SAND with Gravel (SW) - subrounded to rounded gravel .5" minus - wet - brown | |
| 85.0 | | | PA | | | 86.0 Well graded SAND with Silt and Gravel (SW-SM) - subrounded gravel 2" minus - wet - brown | |
| | | 20 | SS | | | | |
| 90.0 | | | | | | ... continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 3 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR3 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,849.3 Feet (Continued) | |
| | | | PA | | | 90.5 Poorly graded fine SAND (SP) - wet - tan-brown | |
| | | 21 | SS | | | 94.0 | |
| 95.0 | | | PA | | | Poorly graded very fine SAND with Silt (SP-SM) - wet - brown<br>*NOTE: Includes 3" layers of poorly graded very fine sand with clay (SP-SC) 97.0 | |
| | | 22 | SS | | | Poorly graded very fine SAND, trace Silt (SP) - wet - brown | |
| 100.0 | | | PA | | | Gravel-cobbles 4" minus - subangular to subrounded 100.0 | |
| | | | | | | End of Boring<br>Boring logged by: S. Johnston<br>Casing: 7.0" I.D. | |

UNCONFINED COMPRESSIVE STRENGTH TONS/FT² (1, 2, 3, 4, 5)

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % (10, 20, 30, 40, 50)

STANDARD PENETRATION BLOWS/(FT) (10, 20, 30, 40, 50)

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388867 | BORING STARTED 10/10/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268034 | BORING COMPLETED 10/13/11 | ENTERED BY SJH | SHEET NO 4 OF 4 |
| WL 32.0' WD | RIG/FOREMAN SONIC C600/ | APP'D BY EED | AECOM JOB NO 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR4 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839.5 Feet | | |
| | | | GB | | | PDF EMBANKMENT FILL (GW) - Not logged | | |
| | | | | | | 4.0 | | |
| 5.0 | | 1 | GB | | | FILL - Calcines (SM-SP) - sand and silt sized - medium dense to loose | | 24 |
| | | | GB | | | | | |
| 10.0 | | 2 | GB | | | | | 9 |
| | | | GB | | | | | |
| 15.0 | | 3 | GB | | | | | 11 / 14 |
| | | | GB | | | | | |
| 20.0 | | 4 | GB | | | | | 4 |
| | | | GB | | | | | |
| 25.0 | | 5 | GB | | | 25.0 ALLUVIUM - Silty Sandy Cobbly GRAVEL (GW) - subrounded to subangular - cobbles to 3.0" - less than approximately 5-10% silt - very dark gray 7.5YR 3/1 - extremely dense to dense<br>25.0-30.0' - Significant sample loss - log/depth approximate - no sample taken<br><br>Sample 5: Recorded as "51/Driller recalls "refusal"" | | 51/6" |
| | | | GB | | | | | |
| 30.0 | | | | | | 30.0 | | 18/6" |
| | | | | | | ... continued | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

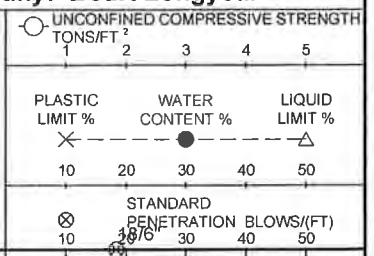
AECOM JOB NO. 60157757 | SHEET NO. 1 OF 3

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR4 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839.5 Feet (Continued) | |
| | | 6 | GB | | | ALLUVIUM - Silty Sandy Cobbly GRAVEL (GW) - subrounded to subangular - cobbles to 3.0" - less than approximately 5-10% silt - very dark gray 7.5YR 3/1 - dense and extremely dense above 50.0' Becoming dark brown 7.5YR 3/4 with cobbles to 4.0" at 30.0' Sample 6: Recorded as "18/Driller recalls "refusal"" | |
| | | | GB | | | | |
| 35.0 | | | | | | | |
| | | 7 | GB | | ▼ | Becomes strong brown 7.5YR 4/6 Sample 7: Recorded as "25/Driller recalls "refusal"" | |
| 40.0 | | | GB | | | Becomes yellowish brown 10YR 4/6 - wet (Approximate depth) | |
| | | 8 | GB | | | | |
| 45.0 | | | GB | | | | |
| | | 9 | GB | | | Significant reduction in max gravel size to 1.0" - well graded - predom. subrounded with subangular - yellowish red 5YR 4/6 - wet | |
| 50.0 | | | GB | | | | |
| | | 10 | GB | | | ALLUVIUM - Gravelly SAND (SW) - subangular to well rounded gravels - weak red 2.5YR 4/2 - wet Driller reports 5.0' heave, cleanout then 5.0' heave (attempting clean out using flapper bit, driller report 3.0' heave) Skipping to 57.0' Sample 10: Driller lost sample on surface - reports "all same stuff" | |
| 55.0 | | | GB | | | | |
| | | 11 | GB | | | Loose condition may be due to blow-in from ground water | |
| 60.0 | | | GB | | | 60.0 | |




. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 2 OF 3

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **SSR4** |
|---|---|---|
| | PROJECT NAME<br>**Rico-Argentine Site - OU01** | ARCHITECT-ENGINEER<br>**Drilling Company: Boart Longyear** |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² 1 2 3 4 5 | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % 10 20 30 40 50 | STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839 5 Feet (Continued) | | | | |
| | | | | | | End of Boring<br>Boring logged by: R. Anderson (0.0-42.0')/Interpreted by A. Jewell, A. Jewell (42.0-60.0')<br>Casing: 5.5" I.D. | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

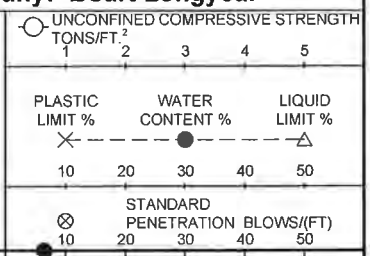
| | | | |
|---|---|---|---|
| NORTHING **1388644** | BORING STARTED **10/13/11** | AECOM OFFICE **Denver** | |
| EASTING **2268005** | BORING COMPLETED **10/13/11** | ENTERED BY **SJH** | SHEET NO. **3** OF **3** |
| WL **38.0' WD Estimated** | RIG/FOREMAN **PROSONIC 800T/** | APP'D BY **EED** | AECOM JOB NO. **60157757** |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR5 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS/FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,832.3 Feet | |
| | | | GB | | | PDF EMBANKMENT FILL - Silty Sandy GRAVEL (GW) - approximately 60% gravel to 2.0" or larger, 30% sand and 10% silt fines - predom. subrounded, also subangular to well rounded - brown 7.5YR 4/4 - moist | |
| | | | | | | 4.0 | |
| 5.0 | | 1 | GB | | | 5.0 FILL - Wasterock - Clayey Sandy GRAVEL (GC) - chunks of highly altered rock forming residual clayey sands - approximately 40 % gravel, 35% sand and 25% clay - well rounded to subangular gravels to 2.0" or larger - various colors, dark reddish brown 2.5YR 3/4, very dark grayish brown 10YR 3/2 and yellowish brown 10YR 5/8 - moist | |
| | | | GB | | | 8.0 FILL - Process waste? and manmade debris (cables) - Clayey Gravelly SAND (SM) - approximately 50 % sand, 30% low plastic clay and 20% gravel - subangular to subrounded gravel to 2.0" or larger - reddish black 10YR 2.5/1 - medium dense - moist | |
| 10.0 | | 2 | GB | | | | |
| | | 3 | ST | | | FILL - Calcines - fine sand and silt sized (SM) - reddish purple to purplish black (no munsell) - moist - loose to very loose<br>11.5-13.5' - Attempted shelby tube - no recovery | |
| | | | GB | | | | |
| 15.0 | | 4 | GB | | ▼ | Becoming wet<br>Higher silt content from 15.0-17.5' | |
| | | | GB | | | Lower silt content, wet and coarser sand sized from 18.0-20.0' | |
| 20.0 | | 5 | GB | | | | |
| | | | GB | | | | |
| 25.0 | | | | | | 25.5 | |
| | | 6 | GB | | | COLLUVIUM/POSSIBLE WASTEROCK - Clayey Sandy Cobbly GRAVEL (GC) - approximately 40% gravel, 35 % sand and 25% clay - cobbles to 5.0" or larger - predom. subangular to angular - fragments predom. greenstone - clay moderately plastic - very dark gray 7.5YR 3/1 - extremely dense - moist | |
| | | | GB | | | | |
| 30.0 | | | | | | 30.0 29.5' - Becomes wet - clay fines approx. 15% (GW-GC) | |
| | | 7 | GB | | | POSSIBLE ALLUVIUM - Clayey Sandy Cobbly GRAVEL (GC) - approximately 40% gravel, 35 % sand and 25% clay - cobbles to 5.0" or larger - predom. subangular to angular - fragments predom. greenstone - clay moderately plastic - very dark gray 7.5YR 3/1 - extremely dense - moist<br>Becomes dark brown 7.5YR 3/2 at 30.0' | |
| | | | GB | | | | |
| 35.0 | | | | | | | |

... continued




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

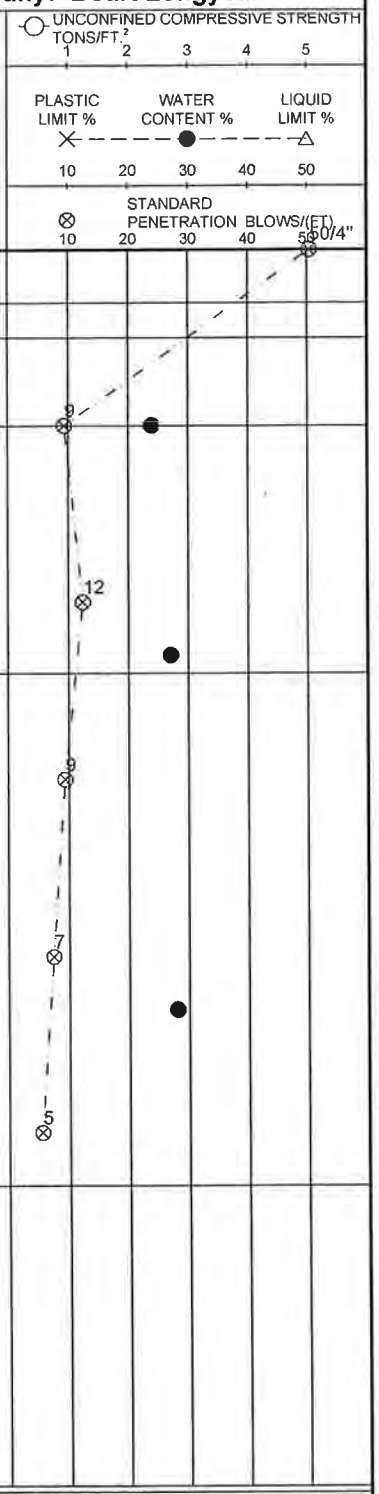
AECOM JOB NO 60157757 | SHEET NO 1 OF 2

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR5 |
|---|---|---|
| | PROJECT NAME: Rico-Argentine Site - OU01 | ARCHITECT-ENGINEER: Drilling Company: Boart Longyear |

SITE LOCATION

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,832.3 Feet (Continued) | |
| | | 8 | GB | | | 34.0' - Becomes dark yellowish brown 10YR 3/4 - silt fines approx. 15% (GM) | |
| | | | | | | 36.5 ALLUVIUM - Silty fine SAND with Gravel (SM) - gap graded - dark yellowish brown 10YR 4/6 - moist | |
| | | | GB | | | 37.5 ALLUVIUM - Silty Sandy GRAVEL (GM) - approximately 50% gravel to 2.0" or larger, 35% sand and 15% silt fines - well graded - subrounded to angular - dark yellowish brown 10YR 4/6 - loose - wet | |
| 40.0 | | | | | | 40.0 Silty SAND (SP) - silt <5% - well graded - scattered gravel to 1.5" - gravel content approx. <5% - predom fine to medium grained sand with subrounded coarse grains - dark yellowish brown 10YR 3/6 - loose to medium dense Dark brown from 40.5-42.0' | |
| | | 9 | GB | | | | |
| | | | GB | | | | |
| 45.0 | | | | | | Gravel content decreases substantially | |
| | | 10 | GB | | | | |
| | | | | | | 47.0 Fine SAND (SP) - silt <5% - weak red 2.5YR 4/2 - loose - wet | |
| | | | GB | | | Driller reports 4.0' heave - pushing casing and cleaning out with flapper bit - may account for lower N values | |
| 50.0 | | | | | | | |
| | | 11 | GB | | | | |
| | | | GB | | | Includes 10-15% silt fines from 52.0-54.0' (SM) | |
| 55.0 | | | | | | | |
| | | 12 | GB | | | Silt content increasing slightly (SP) | |
| | | | GB | | | | |
| 60.0 | | | | | | | |
| | | 13 | GB | | | | |
| 61.5 | | | | | | 61.5 End of Boring<br>Boring logged by: A. Jewell<br>Casing: 5.5" I.D. | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388408 | BORING STARTED 10/12/11 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268067 | BORING COMPLETED 10/13/11 | ENTERED BY SJH | SHEET NO 2 OF 2 |
| WL 15.5' WD | RIG/FOREMAN MINI-SONIC C100/D. Cerventes | APP'D BY EED | AECOM JOB NO 60157757 |

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,845.4 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 1 | SS | | | FILL: Well graded gravel, some fine to coarse sand, little silt/clay - dark brown 7.5YR3/2 - medium dense to dense - moist (FILL: GC) NOTE: Cobbles noted at 1.5 ft | |
| | | | RB | | | | |
| | | 2 | SS | | | | |
| 5.0 | | | RB | | | 5.0 | |
| | | 3 | SS | | | FILL: Well graded sand, some fine to coarse gravel, some silt and clay - brown 10YR4/3 - medium dense - moist (FILL: SC) | |
| | | | RB | | | 7.0 | |
| | | 4 | SS | | | FILL: Well graded gravel, some fine to coarse sand, little silt and clay - very pale brown 10YR8/3 - loose - moist (FILL: GM) | |
| 10.0 | | | RB | | | 10.0 | |
| | | 5 | SS | | | FILL (MINE WASTE ROCK): Well graded gravel and fine to coarse sand, some silt/clay, with pyrite flecks - oxidized colors, grays to red browns grading to mostly yellow 2.5Y7/6 with oxidized zones - dense to loose- moist (FILL: GM - MINE WASTE ROCK) | |
| | | | RB | | | | |
| | | 6 | SS | | | | |
| 15.0 | | | RB | | | | |
| | | 7 | SS | | | | |
| | | | RB | | | | |
| | | 8 | SS | | | | |
| 20.0 | | | RB | | | | |
| | | 9 | SS | | | | |
| | | | RB | | | 23.0 | |
| | | | | | | FILL: Well graded gravel and sand, trace silt/clay - yellowish brown 10YR5/4 - loose - moist (FILL: GW-GM) | |
| 25.0 | | 10 | SS | | | | |
| | | | RB | | | | |
| | | 11 | SS | | | 28.0 | |
| | | 11B | SS | | | 28.5 FILL: Poorly graded gravel and sand, little silt/clay, trace organics - 40% fine gravel, 38% fine to coarse sand, 14% to 22% silt/clay - dark | |
| | | 11C | SS | | | | |
| 30.0 | | | | | | | |

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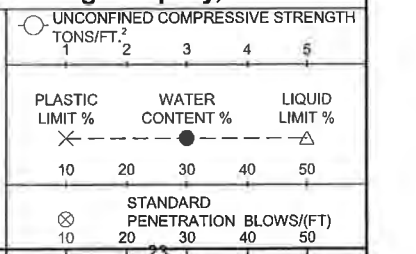



The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 6

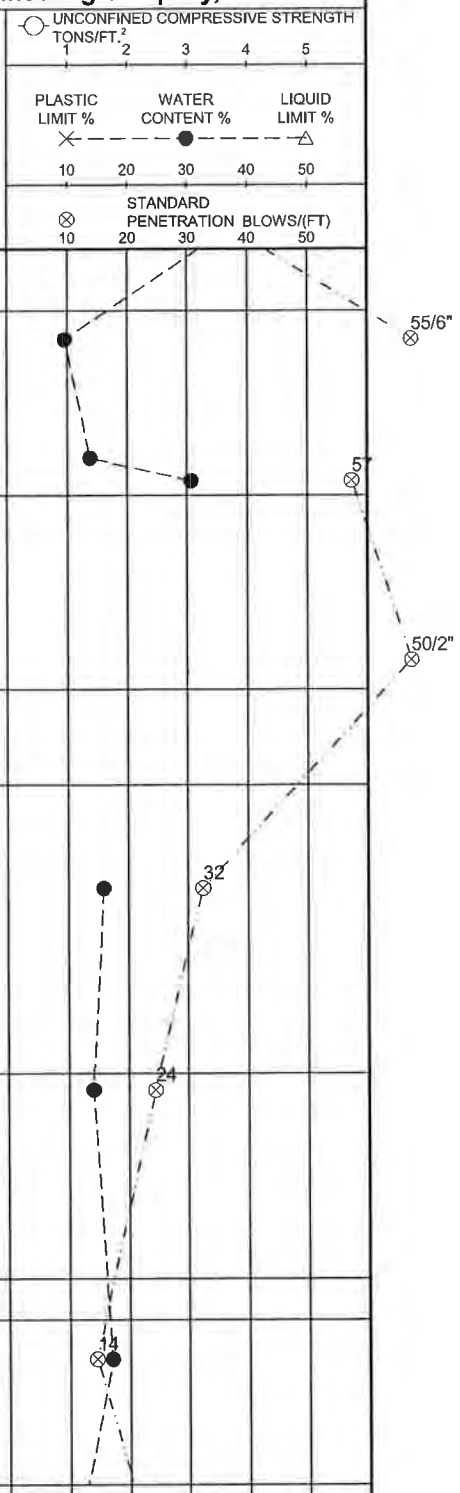
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,845.4 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | RB | | | brown 10YR3/3 - loose - wet (FILL: GM) | |
| | | | | | | 31.5 Organic sandy silt (possible old topsoil), some fine to coarse sand, trace wood fragments, trace roots and fibrous plant material - black 10YR2/1 - stiff - moist (ML-OL) (LOI = 23.1%) | |
| | | 12 | SS | | | | |
| | | | RB | | | Well graded sand and fine to coarse gravel, little silt and clay - very dark grayish brown 2.5Y3/2 with zones of brown, variable color - extremely dense - moist (SM) | |
| 35.0 | | 13 | SS | | | | |
| | | 13A | SS | | | 36.0 35.2' to 35.5' Slightly organic clayey sand - very dark grayish brown 2.5Y3/2 - very dense - wet (SC) | |
| | | | | | | Gravel/Cobble/Boulder | |
| | | | RB | | | | |
| 40.0 | | | | | | | |
| | | 14 | SS | | | 40.7 | |
| | | | | | | Boulder | |
| | | | RB | | | 43.0 | |
| | | | | | | Poorly graded sand, some fine to coarse gravel, little silt and clay, with gravel seams - dark grayish brown 10YR3/4 - dense - wet (SM) | |
| 45.0 | | | | | | | |
| | | 15 | SS | | | | |
| | | | RB | | | | |
| 50.0 | | | | | | 50.0 | |
| | | 16 | SS | | | Poorly graded gravel and fine to coarse sand, trace silt, with seams of less gravel and more sand- reddish brown 5Y4/4 - medium dense - wet (GP-GM) | |
| | | | RB | | | | |
| 55.0 | | | | | | 55.0 | |
| | | | RB | | | Boulder 56.0 | |
| | | 17 | SS | | | Poorly graded sand, little fine gravel, trace silt - dark brown 7.5Y3/2 - medium dense - wet (SP-SM) | |
| | | | RB | | | | |
| 60.0 | | | | | | 60.0 | |

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The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

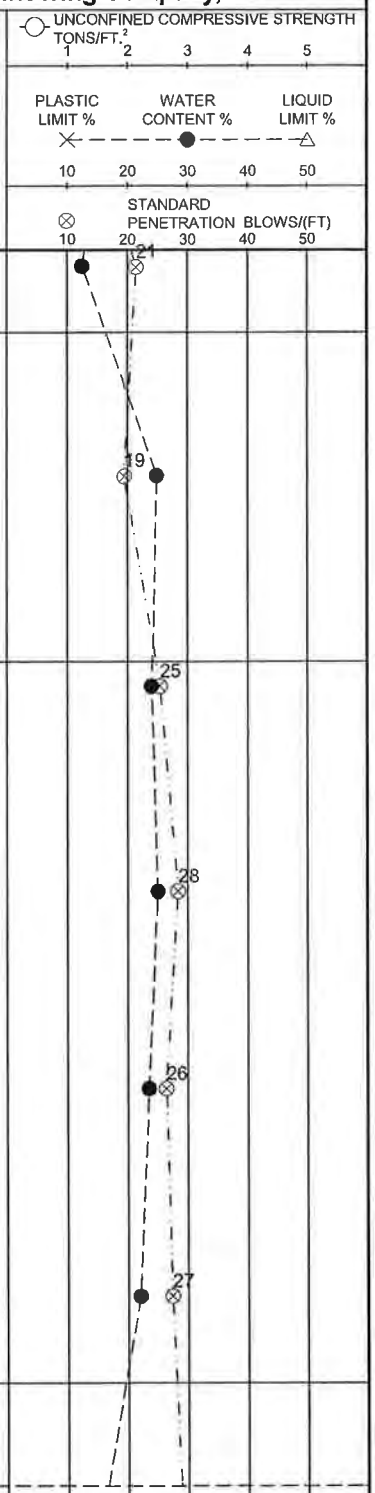
AECOM JOB NO. 60239818 | SHEET NO. 2 OF 6

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,845.4 Feet (Continued) | |
| | | 18 | SS | | | Well graded sand, some fine to coarse gravel, trace silt - dark brown 7.5Y3/2 - medium dense - wet (SW-SM) | |
| | | | | | | 62.0 | |
| | | | RB | | | Poorly graded very fine sand, little silt - dark reddish gray 5YR4/2 - medium dense - wet (SM) | |
| 65.0 | | | | | | | |
| | | 19 | SS | | | | |
| | | | RB | | | | |
| 70.0 | | | | | | 70.0 | |
| | | 20 | SS | | | Fine sand, trace silt - reddish brown 5YR grading to brown 7.5Y4/2 - medium dense - wet (SP) | |
| | | | RB | | | | |
| 75.0 | | | | | | | |
| | | 21 | SS | | | | |
| | | | RB | | | | |
| 80.0 | | | | | | | |
| | | 22 | SS | | | | |
| | | | RB | | | | |
| 85.0 | | | | | | | |
| | | 23 | SS | | | | |
| | | | | | | 87.5 | |
| | | | RB | | | Poorly graded fine to medium sand, trace silt, some fine to coarse subrounded gravel - brown 7.5Y4/2 - medium dense - wet (SP) | |
| 90.0 | | | | | | | |

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The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 3 OF 6

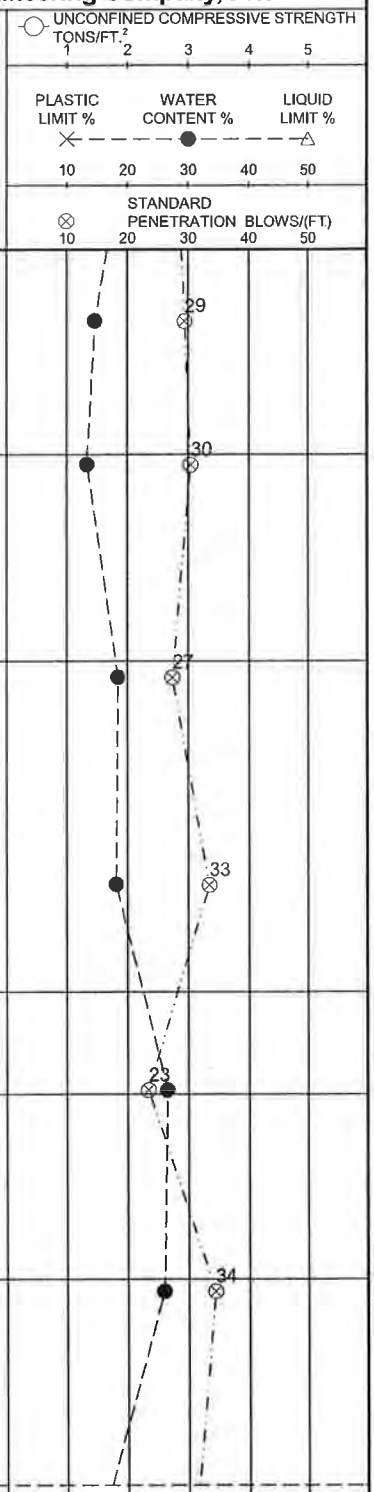
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,845.4 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 24 | SS | | | Poorly graded fine to medium sand, trace silt, some fine to coarse subrounded gravel - brown 7.5Y4/2 - medium dense - wet (SP) | |
| | | | RB | | | | |
| 95.0 | | | | | | 95.0 Poorly graded fine to medium sand, little gravel, little silt and clay - dark brown 10YR3/3 - dense - wet (SM) | |
| | | 25 | SS | | | | |
| | | | RB | | | | |
| 100.0 | | | | | | 100.0 Fine to coarse sand, trace fine gravel, trace silt - brown 7.5Y4/4 - medium dense to dense - wet (SP) | |
| | | 26 | SS | | | | |
| | | | RB | | | | |
| 105.0 | | | | | | | |
| | | 27 | SS | | | | |
| | | | RB | | | 108.0 Poorly graded very fine sand, some silt - reddish brown 5YR4/3 - loose - wet (SM) | |
| 110.0 | | | | | | 110.5 Fat clay, high plasticity, laminated (CH) | |
| | | 28 | SS | | | | |
| | | | RB | | | | |
| 115.0 | | | | | | 115.0 Poorly graded fine to very fine sand, little silt - brown 10YR5/4 changing to dark grayish brown 2.5Y4/2 - dense - wet (SP-SM) | |
| | | 29 | SS | | | | |
| | | | RB | | | | |
| 120.0 | | | | | | | |

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The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

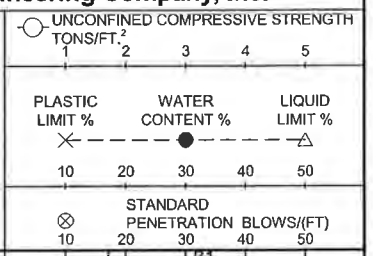
AECOM JOB NO. 60239818 | SHEET NO. 4 OF 6

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,845.4 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 30 | SS | | | Poorly graded fine to very fine sand, little silt - brown 10YR5/4 changing to dark grayish brown 2.5Y4/2 - dense - wet (SP-SM) | |
| | | | RB | | | | |
| 125.0 | | | | | | 125.0 Silt and very fine sand - dark reddish brown 3/3 - dense - wet (ML) | |
| | | 31 | SS | | | | |
| | | | RB | | | | |
| 130.0 | | | | | | 130.5 Silt, fast dilatancy, non-plastic-non-cohesive, bedded to massive bedding, trace fine sand - dark reddish gray 5YR5/2 - dense - wet (ML) | |
| | | 32 | SS | | | | |
| 135.0 | | | RB | | | | |
| | | 33 | SS | | | 137.0 Poorly graded fine to very fine sand, trace silt - brown 7.5Y4/2 - dense - wet (SP) | |
| | | 33A | SS | | | 137.9 | |
| | | | RB | | | 138.5 Poorly graded fine to medium sand, trace fine gravel - very dark grayish brown 2.5Y - dense - wet (SP) | |
| 140.0 | | 34 | SS | | | 138.8 Gravel inferred from drilling resistance | |
| | | | | | | Boulders & weathered slumped sections of Hermosa Sandstone - Colluvium | |
| | | RUN 1 | DB | | | | |
| 145.0 | | | | | | | |
| | | RUN 2 | DB | | | | |
| 150.0 | | | | | | | |

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The stratification lines represent the approximate boundary lines between soil types: In situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 5 OF 6

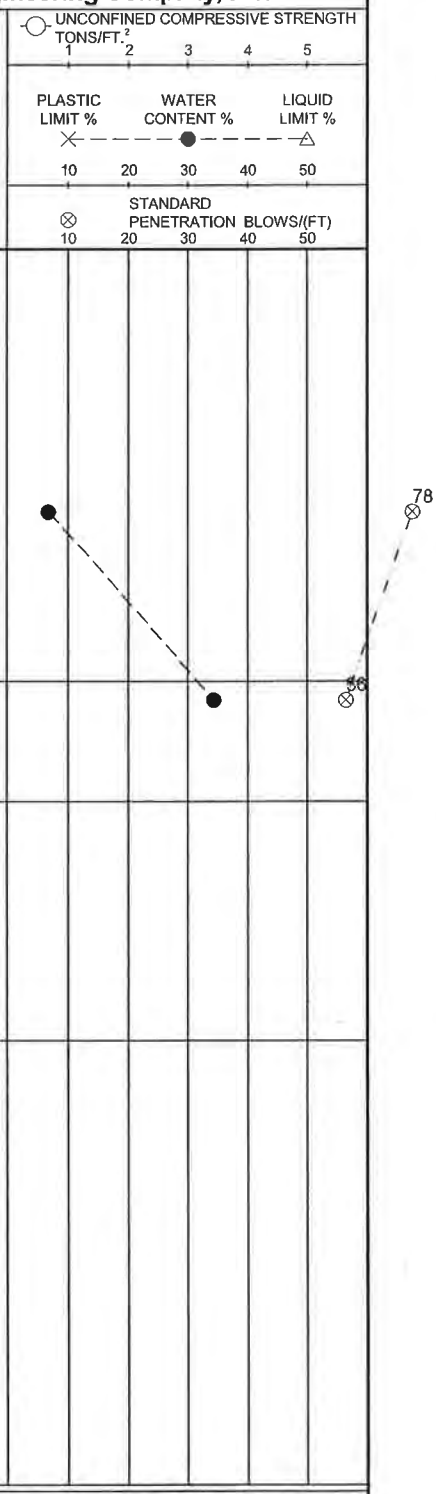
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-101 (MW) DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,845.4 Feet (Continued) | |
| | | | RB | | | Boulders & weathered slumped sections of Hermosa Sandstone - Colluvium | |
| 155.0 | | | | | | | |
| | | 35 | SS | | | | |
| | | | RB | | | | |
| 160.0 | | | | | | | |
| | | | | | | 160.5 | |
| | | 36 | SS | | | Well graded gravel and fine to coarse sand, trace silt - dark brown 7.5YR3/4 - very dense - wet (GW) | |
| | | 37 | WS | | | 163.4 Possible weathered bedrock - Hermosa formation sandstone | |
| 165.0 | | | | | | | |
| | | 38 | WS | | | 166' Hard unfractured rock | |
| | | | RB | | | | |
| 169.2 | | RUN 3 | DB | | | 169.2 | |

End of boring at 169.2 ft. HW casing installed to 162'. Boring advanced to 168.2 feet with roller bit. Boring advanced to 168.2 ft with tricone rock bit. Three attempt to obtain NX rock core, all core runs no recovery. Tremi grouted borehole with high solids bentonite grout to 50 feet. Placed medium bentonite chips from 40' to 50'. Piezometer installed to 37.9 ft.
Note: Sample 37 & 38 WS = rotary wash cutting samples obtained.




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING 1388742.446 | BORING STARTED 10/15/12 | AECOM OFFICE Denver | |
|---|---|---|---|
| EASTING 2268096.74 | BORING COMPLETED 10/24/12 | ENTERED BY AMH | SHEET NO. 6 OF 6 |
| WL W.L. @ 27.8' @ 24 hr A.B. | RIG/FOREMAN Sonic/Kyle King | APP'D BY | AECOM JOB NO. 60239818 |

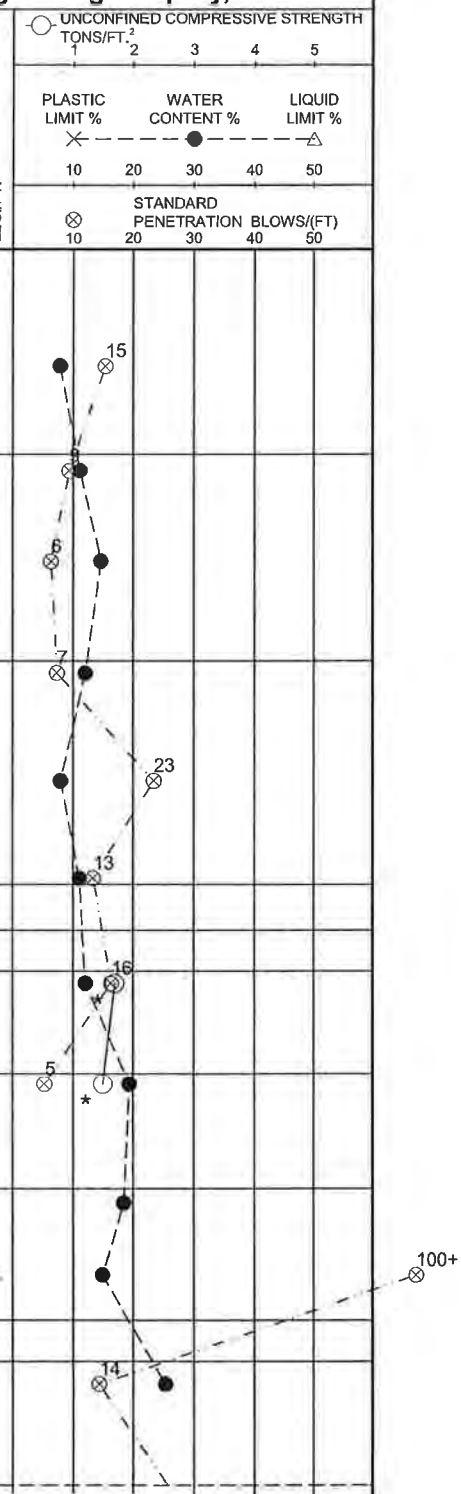
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,839.0 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 1 | AS | | | FILL: Clayey well graded sand, some fine gravel - 26% gravel, 47% sand, 27% fines - brown 10YR5/3 - medium dense - moist (FILL: SC) | |
| | | 2 | SS | | | | |
| 5.0 | | | HSA | | | 5.0 | |
| | | 3 | SS | | | FILL: Clayey gravelly silt, some fine to coarse sand - dark brown 7.5YR3/4 - loose - moist (FILL: ML) | |
| | | | HSA | | | | |
| | | 4 | SS | | | | |
| 10.0 | | | HSA | | | 10.0 | |
| | | 5 | SS | | | FILL: Clayey gravel, some fine to coarse sand - 89% sand and gravel, 11% fines - dark brown 10YR3/3 - loose to medium dense - wet (FILL: GC) | |
| | | | HSA | | | | |
| | | 6 | SS | | | | |
| 15.0 | | | HSA | | | 15.4 | |
| | | 7 | SS | | | Partly organic gravelly clay (possible buried topsoil), low plasticity - black - medium dense - moist (GC) | |
| | | | HSA | | | 16.5 Cobbles and gravel 17.5 | |
| | | 8 | SS | | | Silt, little coarse sand, little gravel, non-plastic - dark brown 10YR3/4 - stiff (CL) | |
| 20.0 | | | HSA | | | 20.0 | |
| | | 9 | SS | | | Lean clay, some fine to coarse gravel, little fine to coarse sand - dark brown 10YR3/4 - stiff (CL) | |
| | | | HSA | | | 22.8 | |
| | | 10 | ST | | | Well graded gravel, some fine to coarse sand, little silt and clay - dark grayish brown 10YR4/2 - extremely dense - wet (GC-GM) | 109 |
| 25.0 | | 11 | SS | | | 26.0 | |
| | | | HSA | | | Cobble 27.0 | |
| | | 12 | SS | | | Well graded gravel, some fine to coarse sand, little silt and clay - dark grayish brown 10YR4/2 - medium dense - wet (GC-GM) | |
| 30.0 | | | | | | | |




. . . continued

* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 6

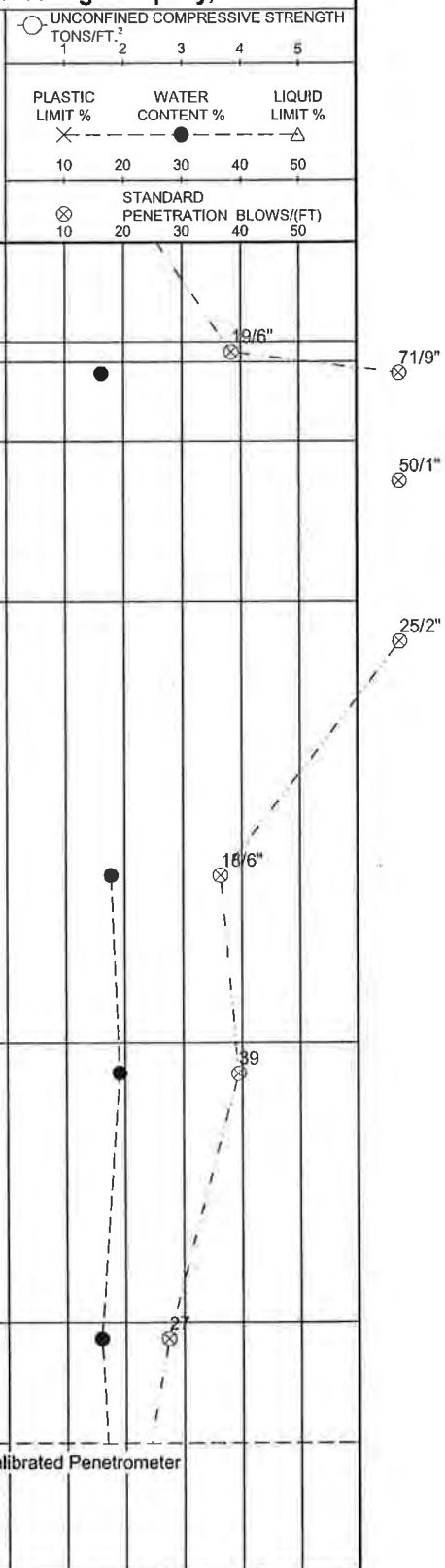
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,839.0 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | RB | | | Well graded gravel, some fine to coarse sand, little silt and clay - dark grayish brown 10YR4/2 - medium dense - wet (GC-GM) | |
| | 32.5 | | | | | | |
| | | 13 | SS | | | 33.0 Possible FILL: Well graded gravel with silt and fine to coarse sand size rock fragments - dark red 2.5Y3/6 - extremely dense - wet (GC-GM) | |
| | | 13A | SS | | | | |
| 35.0 | | | RB | | | 35.0 Silty fine to coarse sand and gravel - 35% gravel, 35% sand, 30% fines - dark yellowish brown 10YR3/4 - extremely dense - wet (SM-GM) | |
| | | | HS | | | | |
| | | 14 | SS | | | Boulders/cobbles - fine to coarse sand and gravel fragments in wash cuttings<br>NOTE: Boring SSR-102 ended at 35'. See Notes below. | |
| | | | RB | | | | |
| | 39.0 | | | | | | |
| 40.0 | | 15 | SS | | | Well graded sand, some fine to coarse gravel, little silt and clay - dark yellowish brown 10YR4/4 - dense - wet (SM) | |
| | | | RB | | | | |
| 45.0 | | | | | | | |
| | | 16 | SS | | | | |
| | | | RB | | | | |
| 50.0 | 50.0 | | | | | | |
| | | 17 | SS | | | Well graded sand, some fine to coarse gravel, little silt and clay (19.1%) - dark yellowish brown 10YR4/4 - dense - wet (SM) | |
| 55.0 | | | RB | | | | |
| | 57.0 | | | | | | |
| | | 18 | SS | | | Poorly graded sand, little silt - 15.9% fines - dark yellowish brown 10YR4/4 - medium dense - wet (SM) | |
| 60.0 | | | RB | | | | |




. . . continued

* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

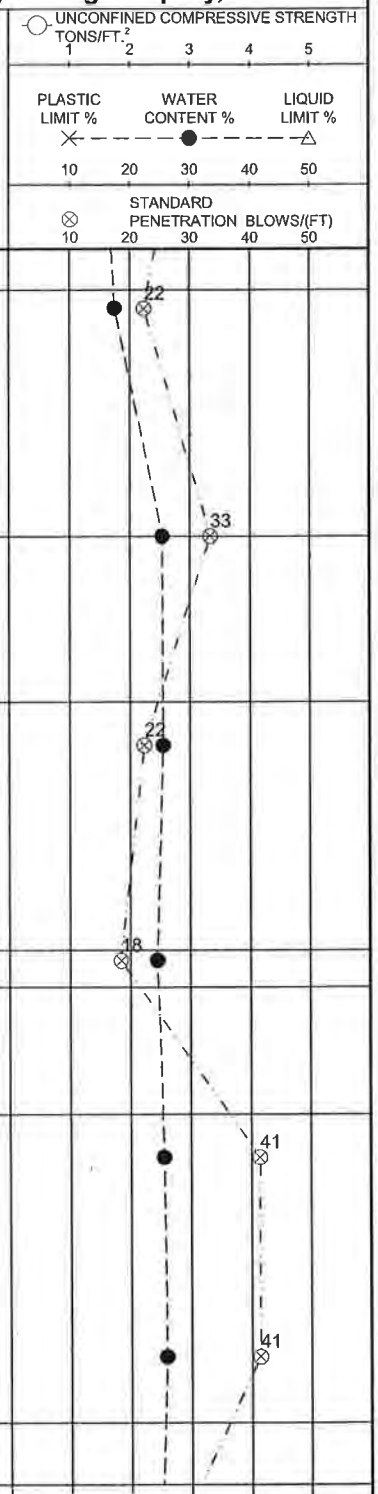
AECOM JOB NO. 60239818 | SHEET NO. 2 OF 6

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839.0 Feet (Continued) | |
| | | | | | | 61.0 | |
| | | 19 | SS | | | Poorly graded fine to coarse sand, little silt and clay (17.5%-25.4%) - dark yellowish brown 10YR4/4 - medium dense - wet (SM) | |
| 65.0 | | | RB | | | | |
| | | | | | | 67.0 | |
| | | 20 | SS | | | Silt with very fine sand in thin bedding seams - brown 7.5Y4/4 - dense - wet (ML-SM) | |
| 70.0 | | | RB | | | | |
| | | | | | | 71.0 | |
| | | 21 | SS | | | Poorly graded fine sand, trace silt - brown 10YR4/3 - medium dense - wet (SP) | |
| 75.0 | | | RB | | | | |
| | | | | | | 77.0 | |
| | | 22 | SS | | | Silt (non-plastic) - brown 7.5Y4/2 - medium dense - wet (ML) | |
| | | | | | | 77.9 | |
| | | | | | | Poorly graded fine sand, trace silt with bedded seams of silt and very fine sand - brown 7.5YR4/2 - wet (SP) | |
| 80.0 | | | RB | | | | |
| | | | | | | 81.0 | |
| | | 23 | SS | | | Thickly bedded to laminated silt (non-plastic), silty clay, clay silt, and fine to very fine sand - 79% fines - slight changes in color from brown clays to red brown silt and sand, brown 7.5YR4/2 - dense - wet (ML) | |
| 85.0 | | | RB | | | | |
| | | 24 | SS | | | | |
| | | | | | | 88.5 | |
| | | | | | | Gravel | |
| 90.0 | | | RB | | | 90.0 | |
| | | | | | | ... continued | |




* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

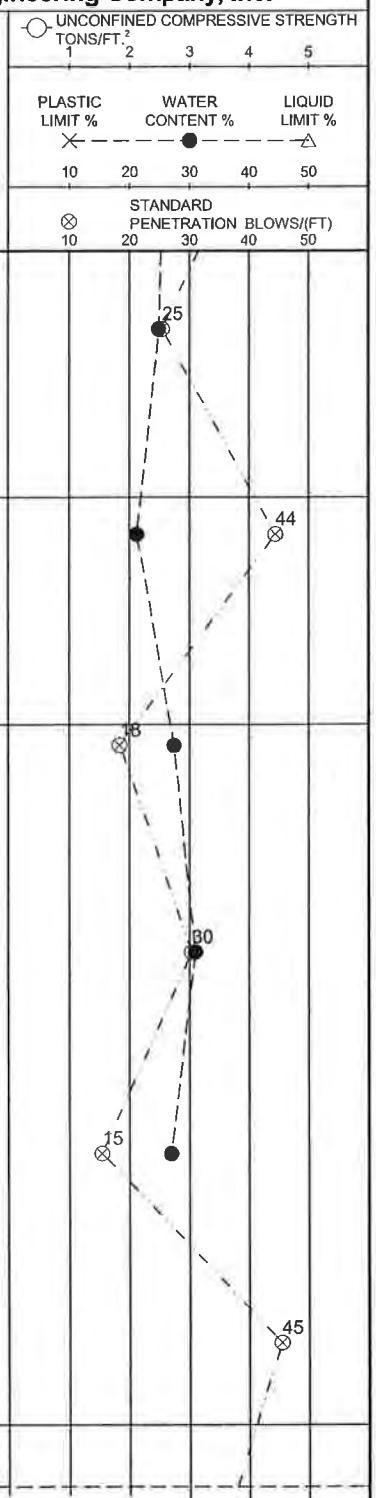
AECOM JOB NO. 60239818 | SHEET NO. 3 OF 6

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839.0 Feet (Continued) | |
| | | | | | | Silt, with seams of very fine sandy silt - 94.6% fines - brown 7.5YR4/2 - medium dense - wet (ML) | |
| | | 25 | SS | | | | |
| 95.0 | | | RB | | | | |
| | | | | | | 96.0 Silt and fine sand - 51.4% fines - brown 7.5YR4/2 - dense - wet (ML) | |
| | | 26 | SS | | | | |
| 100.0 | | | RB | | | | |
| | | | | | | 101.5 Silt (non-plastic) with very fine sand and occasional silty very fine sand seams - 52.5% - 83.2% fines - brown 7.5YR4/2 - medium dense to dense - wet (ML) | |
| | | 27 | SS | | | | |
| 105.0 | | | RB | | | | |
| | | 28 | SS | | | | |
| 110.0 | | | RB | | | | |
| | | 29 | SS | | | | |
| 115.0 | | | RB | | | | |
| | | 30 | SS | | | | |
| | | | | | | 118.5 Well graded sand, some fine to coarse gravel, trace silt - brown 7.5YR4/2 - dense - wet (SW-SM) | |
| 120.0 | | | RB | | | | |
| | | | | | | . . . continued | |




* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 4 OF 6

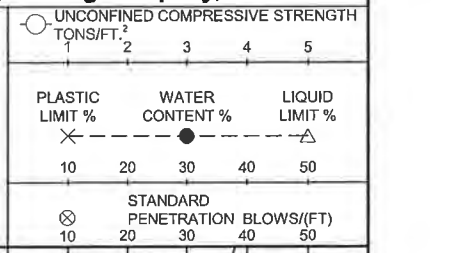
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,839.0 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | | | | | Well graded sand, some fine to coarse gravel, trace silt - brown 7.5YR4/2 - dense - wet (SW-SM) | |
| | | 31 | SS | | | 122.0 | |
| | | 31A | SS | | | Well graded sand and gravel, little silt - 42% gravel, 46% sand, 12% fines - brown 7.5YR4/4 - dense to very dense - wet (SM) | |
| 125.0 | | | RB | | | | |
| | | | | | | 126.0 | |
| | | 32 | SS | | | Fine to coarse sand, silty very fine sand, and silty gravel in 3" layers - very dense - wet (SM) | |
| 130.0 | | | | | | 130.0 | |
| | | | | | | Boulder | |
| | | | | | | 131.0 | |
| | | | RB | | | Well graded gravel with fine to coarse sand, some clay - gray 10YR5//1 - extremely dense - wet (GC) | |
| 135.0 | | | | | | | |
| | | 33 | SS | | | 136.3 | |
| | | | RB | | | Hermosa altered sandstone - very strong - greenish gray with pyrite flecks - fine grained - massive bedding - fresh - competent - moderately fractured, joints and possibly shear clay infilling zone from 141.9'-142.4' RQD = 48.7% poor no drilling fluid loss during core run. | |
| 140.0 | | RUN 1 | DB | | | 141.9 | |
| | | | RB | | | 142.6 Clay with gravel and sand (CH) possible shear clay and or joint infilling | |
| | | | | | | Sandstone - Solid rock noted during drilling | |
| | | 34 | WS | | | | |
| 145.0 | | | | | | Fractured zone noted during drilling Solid rock noted during drilling | |
| | | | RB | | | Fractured zone noted during drilling Solid rock noted during drilling | |
| 150.0 | | | | | | 150.0 | |

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* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 5 OF 6

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-102/102A DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,839.0 Feet (Continued) | | |
| | | | | | | Boring SSR-102 ended at 35 feet due to 4 1/4" ID HSA becoming crooked. Borehole abandoned with bentonite chips. Offset boring SSR-102A performed 5.5 feet south of boring SSR-102. Boring SSR-102A blind drilled to 35 feet. Advanced SSR-102A to a depth of 150.0 feet using a combination of mud rotary with 3 7/8" tricone roller bit & following with HSA in stages as needed to prevent caving. The HSA were set to 115 feet after sampling. Conventional NX size coring was completed from 140.0 to 142.4 feet with 100% recovery of core. NX coring could not be continued in borehole as it was uncased from 115 to 142.4 feet. From 142.4 to 150.0 feet mud rotary with 3 7/8" tricone roller bit was drilled to confirm bedrock. | * Calibrated Penetrometer | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING 1388431.331 | BORING STARTED 11/2/12 | AECOM OFFICE Denver | |
| EASTING 2268226.372 | BORING COMPLETED 11/11/12 | ENTERED BY AMH | SHEET NO. 6 OF 6 |
| WL W.L. @ 22.8' W.D. | RIG/FOREMAN CME-85/Reggie Castro Reggie Castro | APP'D BY | AECOM JOB NO. 60239818 |

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-103 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,909.7 Feet | | |
| | | | | | | Silty gravel with sand - dark yellowish brown 10YR3/4 - very stiff (GM) | | |
| | | 1 | BS | | | | | |
| 5.0 | | | | | | | | |
| | | 1 | BS | | | | | |
| 10.0 | | | | | | | | |
| | | 1 | BS | | | | | |
| 15.0 | | | | | | | | |
| | | 1 | BS | | | | | |
| | | | | | | 17.5 Boulder 18.5 | | |
| 20.0 | | | | | | Sandy clay, little to some gravel, occasional cobbles and boulders, rock clasts predominantly fine-grained altered sandstone - brown 10YR4/3 (CL) | | |
| | | 1 | BS | | | | | |
| 25.0 | | | | | | | | |
| | | 1 | BS | | | | | |
| 30.0 | | | | | | | | |

. . . continued

The stratification lines represent the approximate boundary lines between soil types: In situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 4

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-103 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,909.7 Feet (Continued) | | | | |
| | | 1 | BS | | | Sandy clay, little to some gravel, occasional cobbles and boulders, rock clasts predominantly fine-grained altered sandstone - brown 10YR4/3 (CL) | | | | |
| 35.0 | | | | | | 35.0 | | | | |
| | | 1 | BS | | | Sandstone boulder | | | | |
| | | | | | | 37.0 | | | | |
| | | 2 | BS | | | Gravel size rock fragments, arkosa, shale, sandstone in sandy silty clay matrix, 25% gravel (GC) | | | | |
| 40.0 | | | | | | | | | | |
| | | 2 | BS | | | | | | | |
| 45.0 | | | | | | 45.0 | | | | |
| | | 2 | BS | | | Gravel size rock fragments, arkosa, shale, sandstone in sandy silty clay matrix, 15% gravel (GC) | | | | |
| 50.0 | | | | | | 50.0 | | | | |
| | | 2 | BS | | | Gravel size rock fragments, arkosa, shale, sandstone in sandy silty clay matrix, 30% gravel (GC) | | | | |
| 55.0 | | | | | | 55.0 | | | | |
| | | 2 | BS | | | Sandy silty with 15% rock clasts, deeply weathered rock (ML) | | | | |
| 60.0 | | | | | | 60.0 | | | | |
| | | | | | | . . . continued | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 2 OF 4

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-103 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ (1 2 3 4 5) | PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) | STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,909.7 Feet (Continued) | | | | |
| | | 2 | BS | | | Sandy silt with 20% sand to gravel sized rock clasts (1/4" -2") of sandstone, arkosa, or shale (ML) | | | | |
| 65.0 | | | | | | | | | | |
| | | 2 | BS | | | | | | | |
| 70.0 | | | | | | 70.0 | | | | |
| | | 3 | BS | | | Sandy silt with gravel, 30% rock clasts 1/4"-3" in diameter, predominantly angular to subangular fine gravel, sandstone - moist, with 5% deeply weathered black shale clasts. (ML) | | | | |
| 75.0 | | | | | | | | | | |
| | | 3 | BS | | | | | | | |
| 80.0 | | | | | | 80.0 | | | | |
| | | 3 | BS | | | Sandy silt with gravel, stiff, moist, with 10-15% rock fragments | | | | |
| 85.0 | | | | | | | | | | |
| | | 3 | BS | | | 86.4 | | | | |
| | | | SON | | | Hard consistent drilling in possible hard boulder or bedrock | | | | |
| 90.0 | | | | | | 90.0 | | | | |
| | | | | | | . . . continued | | | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 3 OF 4

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-103 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,909.7 Feet (Continued) | | |
| | | 1 | C | | | Siltstone, dark greenish gray (3/1), closely fractured, hard, moderately strong, slightly weathered. Intensely fractured from 92.0'-95.0' | | |
| | | 2 | C | | | | | |
| 95.0 | | | | | | End of boring @ 95.0'. Boring advanced with sonic drilling methods and roller bit rotary wash techniques to 90.0'. Borehole advanced to 95.0' with double barrel NX core. | | |

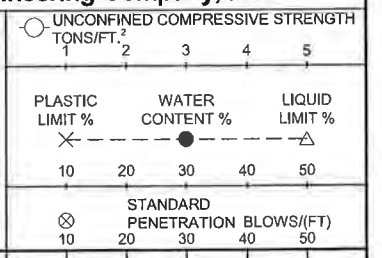
The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| NORTHING | BORING STARTED | AECOM OFFICE | |
|---|---|---|---|
| 1388844.294 | 10/25/12 | Denver | |
| EASTING | BORING COMPLETED | ENTERED BY | SHEET NO. OF |
| 2268406.699 | 10/29/12 | AMH | 4 4 |
| WL | RIG/FOREMAN | APP'D BY | AECOM JOB NO. |
| W.L. @ 9' W.D. | AMS Compact Sonic 10-C/Kyle King | | 60239818 |

| AECOM | CLIENT<br>**Atlantic Richfield Company** | LOG OF BORING NUMBER **SSR-104**<br>**DRAFT** |
|---|---|---|
| | PROJECT NAME<br>**Rico - Argentine Mine Site** | ARCHITECT-ENGINEER<br>**Anderson Engineering Company, Inc.** |

SITE LOCATION
**Rico-Argentine**

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,887.8 Feet | |
| | | 1 | SON | | | Well graded gravel and fine to coarse sand, some silt - brown 7.5YR4/4 - dry (GM) | |
| 5.0 | | 2 | SON | | | | |
| | | 3 | SON | | | 8.0 Well graded gravel, some fine to coarse sand, some clay, with cobbles and possible small boulders - dark brown 10YR3/3 - moist (GC) | |
| 10.0 | | 4 | SON | | | | |
| 15.0 | | | | | | 17.5 | |
| 20.0 | | 1 | SON | | | Well graded gravel with clay, 60% gravel (angular to subrounded), 25% sand, 15% fines, HCL = strong - 2.5Y4/2 (dark grayish brown) (GW-GC) 20.0 | |
| | | 2 | SON | | | Clayey gravel, 35% gravel (angular to subrounded), 30% sand, 25% fines, HCL=strong - 10YR4/3 (brown) (GC) 22.5 | |
| 25.0 | | 3 | SON | | | Well graded gravel with clay, 65% gravel (angular to subrounded), 25% sand, 10% fines, HCL = strong - 10YR4/4 (Dark Yellowish Brown (GW-GC) 25.0 | |
| | | 4 | SON | | | Clayey gravel, 35% gravel (angular to subrounded), 30% sand, 25% fines, HCL=strong - 10YR4/3 (brown) (GC) | |
| 30.0 | | | SON | | | 30.0 | |
| | | | | | | . . . continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 5

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

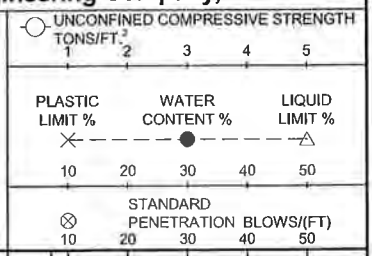
| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-104 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,887.8 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 5 | SON | | | Well graded gravel with clay, 60% gravel (subangular to well rounded), 25% sand, 15% fines, HCL=strong - 2.5Y3/3 (dark olilve brown) (GW-GC) (possible mix with alluvium) | |
| | | 6 | SON | | | | |
| 35.0 | | | | | | 35.0 | |
| | | 7 | SON | | | Well graded gravel with silt, 60% gravel (subangular to well rounded), 30% sand, 10% fines, HCL=strong - 2.5Y4/2 (dark grayish brown) (GW-GM) | |
| 40.0 | | | | | | 40.0 | |
| | | 8 | SON | | | Clayey gravel, 50% gravel (angular to subrounded), 30% sand, 20% fines, HCL=weak - 10YR4/4 (dark yellowish brown) (GC) scattered oxidized rock | |
| 45.0 | | | | | | 44.5 | |
| | | 9 | SON | | | Clayey gravel, 55% gravel (angular to rounded), 30% sand, 25% fines, HCL=strong - 10YR4/2 (dark grayish brown) (GC) | |
| | | 10,11 | SON | | | 48.5 | |
| 50.0 | | | | | | Poorly graded gravel with silt, 70% gravel (subangular to rounded), 20% sand, 10% fines, HCL = strong - 10YR4/3 (brown) (GP-GM) 50.0 | |
| | | 12 | SON | | | Clayey gravel, 55% gravel (angular to rounded), 30% sand, 25% fines, HCL=strong - 10YR4/2 (dark grayish brown) (GC) | |
| | | | | | | 52.5 | |
| | | 13 | SON | | | Poorly graded gravel with silt, 70% gravel (subangular to rounded), 20% sand, 10% fines, HCL = strong - 10YR4/3 (brown) (GP-GM) | |
| 55.0 | | | | | | 55.0 | |
| | | 14,15 | SON | | | Clayey gravel, 55% gravel (angular to rounded), 30% sand, 25% fines, HCL=strong - 10YR4/2 (dark grayish brown) (GC) 56.5 | |
| | | 15 | SON | | | Poorly graded gravel with clay, 70% ravel (angular to subrounded), 20% sand, 10% fines, HCL=strong - 10YR4/3 (brown) (GP-GC) | |
| 60.0 | | | | | | 60.0 | |

. . . continued




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

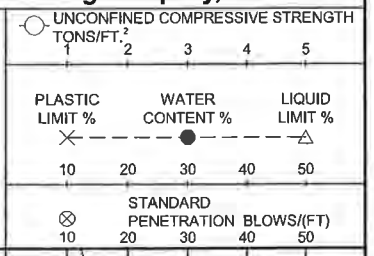
AECOM JOB NO. 60239818 | SHEET NO. 2 OF 5

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-104 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,887.8 Feet (Continued) | |
| | | 16 | SON | | | Well graded gravel with clay, 55% gravel (subangular to rounded), 30% sand, 15% fines, HCL=Weak - 10YR4/3 (brown) (GW-GC) some non-hermosa gravel | |
| | | | | | | 62.5 | |
| | | 17 | SON | | | Poorly graded gravel with clay, 70% ravel (angular to subrounded), 20% sand, 10% fines, HCL=strong - 10YR4/3 (brown) (GP-GC) | |
| 65.0 | | | | | | 65.0 | |
| | | 18 | SON | | | Poorly graded gravel with silt, 70% gravel (angular to subrounded), 25% sand, 5% fines, HCL=strong - 10YR4/2 (dark grayish brown) (GP-GM) (mostly hermosa gravel) | |
| 70.0 | | | | | | 70.0 | |
| | | 19,20 | SON | | | Well graded gravel with silt, 45% gravel (subangular to well rounded), 40% sand, 15% fines, HCL=strong - 10YR4/2 (dark grayish brown) (GW-GM) | |
| | | | | | | 71.5 | |
| | | 20 | SON | | | Well graded gravel with clay, 50% gravel (subangular to well rounded), 35% sand, 15% fines, HCL=N/A - 10YR3/2 (very dark grayish brown) (GW-GC) (scattered oxidized zones) | |
| 75.0 | | | | | | 75.0 | |
| | | 21,22,23 | SON | | | Well graded gravel with clay, 50% gravel (subangular to rounded), 30% sand, 15% fines, HCL=N/A - 2.5Y2.5/1 (black) (GW-GC) (contains organics, red sandstone) | |
| | | | | | | 76.5 | |
| | | | | | | Poorly graded gravel with silt, 75% gravel (subangular to rounded), 20% sand, 5% fines, HCL=N/A - 10YR3/3 (dark grayish brown) (GP-GM) (red sandstone gravels) | |
| | | | | | | 77.5 | |
| 80.0 | | | | | | Well graded gravel with clay, 50% gravel (subangular to rounded), 30% sand, 15% fines, HCL=N/A - 2.5Y2.5/1 (black) (GW-GC) (contains organics, red sandstone) | |
| | | | | | | 81.5 | |
| | | 23 | SON | | | Well graded gravel with silt, 60% gravel (subangular to rounded), 35% sand, 5% fines, HCL=N/A - 10YR4/3 (brown) (GW-GM) | |
| 85.0 | | | | | | 85.0 | |
| | | 24 | SON | | | Poorly graded gravel with silt, 15% gravel (subangular to well rounded), 30% sand, 15% fines, HCL=None - 2.5Y2.5/1 (black) (GP-GC) (decreasing organic content with depth) | |
| | | 24 | SON | | | 89.0 | |
| 90.0 | | | | | | Oxidized/weathered cobbles/boulders (89'-90') | |
| | | | | | | 90.0 | |
| | | | | | | . . . continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 3 OF 5

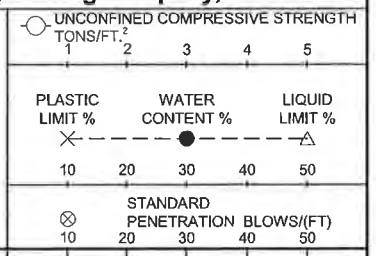
AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-104 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

SURFACE ELEVATION +8,887.8 Feet (Continued)

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | 25 | SON | | | Poorly graded gravel with silt, 15% gravel (subangular to well rounded), 65% sand, 20% fines, HCL=weak - 2.5Y3/2 (very dark grayish brown) (GP-GM) (trace organics, oxidizes brown, decreasing organics with depth) | |
| | | 25,26 | SON | | | 93.0 Poorly graded gravel, 70% gravel (subangular to subrounded), 25% sand, 5% fines, HCL=Strong - (GP) (gradation impacted by drilling red sandstone and weathered hermosa gravels) | |
| 95.0 | | 26 | SON | | | 96.0 Poorly graded gravel with clay, 65% gravel (angular to subrounded), 25% sand, 10% fines, HCL=strong - (GP-GC) mostly hermosa gravels scattered tabular black shale fine gravels) | |
| 100.0 | | 27 | SON | | | 102.0 | |
| | | 28 | SON | | | Clayey gravel, 50% gravel (angular to subrounded), 30% sand, 20% fines, HCL=weak (GC) 104.0 | |
| 105.0 | | RUN 2 | C | | | Siltstone, thinly bedded to laminated, slightly weathered, hard - fair quality, 24 deg inclination, HCL=non, pyrite alterations, 2.5/5GY (grey) (RQD = 70%) 106.5 | |
| 110.0 | | RUN 3 | C | | | Sandstone, thickly bedded, slightly weathered, hard to very hard, moderately to intensely fractured, 24 deg inclination, HCL=None, grey (2.5/5GY) (RQD = 23%) 111.5 | |
| | | RUN 4 | C | | | Sandstone, thickly bedded, slightly weathered, hard to very hard, moderately to intensely fractured, 24 deg inclination, HCL=None, grey (2.5/5GY) (RQD = 40%) 114.5 | |
| 115.0 | | RUN 5 | C | | | Sandstone, thickly bedded, slightly weathered, hard to very hard, moderately to intensely fractured, 24 deg inclination, HCL=None, grey (2.5/5GY) (RQD = 43%) 119.5 | |
| 120.0 | | | | | | | |




. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 4 OF 5

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

| AECOM | CLIENT: Atlantic Richfield Company | LOG OF BORING NUMBER: SSR-104 DRAFT |
|---|---|---|
| | PROJECT NAME: Rico - Argentine Mine Site | ARCHITECT-ENGINEER: Anderson Engineering Company, Inc. |

SITE LOCATION: Rico-Argentine

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ | UNCONFINED COMPRESSIVE STRENGTH TONS/FT.² (1 2 3 4 5) / PLASTIC LIMIT % / WATER CONTENT % / LIQUID LIMIT % (10 20 30 40 50) / STANDARD PENETRATION BLOWS/(FT) (10 20 30 40 50) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,887.8 Feet (Continued) | | |
| | | RUN 6 | C | | | Sandstone, thickly bedded, slightly weathered, hard to very hard, moderately to intensely fractured, 24 deg inclination, HCL=None, grey (2.5/5GY) (RQD = 44%) | | |
| 124.5 | | | | | | 124.5 | | |
| | | | | | | End of boring @ 124.5'. Boring advanced to 104 ft using sonic equipment. Boring advanced to 124.5' with NX core barrel. | | |

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

| | | | |
|---|---|---|---|
| NORTHING 1388530.939 | BORING STARTED 10/30/12 | AECOM OFFICE Denver | |
| EASTING 2268370.687 | BORING COMPLETED 11/4/12 | ENTERED BY AMH | SHEET NO. 5 OF 5 |
| WL None Observed | RIG/FOREMAN AMS Compact Sonic 10-C/Kyle King | APP'D BY | AECOM JOB NO. 60239818 |

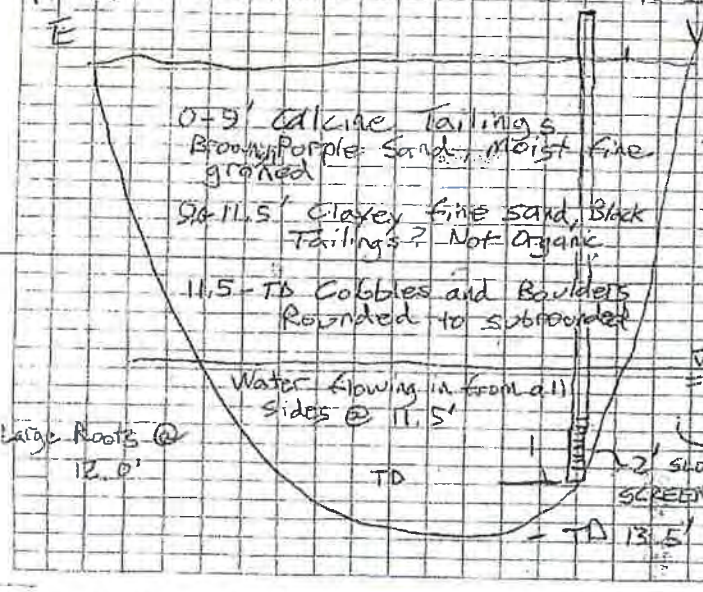
# Test Pit Logs

SEH 2001

TP-A.

2:35 PM

TP-A ~13 Paces N-NE of Stake 18 D

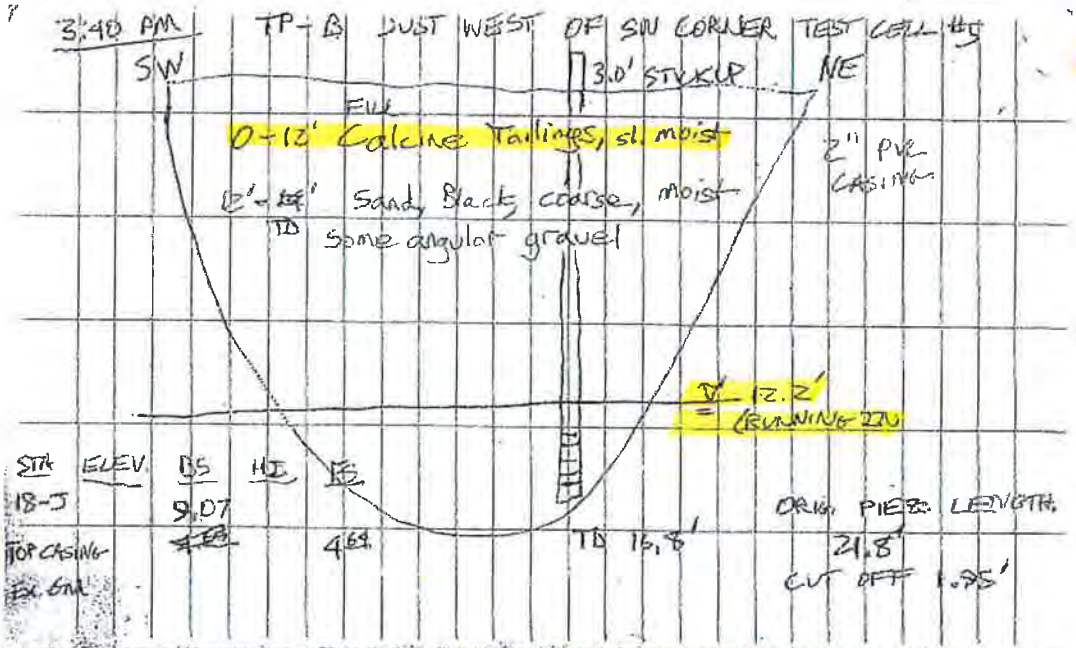



| STA | BS | HI | BS |
|---|---|---|---|
| 18D | 9.15 | | |
| TOP PIEZO | | | 5.36 |
| E.G. | | | 8.10 |

INITIAL PIEZO LENGTH 21.8' CUT OFF 6.85'

TP-B

3:40 PM TP-B DUST WEST OF SW CORNER TEST CELL #5




| STA | ELEV | BS | HI | FS |
|---|---|---|---|---|
| 18-J | | 9.07 | | |
| TOP CASING | | | | 4.69 |
| EX. GND | | | | |

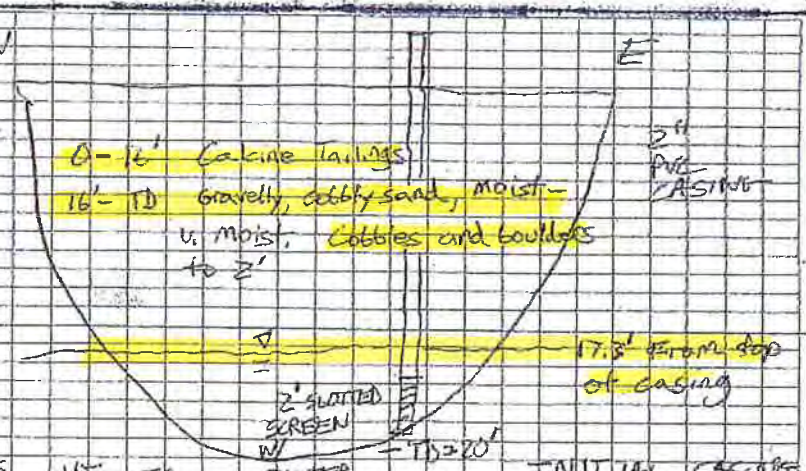
ORIG. PIEZ. LENGTH 21.8' CUT OFF 1.95'

TP-C

4:10 PM

TP-C

54' YARDS DUE EAST OF 18-G HUB NEAR EDGE OF ROAD ~20' S. OF LINE TAR 18-A, 18-G




| STA | ELEV | BS | HI | FS |
|---|---|---|---|---|
| 18-G | | 3.57 | | |
| TOP CASING | | | | 2.50 |
| EX. GND | | | | 5.90 |

INITIAL CASING LENGTH 28.3' CUT OFF 5.13'

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME: Rico CO<br>PROJECT NO: St. Louis Ponds | BORING NUMBER: TP-13 | COORDINATES OR LOCATION: |
| LOGGED BY: KC<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 No water<br>GWL DEPTH ~~(ENCOUNTERED)~~ (STATIC) |
| DRILLING METHOD: Backhoe Test Pit | HOLE DIAMETER: NA / FLUID USED: NA | DATE STARTED: 10-14-08<br>DATE COMPLETED: 10-14-08 |
| CASING TYPE AND SIZE<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S |

| DEPTH (') | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | | | | | Ground Surface | |
| 1.0 | | | | | | Gray Sandy Silt and gravel, Stiff | |
| 1.5 | | | | | | Brown silty sand and gravel | |
| 2.0 | | | | | | | |
| 2.5 | | | | | | | |
| 3.0 | | | | | | Gray Sandy Silt and gravel, Stiff | |
| 3.5 | | | | | | Red Oxidized Tailings | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | | | | | | | |
| 7.5 | | | | | | | |
| 8.0 | | | | | | | |

NOTES

TD= 8.0

1) Test Pit Backfilled + compacted

x - Sample collected, Composit of Material

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: Rico, Co<br>PROJECT NO.: ST COUIS PONDS | BORING NUMBER: TP-14 | COORDINATES OR LOCATION |
| LOGGED BY: [illegible]<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 No water (ENCOUNTERED)<br>GWL DEPTH (STATIC) |
| DRILLING METHOD: BACKHOE TEST PIT | HOLE DIAMETER: PIT / FLUID USED: NA | DATE STARTED 10-10-08<br>DATE COMPLETED: 10-10-08 |
| CASING TYPE AND SIZE: NA<br>SCREEN TYPE AND SIZE: | | FROM ____ A G S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | 0.3 | | | | | Gravel (Aggre Course | |
| 1.0 | | | | | | Red to dark red tailings (calcine) mixed with stained rock & tailings (cream colored) Rock mixed in tailings (2"-14") ~10% rock sandy to silty sand, moist | |
| 1.5 | | | | | | | |
| 2.0 | | | | | | | |
| 2.5 | | | | | | | |
| 3.0 | | | | | | | |
| 3.5 | | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | | | | | | | |
| 7.5 | | | | | | | |
| 8.0 | 7.0 | | | | | | no water |

NOTES

TD= 8.0'

NO WATER

BACKFILLED & COMPACTED

X - SAMPLE collected, Composit of Material

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME: Rico CO<br>PROJECT NO.: St Louis Ponds | BORING NUMBER: TP-15 | COORDINATES OR LOCATION: |
| LOGGED BY: CL<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH: 0 (ENCOUNTERED)<br>GWL DEPTH: (STATIC) |
| DRILLING METHOD: Back hoe Test Pit | HOLE DIAMETER: NA / FLUID USED: NA | DATE STARTED: 10-13-08<br>DATE COMPLETED: 10-13-08 |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5<br>1.0<br>1.5<br>2.0<br>2.5<br>3.0<br>3.5<br>4.0<br>4.5<br>5.0<br>5.5<br>6.0 | (1) | | | | | Light Brown soil, silty Clay with some sand. Large rock (2"-30") ~35-40% rock | |
| 6.5<br>7.0 | 6.2 | | | | | Large rock difficult to dig | no water encountered |

NOTES

TD= 6.2'

1) TP 15 and 16 similar soil profiles

2) Test Pit Backfilled + Compacted

x - Sample collected, Composit of Material

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: RICO CO<br>PROJECT NO.: ST LOUIS PONDS | BORING NUMBER: TP-16 | COORDINATES OR LOCATION: |
| LOGGED BY: [illegible]<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 (ENCOUNTERED)<br>GWL DEPTH NO water for (STATIC) |
| DRILLING METHOD: BACKHOE TEST PIT | HOLE DIAMETER: PIT / FLUID USED: NA | DATE STARTED: 10-13-08<br>DATE COMPLETED: 10-13-08 |
| CASING TYPE AND SIZE: NA<br>SCREEN TYPE AND SIZE: | | FROM ____ A.G.S TO ____ B.G.S<br>FROM ____ TO ____ B.G.S. |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | | | | | Gravel on surface | |
| 1.0 | | | | | | Light Brown soil, silty clay | |
| 1.5 | | | | | | with some sand, large | |
| 2.0 | | | | | | rock (2" to ~48") | |
| 2.5 | | | | | | ~30-35% Rock | |
| 3.0 | | | | | | | |
| 3.5 | (1) | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | 5.4 | | | | | | No water encountered |
| 6.0 | | | | | | Large rocks, very difficult excavation | |

NOTES

TD= 5.4'

1) TP-16 & TP-15 similar soil profiles

2) Test Pit Backfilled & Compacted

1 - Sample collected & Composit of Material

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME: Rico Co<br>PROJECT NO: St Louis Park | BORING NUMBER: TP-17 | COORDINATES OR LOCATION: |
| LOGGED BY: CA<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 No water ~~(ENCOUNTERED)~~<br>GWL DEPTH (STATIC) |
| DRILLING METHOD: Backhoe Test Pit | HOLE DIAMETER: NA / FLUID USED: NA | DATE STARTED: 10-13-08<br>DATE COMPLETED: 10-13-08 |
| CASING TYPE AND SIZE: NA<br>SCREEN TYPE AND SIZE: | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S |

| DEPTH (ft) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | X | | | | Gravel on surface, Brown sandy silt with some clay and gravel and Rock (2" to 14") Rock content 25% | |
| 1.0 | | X | | | | | |
| 1.5 | | X | | | | | |
| 2.0 | | X | | | | | |
| 2.5 | | X | | | | | |
| 3.0 | 2.8 | X | | | | Very Dark Brown silty clay with organic material, little to no rock, soil moist | |
| 3.5 | | X | | | | | |
| 4.0 | 4.0 | X | | | | Brown silty clay with some large rock (6" - 14") ~5% soil moist | |
| 4.5 | | X | | | | | |
| 5.0 | | X | | | | | |
| 5.5 | | X | | | | | |
| 6.0 | | X | | | | | |
| 6.5 | 6.4 | X | | | | | NO WATER ENCOUNTERED |
| 7.0 | | | | | | | |

NOTES

TD= ____

1) Test Pit Back filled & Compacted
2) Sample collected, Composit of Material

TP-17

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME: Rico Co<br>PROJECT NO: St. Louis Ponds | BORING NUMBER: TP-18 | COORDINATES OR LOCATION: |
| LOGGED BY: RC<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH: 0 NO WATER (ENCOUNTERED)<br>GWL DEPTH: (STATIC) |
| DRILLING METHOD: Backhoe Test Pit | HOLE DIAMETER: NA / FLUID USED: NA | DATE STARTED: 10-14-08<br>DATE COMPLETED: 10-14-08 |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | | | | | Brown clayey silt with gravel and cobble (3" - >12" Ø) ~10% rock moist | |
| 1.0 | | | | | | | |
| 1.5 | | | | | | | |
| 2.0 | | | | | | | |
| 2.5 | | | | | | | |
| 3.0 | | | | | | | |
| 3.5 | | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | | | | | | | |

NOTES

TD= 7.0

1) Test Pit Backfilled & Compacted

2. Sample collected, Composit of Material

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME Rico Co<br>PROJECT NO: St. Louis Pond | BORING NUMBER: TP-19 | COORDINATES OR LOCATION |
| LOGGED BY KC<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 (ENCOUNTERED) NO WATER<br>GWL DEPTH (STATIC) |
| DRILLING METHOD: Backhoe Test Pit | HOLE DIAMETER: NA / FLUID USED: N/A | DATE STARTED 10-13-08<br>DATE COMPLETED 10-13-08 |
| CASING TYPE AND SIZE<br>SCREEN TYPE AND SIZE NA | | FROM ____ A.G.S TO ____ B.G.S<br>FROM ____ TO ____ B.G.S NA |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | X | | | | Brown clayey silt with gravel and roots (2 cm / 2), Moist 25-30% roots | |
| 1.0 | | | | | | | |
| 1.5 | | | | | | | |
| 2.0 | | | | | | | |
| 2.5 | | | | | | | |
| 3.0 | | | | | | | |
| 3.5 | | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | 4.4 | | | | | | |
| 5.0 | | | | | | Concrete foundation | refusal |
| 5.5 | | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | | | | | | | |

NOTES

TD= ____

1) Test Pit Back filled & Compacted

X = Sample Collected, Composit of Material

ANDERSON

# BORING LOG

PAGE ____ OF ____

| | | |
|---|---|---|
| PROJECT NAME: Rico Co<br>PROJECT NO: St. Louis Ponds | BORING NUMBER: TP-20 | COORDINATES OR LOCATION: |
| LOGGED BY: KC<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH: D (~~ENCOUNTERED~~)<br>GWL DEPTH: Nearest (STATIC) |
| DRILLING METHOD: Backhoe Test Pit | HOLE DIAMETER: NA / FLUID USED: NA | DATE STARTED: 10-14-08<br>DATE COMPLETED: 10-14-08 |
| CASING TYPE AND SIZE: NA<br>SCREEN TYPE AND SIZE: | | FROM ____ A.G.S TO ____ B.G.S<br>FROM ____ TO ____ B.G.S. |

| DEPTH (') | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | | | | | Brown clayey silt with gravel and some cobbles (6" - 12" ø) 5-10% Rock | |
| 1.0 | | | | | | | |
| 1.5 | | | | | | | |
| 2.0 | | | | | | | |
| 2.5 | | | | | | | |
| 3.0 | | | | | | Cons of Red calcine tailings @ 3' | |
| 3.5 | | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | | | | | | | |
| 7.5 | | | | | | | |

NOTES

TD= 7.5

Piece of Concrete foundation W. end of pit at 2' deep
metal debris found in zone containing the calcine tailings
Test Pit Backfilled & Compacted
V. Sample Collected, Composit of Material

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: Rico Co<br>PROJECT NO.: ST LOUIS PONDS | BORING NUMBER: TP 21 | COORDINATES OR LOCATION |
| LOGGED BY: KC<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH 0 (ENCOUNTERED)<br>GWL DEPTH minute (STATIC) |
| DRILLING METHOD: BACK HOE TEST PIT<br>HOLE DIAMETER: NA<br>FLUID USED: NA | | DATE STARTED: 10-13-08<br>DATE COMPLETED: 10-13-08 |
| CASING TYPE AND SIZE<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S. TO ____ B.G.S. NA<br>FROM ____ TO ____ B.G.S. |

| DEPTH (') | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | | | | | | Brown Silty sand and gravel | |
| 1.0 | 1 | | | | | | |
| 1.5 | | | | | | | |
| 2.0 | 2.0 | | | | | | |
| 2.5 | 2 | | | | | White and yellow crushed rock | |
| 3.0 | 3.0 | | | | | Mine waste (3-6" @) rock w/70% rock | |
| 3.5 | | | | | | Brown Silty sand with gravel | |
| 4.0 | | | | | | and cobbles 10-15% rounded | |
| 4.5 | | | | | | | |
| 5.0 | | | | | | | |
| 5.5 | 3 | | | | | | |
| 6.0 | | | | | | | |
| 6.5 | | | | | | | |
| 7.0 | 7.0 | | | | | TD | No water encountered |
| 7.5 | | | | | | | |

NOTES

TD= 7.0

1) Test Pit Backfilled + Compacted

2) Sample collected, Composit of Material

ANDERSON

# BORING LOG

PAGE 1 OF 1

| | | |
|---|---|---|
| PROJECT NAME: Rico, Co<br>PROJECT NO: St Louis Ponds | BORING NUMBER: TP-22 | COORDINATES OR LOCATION: |
| LOGGED BY: KC/CS<br>CHECKED BY: | SURFACE ELEVATION: | GWL DEPTH: 0 no water (ENCOUNTERED)<br>GWL DEPTH: (STATIC) |
| DRILLING METHOD: Back hoe Test Pit<br>HOLE DIAMETER: NA<br>FLUID USED: NA | | DATE STARTED: 10-13-08<br>DATE COMPLETED: 10-13-08 |
| CASING TYPE AND SIZE:<br>SCREEN TYPE AND SIZE: NA | | FROM ____ A.G.S TO ____ B.G.S.<br>FROM ____ TO ____ B.G.S. NA |

| DEPTH ( ) | SAMPLE TYPE AND NUMBER | SAMPLE DEPTH INTERVAL | BLOW COUNT | RECOVERY LENGTH (%) | PROFILE | DESCRIPTION | WELL CONSTRUCTION SUMMARY |
|---|---|---|---|---|---|---|---|
| 0.5 | 1 | X | | | | Crushed stone and solidified Red Sandy tailings - estuine | |
| 1.0 | 1.0 | | | | | | |
| 1.5 | 2 | X | | | | Orange Silty Sand with gravel & cobbles - mine waste | |
| 2.0 | 2.0 | | | | | | |
| 2.5 | 3 | X | | | | Brown silty sand with gravel and cobbles | |
| 3.0 | | | | | | | |
| 3.5 | | | | | | | |
| 4.0 | | | | | | | |
| 4.5 | | | | | | | |
| 5.0 | 5.0 | | | | | | |
| 5.5 | | | | | | TD | Large rocks, could not remove - refusal |
| 6.0 | | | | | | | No water encountered |
| 6.5 | | | | | | | |

NOTES

TD= 5.0

1) Steel pipe in trench, running N/S at 1.2' deep. Pipe 9" Ø

2) Test Pit Back Filled + Compacted

x - Sample collected, Composite of Material

TP-2004D

TP-2004D
0.0-1.5' TOPSOIL
1.5-6.0' COLLUVIUM
SILTY GRAVELLY SAND,
DARK REDDISH BROWN (3/4),
SLIGHTLY MOIST, LOOSE,
BOULDERS TO 1.0', SUBROUNDED
TO SUB ANGULAR. ESTIMATE
5-10% > 2"

TP-2004E

TP-2004E
N. OF POND 18 IN CALCINE
TAILINGS
0'-9.0' Calcine Tailings
9.0-12.0' RIVER COBBLES
WATER @ 8.0'

TP-2004F

TP-2004F
EAST OF POND 18
0-0.5' FILL
0.5-12.0' CALCINE TAILINGS

TP-2004G

TP-2004G
EAST OF POND 18
0-0.5 FILL
0.5-12.0' Calcine tailings

TP-2004 H
POND 16/17
0-4.0' FILL
4.0'-12.0' Calcine tailing
GW@ 11.0'

TP-2004 H

TP-2004 I
POND 16-17
0-12.0' Calcine Tailings
~~GW~~ GW@ 12.0'

3 SAMPLES EACH PIT

TP-2004 I

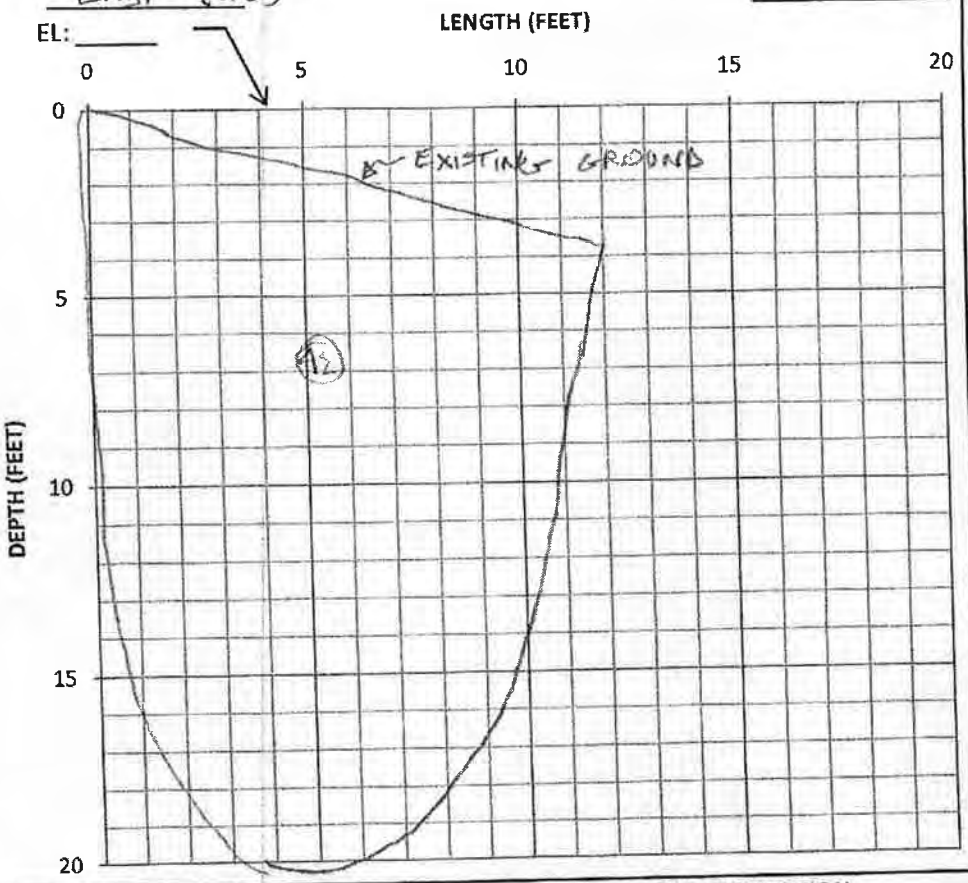
# TEST PIT LOG

| | |
|---|---|
| PROJECT: Rico St. Louis Ponds | DATE: 23 SEP 11 |
| NO: | LOGGED BY: ACJ |
| TEST PIT # | TP2011-17 |
| WEATHER: SUNNY, 65°F | EXCAVATION METHOD: |
| LOCATION: SOUTH STACKED REPOS, N. END | |

Start Time: 12:30PM End Time: _____ Note: _____

EAST (HOE) WEST

EL: _____




NOTES/SAMPLES

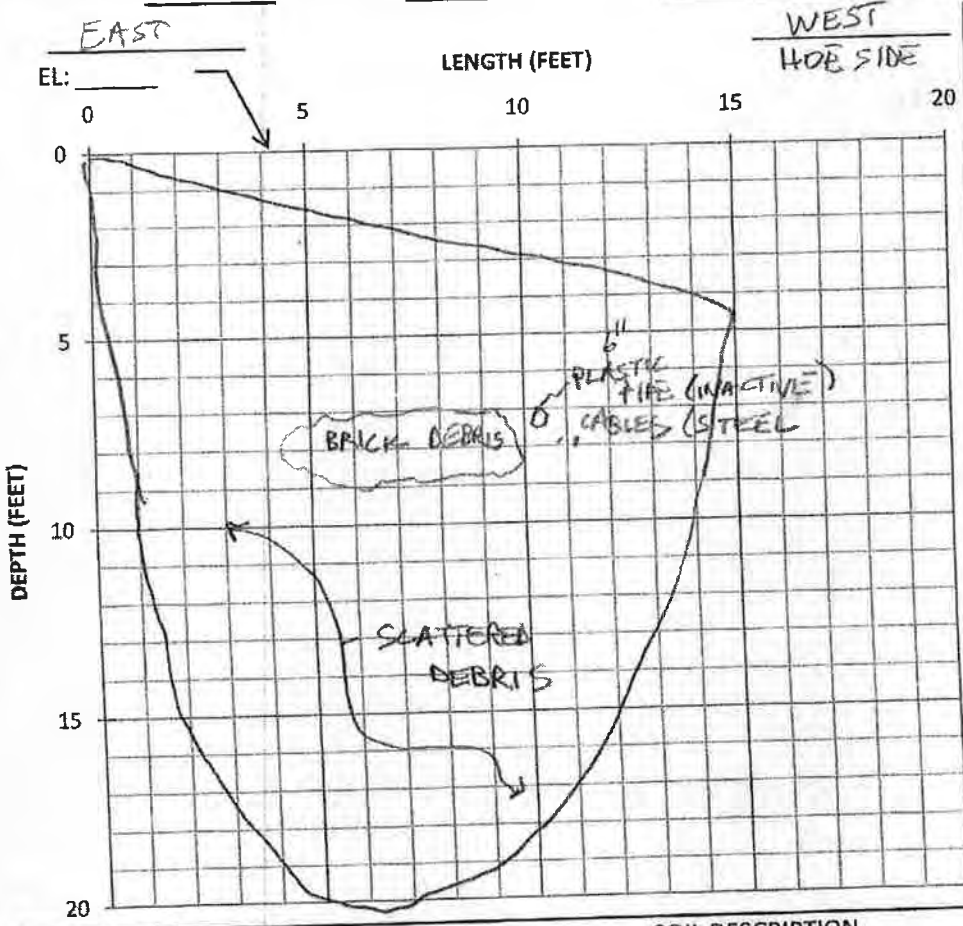
- HOE SWITCHING TO WEST END OF PIT @ ~8'
- 2 5GAL BUCKETS MAT 42 3" - ONLY
- FREQUENT SLOUGHING OF HOLE (SEE PHOTOS FOR EXTENTS

| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| 1<br>42 | COLLUVIUM OR POSSIBLE FILL<br>CLAYEY SANDY GRAVEL, MOIST, 10YR 3/3 DARK BROWN, BOULDERS TO 18", ~3% BOULDERS, ~[illegible]% COBBLES, ~30% GRAVEL, ~30% SAND, ~25% CLAY FINES, FINES MOD PLASTIC, PREDOM. SUBANGULAR TO ANGULAR GRAVEL/COBBLES, WITH SCATTERED SUBROUNDED, MOD. HARD TO HARD ROCK, PROBABLE HERMOSA FM DERIVED. BELOW ~8', ALTERNATING LAYERS OF HIGHER COBBLE AND BOULDER CONTENT (SEE PHOTOS). |

# TEST PIT LOG

| | |
|---|---|
| PROJECT: Rico St. Louis Ponds | DATE: 23 SEP 11 |
| NO: | LOGGED BY: ACJ |
| TEST PIT # | TP 2011-18 |
| WEATHER: 65°F SUNNY | EXCAVATION METHOD: |
| LOCATION: SOUTH STACKED NE PDS, MIDDLE | |

Start Time: 1:30 AM End Time: 2:05 AM Note:




NOTES/SAMPLES

2 5 GAL BUCKETS
0-20'
MAT (43)

| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| (42) (43) | COLLUVIUM/~~FILL~~ COLLUVIUM OVER FILL, SAME AS MAT (42), EXCEPT FOR DEBRIS AS NOTED, 24" MAX BOULDER SIZE, WHITE IN PHOTOS IS DISINTEGRATED BRICK |

# TEST PIT LOG

TEST PIT # TP2011-19

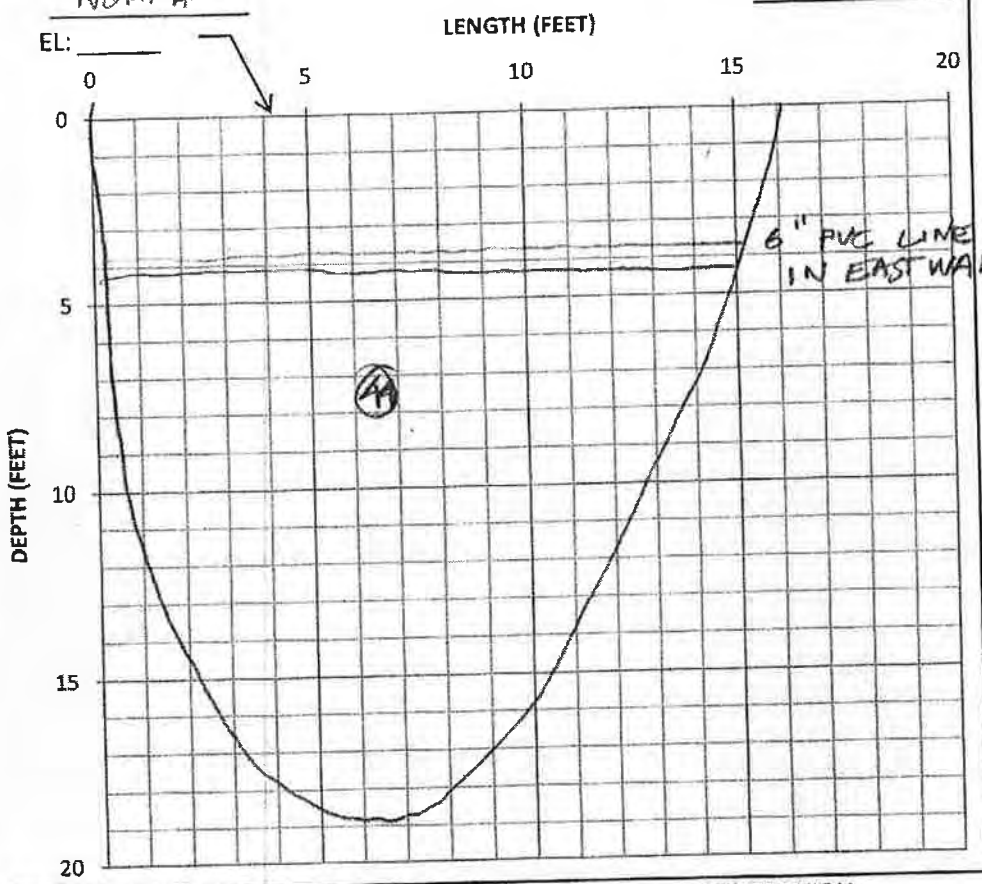
PROJECT: Rico St. Louis Ponds
NO:
DATE: 23 SEP 11
LOGGED BY: ACJ

WEATHER:
EXCAVATION METHOD:
LOCATION: SOUTH STACKED RESTORY, SOUTH SIDE, ON ROAD

Start Time: 2:35 PM End Time: 3:15PM Note:

NORTH SOUTH

EL:




NOTES/SAMPLES

2 5 GAL BUCKETS. 0'-20' MAT 4A

| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| 1 | FILL, |

TP 2013-8

# TEST PIT LOG

TEST PIT # ~~2013-~~ ~~SSR-1~~

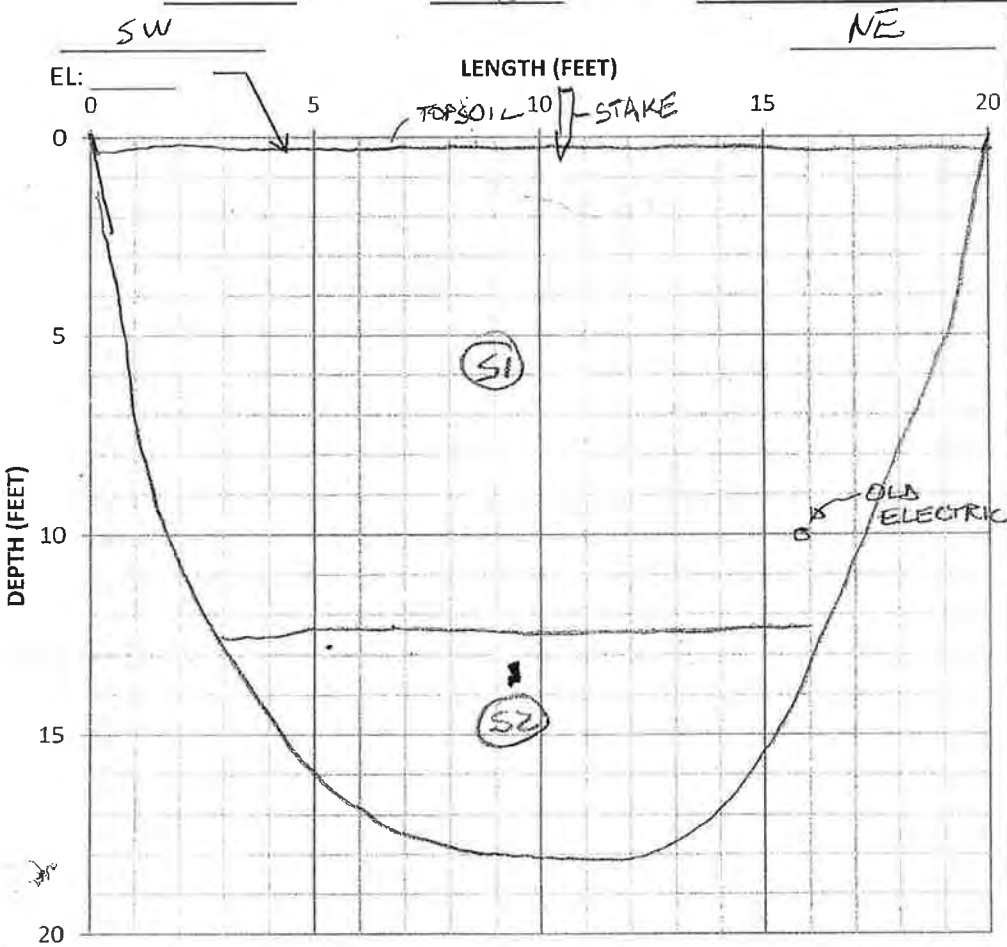
PROJECT: Rico St. Louis Ponds DATE: 22 OCT 13

NO: ~~2013-SSR-1~~ LOGGED BY: ACJ

WEATHER: CLEAR, 40° EXCAVATION METHOD: KOMATSU PC 300

LOCATION: 150' EAST OF LIME PLANT BLDG

Start Time: 1030 End Time: 1145 Note:




NOTES/SAMPLES

OLD FOUNDATION ENCOUNTERED 10' SW @ 3' AREA, MOIST

10' NE

SM (SLIGHT MOIST)

MOIST

3 BUCKETS S1: 1'-12.5'

3 BUCKETS S2: 12.5'-18'

| SOIL TYPE | SOIL DESCRIPTION (SEE ATTACHED SHEET) |
|---|---|
| ~~1 TOPSOIL~~ | |
| ~~2 SEE S2 (FILL)~~ | |
| ~~3 ~~ ~~PILL (WASTE ROCK)~~ | ~~(SEE S3)~~ |
| S1 | FILL, WASTE ROCK, NOT OXIDIZED, SOME SCATTERED WOODY PLANT DEBRIS |
| S2 | FILL, WASTE ROCK, OXIDIZED (PYRITE OXIDATION) ROCK SCATTERED |

# TEST PIT LOG

| | |
|---|---|
| PROJECT: Rico St. Louis Ponds | DATE: 22 |
| NO: | LOGGED BY: ACJ |

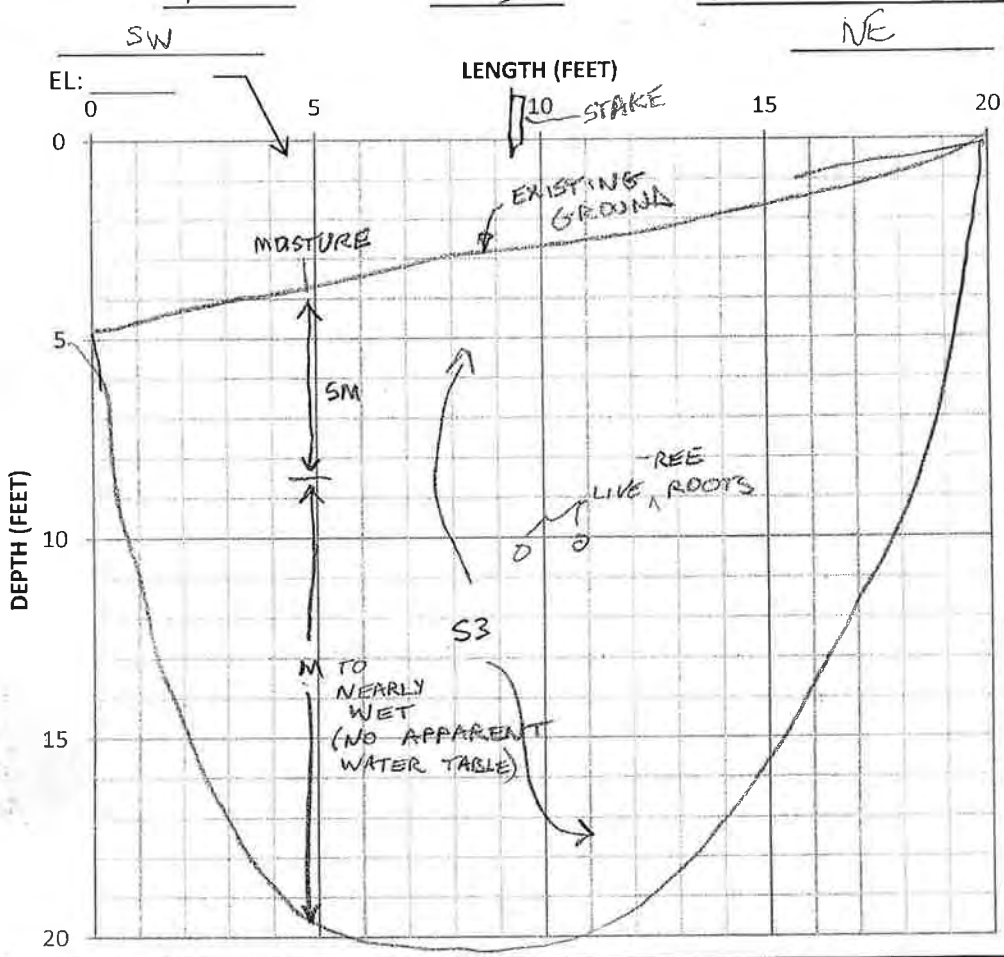
**TEST PIT #** TP2013-9

WEATHER: CLEAR, 60°F

EXCAVATION METHOD: KOMATSU PC 300 LC

LOCATION: SOUTH STACKED REPOSITORY NEAR BASE OF HILL
ACCESS TO SOUTH PAD

Start Time: 1200 End Time: 1415 Note:




NOTES/SAMPLES

FIRST TRY
VARIOUS STEEL BEAMS, BLACK POLY PIPE ENCOUNTERED 15' TO SW.
LARGE STEEL BEAM ENCOUNTERED
MOVE 15' NE.
DEBRIS IN PIT FROM 5'-8'.

SAMPLE (3)
0'-20'
3 5 GAL BUCKETS

| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| | SEE SEPARATE SHEET |
| (S3) | COLLUVIUM DERIVED FILL, SCATTERED DEBRIS (ELECTRICAL INSULATORS, TUBING) |

# TEST PIT LOG

| | |
|---|---|
| PROJECT: Rico St. Louis Ponds | DATE: 22 OCT 13 |
| NO: | LOGGED BY: ACJ |

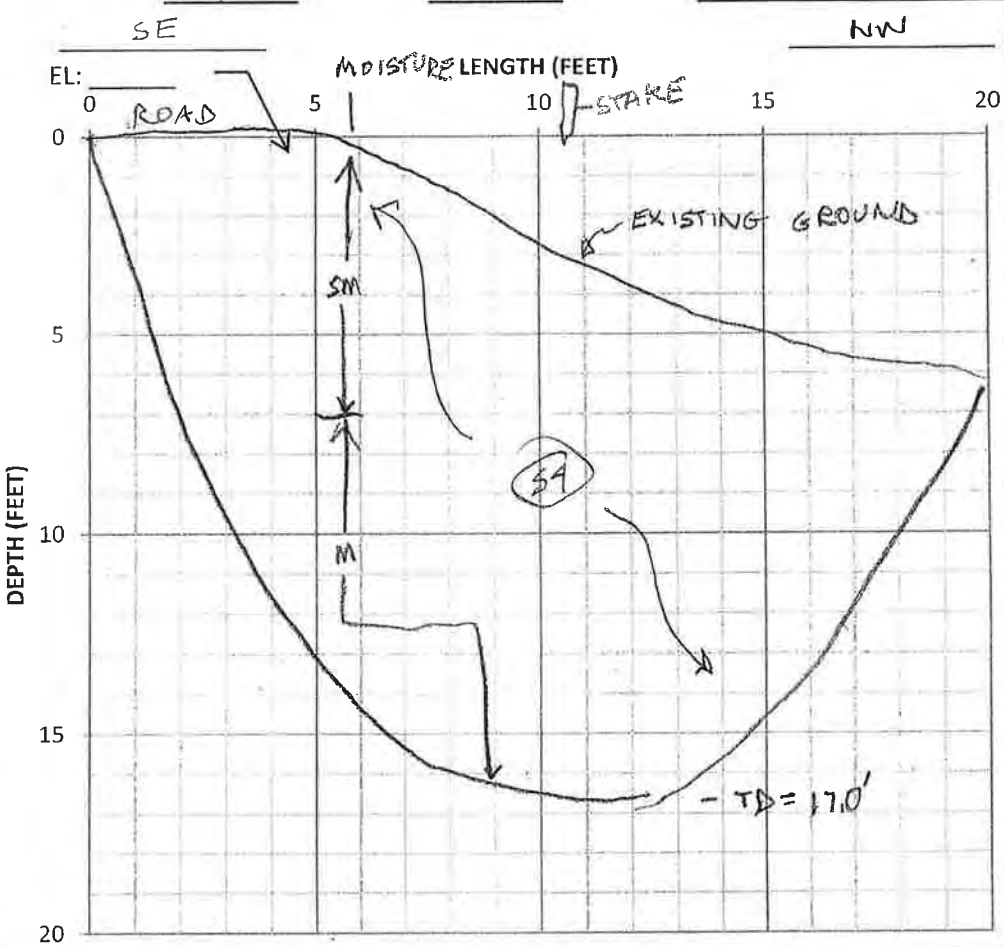
**TEST PIT #** TP2013 - 10

WEATHER: CLEAR, 60°F

EXCAVATION METHOD: KOMATSU PC 300 LC

LOCATION: SIDE OF ROAD ABOVE MAIN HAUL ROAD IN SOUTH STACKER REPOSITORY AREA; SOUTH OF ROAD TO S. DRILL PAD

Start Time: 1430 End Time: 1500 Note:




NOTES/SAMPLES

SAMPLES:

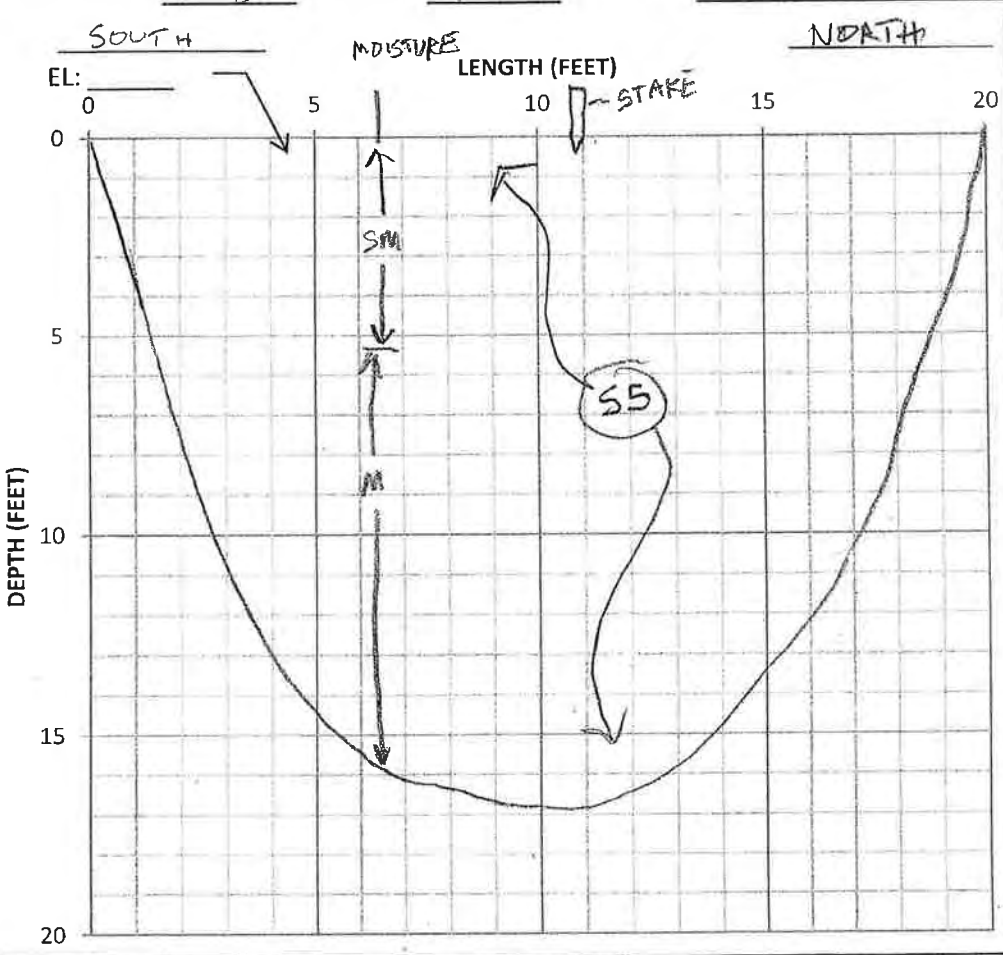
(4) 0-17.0' 3 5-GAL BUCKETS

| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| (X) | |
| (SA) | COLLUVIUM - DERIVED FILL, SEE ATTACHED SHEET |

# TEST PIT LOG

| | |
|---|---|
| PROJECT: Rico St. Louis Ponds | DATE: 22 OCT 13 |
| NO: | LOGGED BY: ACJ |
| TEST PIT # | TP 2013-11 |
| WEATHER: CLEAR, 60°F | EXCAVATION METHOD: KOMATSU PC300 LC |
| LOCATION: 300' S, TP 2013-3 | |

Start Time: 1515 End Time: 1600 Note:




NOTES/SAMPLES

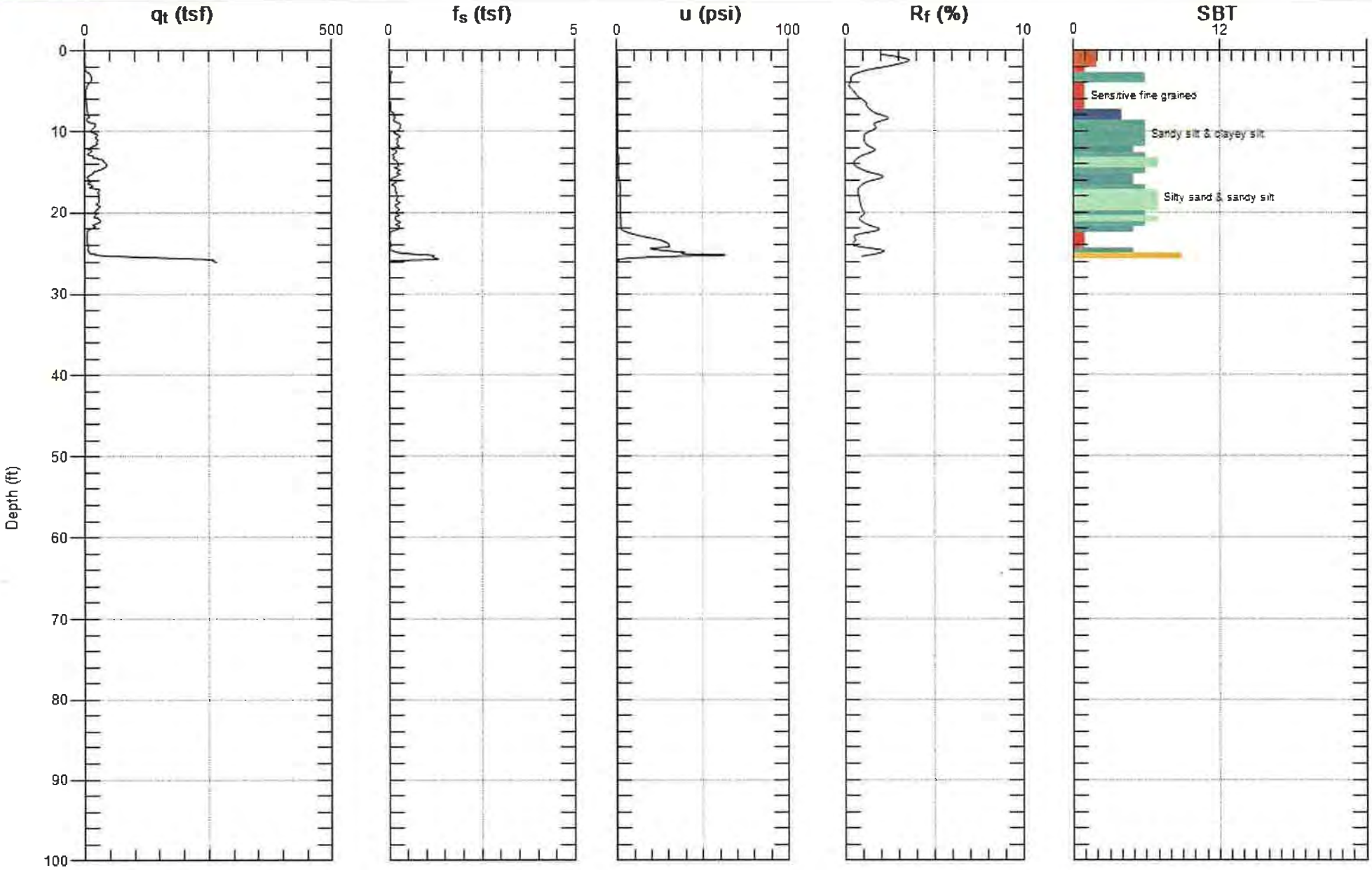
| SOIL TYPE | SOIL DESCRIPTION |
|---|---|
| 1 | |
| SS | COLLUVIUM-DERIVED FILL, SEE "SOIL DESCRIPTION DETAIL" SHEET |

# CPT Logs

GREGG AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-01 Date: 10/31/2011 03:51



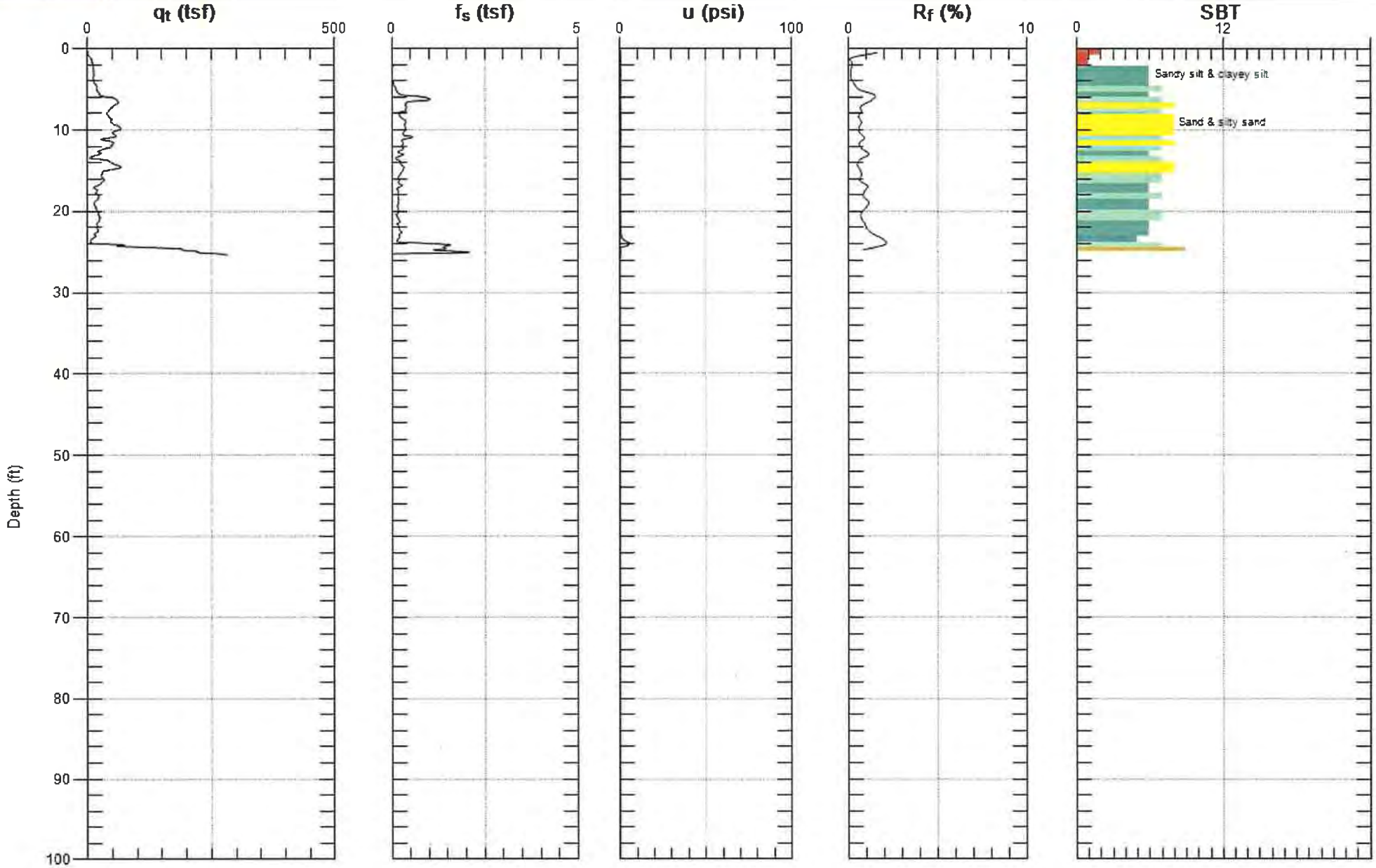

Max. Depth: 26.083 (ft)
Avg. Interval: 0.656 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-02 Date: 10/31/2011 02:50



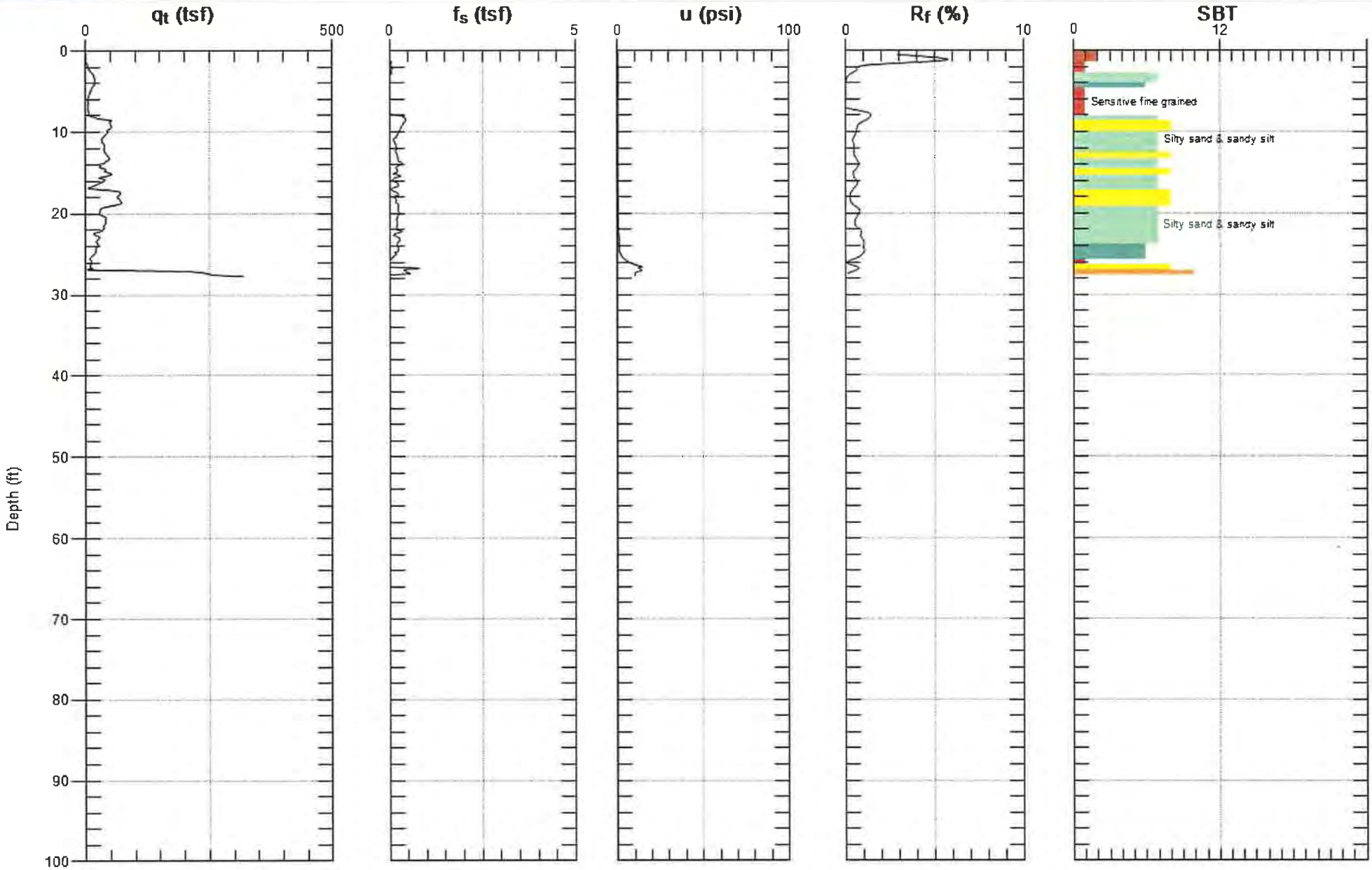

Max. Depth: 25.427 (ft)
Avg. Interval: 0.656 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-03 Date: 10/31/2011 03:24




Max. Depth: 27.723 (ft)
Avg. Interval: 0.656 (ft)

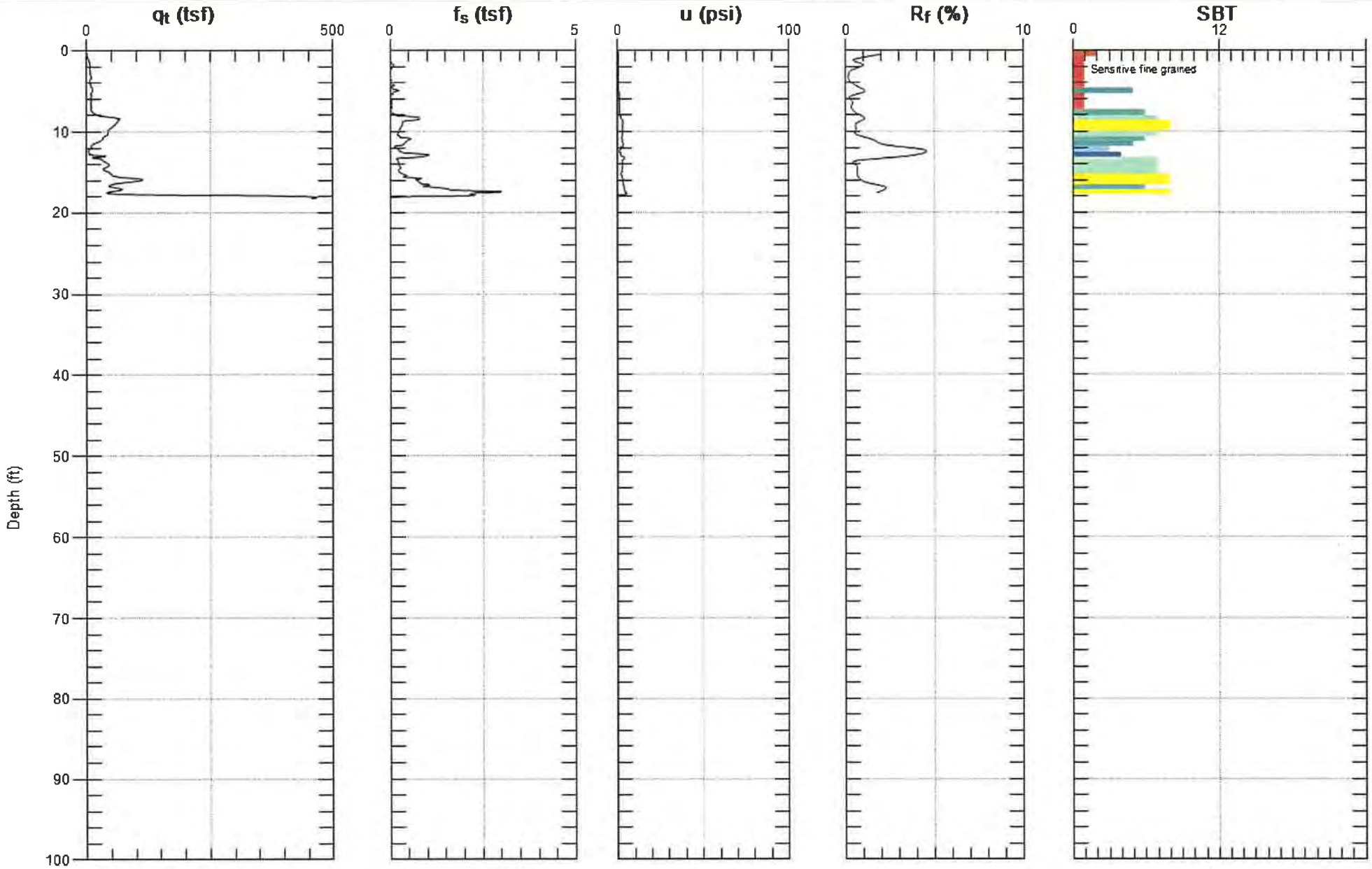
SBT: Soil Behavior Type (Robertson 1990)

GREGG

# AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-04 Date: 11/1/2011 08:03



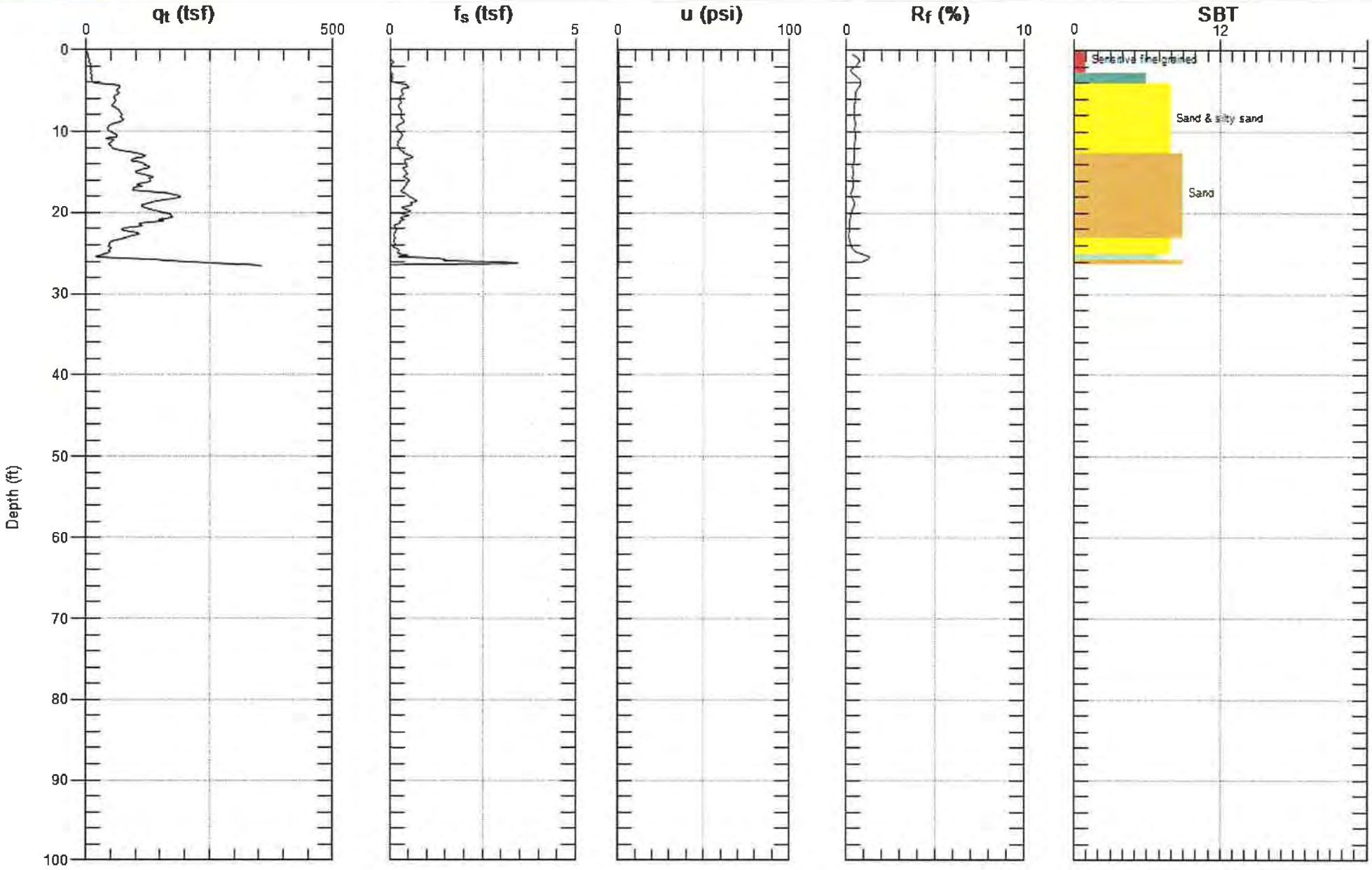

Max. Depth: 18.209 (ft)
Avg. Interval: 0.656 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-05 Date: 11/1/2011 07:42



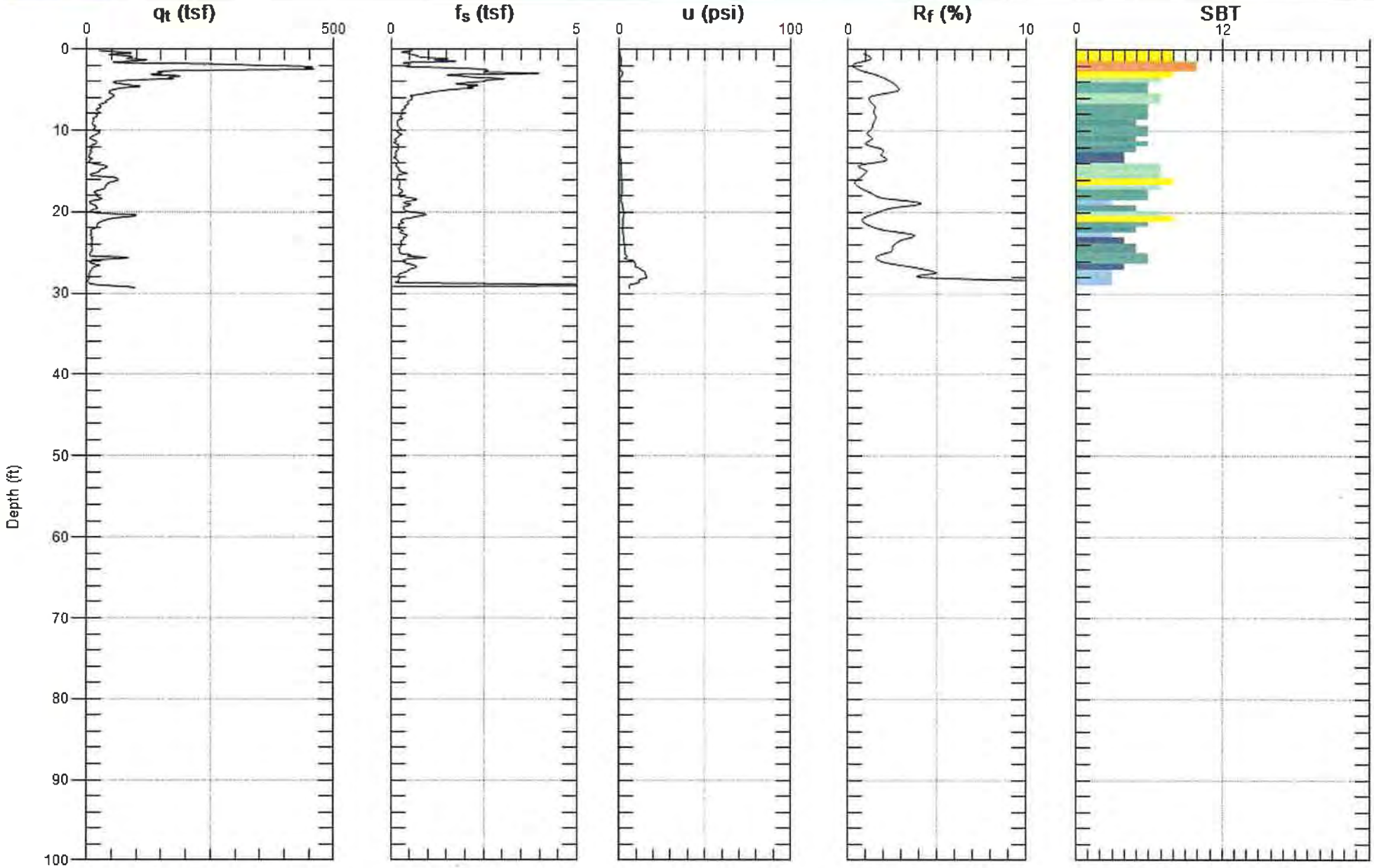

Max. Depth: 26.575 (ft)
Avg. Interval: 0.656 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG AECI

Site: RICO ST LUIS DRYING CELL Engineer: C. SANCHEZ

Sounding: CPT-06 Date: 10/31/2011 01:31



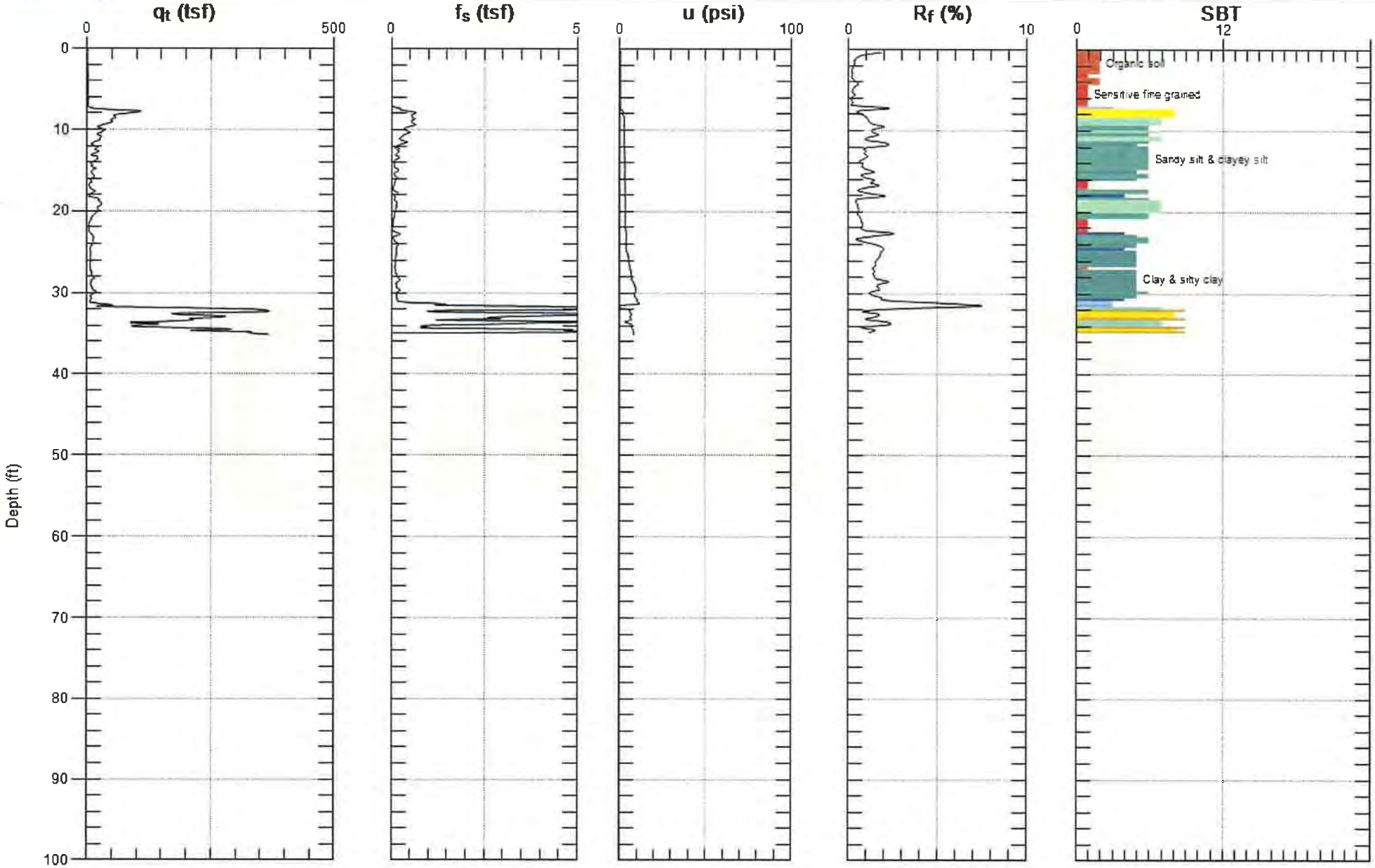

Max. Depth: 29.364 (ft)
Avg. Interval: 0.656 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG AECI

Site: RICO ST LUIS DRYING CEL Engineer: C. SANCHEZ

Sounding: CPT-PDF-03 Date: 11/2/2011 08:41




Max. Depth: 35.105 (ft)
Avg. Interval: 0.328 (ft)

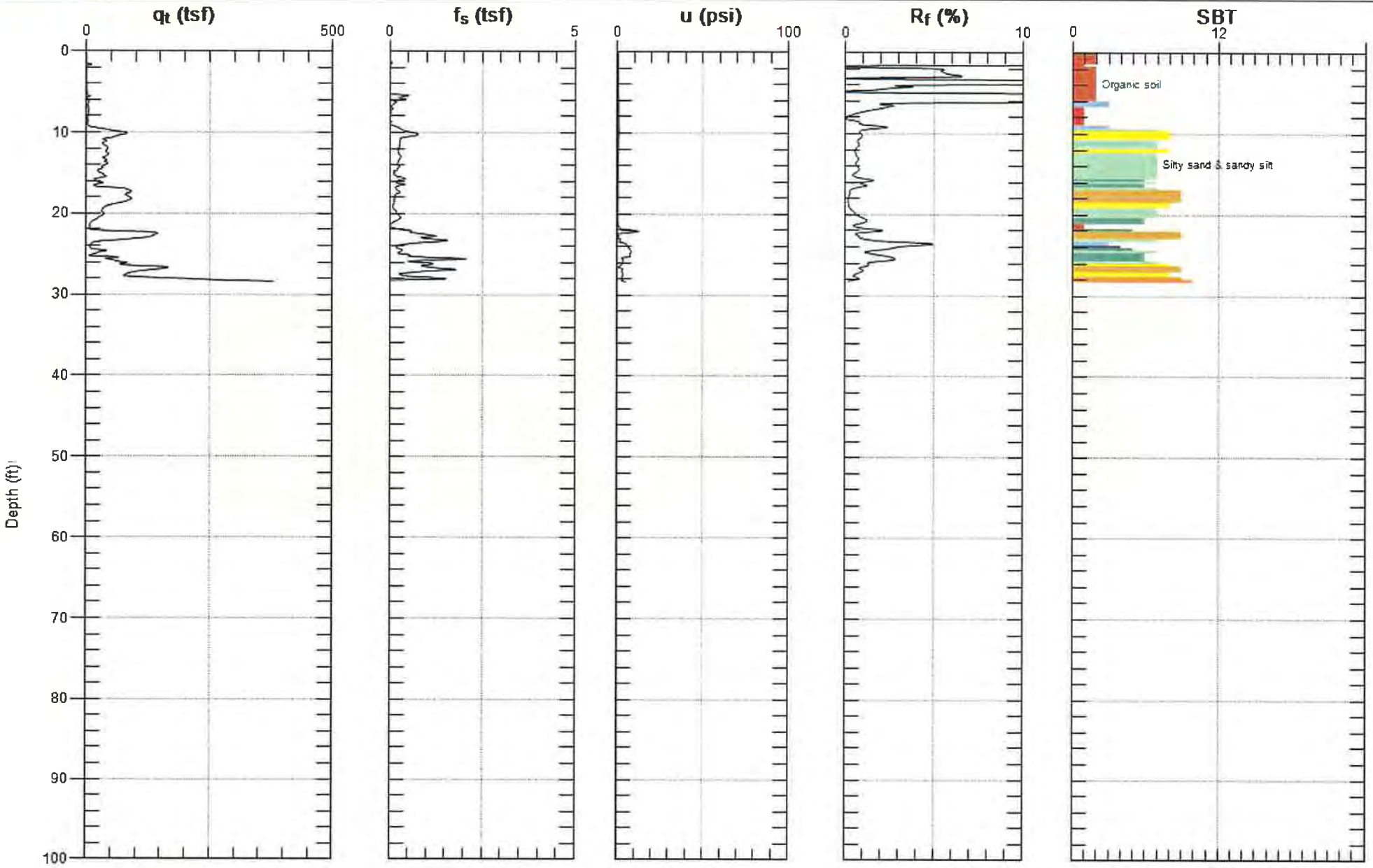
SBT: Soil Behavior Type (Robertson 1990)

GREGG

# AECI

**Site: RICO ST LUIS DRYING CEEngineer: C. SANCHEZ**

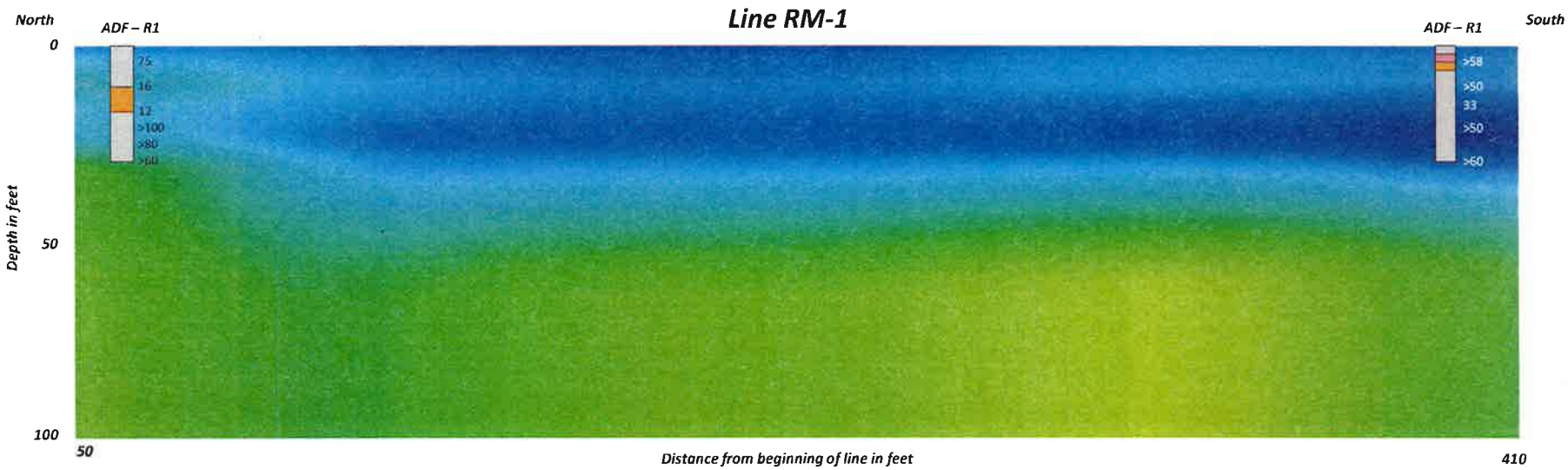
**Sounding: CPT-SSR-05** **Date: 11/1/2011 03:37**

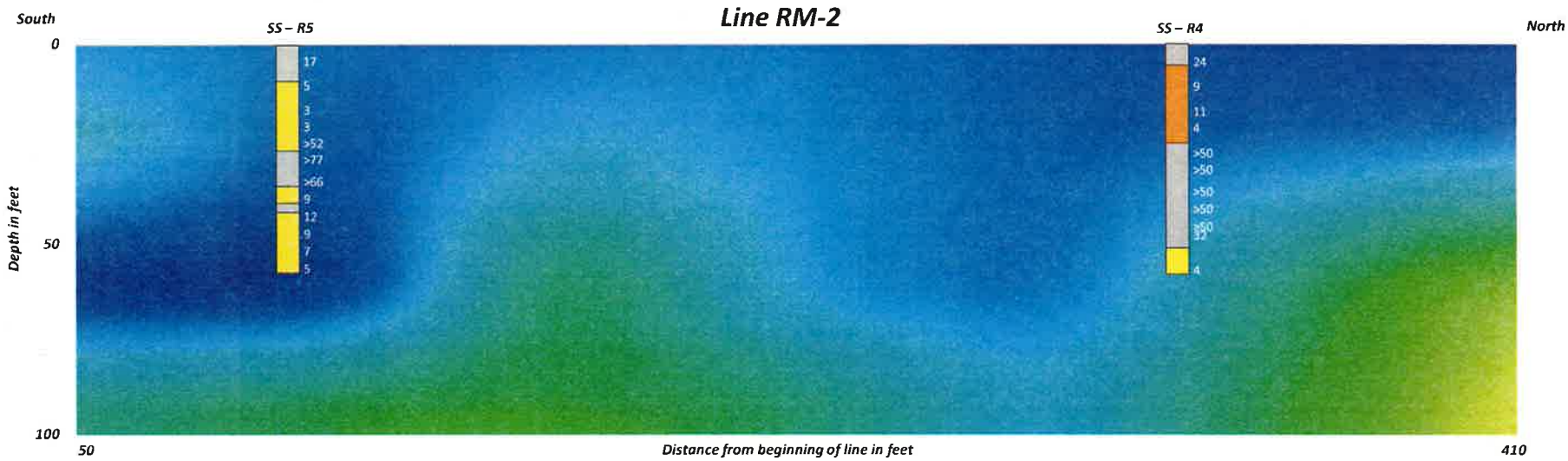



Max. Depth: 28.379 (ft)
Avg. Interval: 0.328 (ft)

SBT: Soil Behavior Type (Robertson 1990)

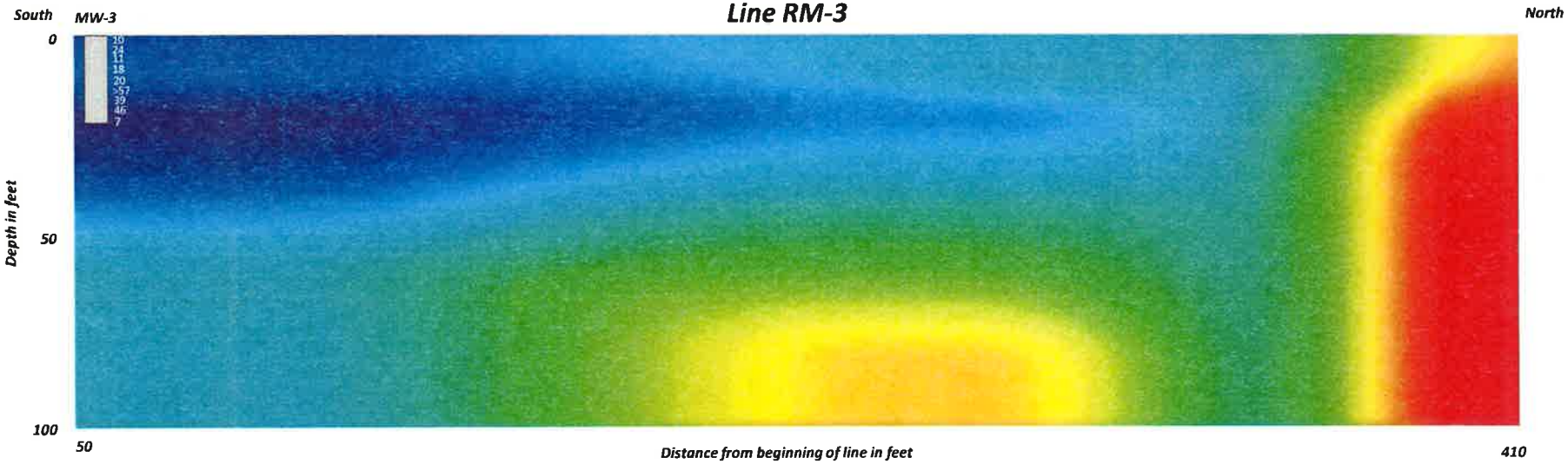
# Refraction Microtremor Logs


Line RM-1
North
South
ADF – R1
ADF – R1
75
16
12
>100
>80
>60
>58
>50
33
>50
>60
0
50
100
Depth in feet
50
410
Distance from beginning of line in feet

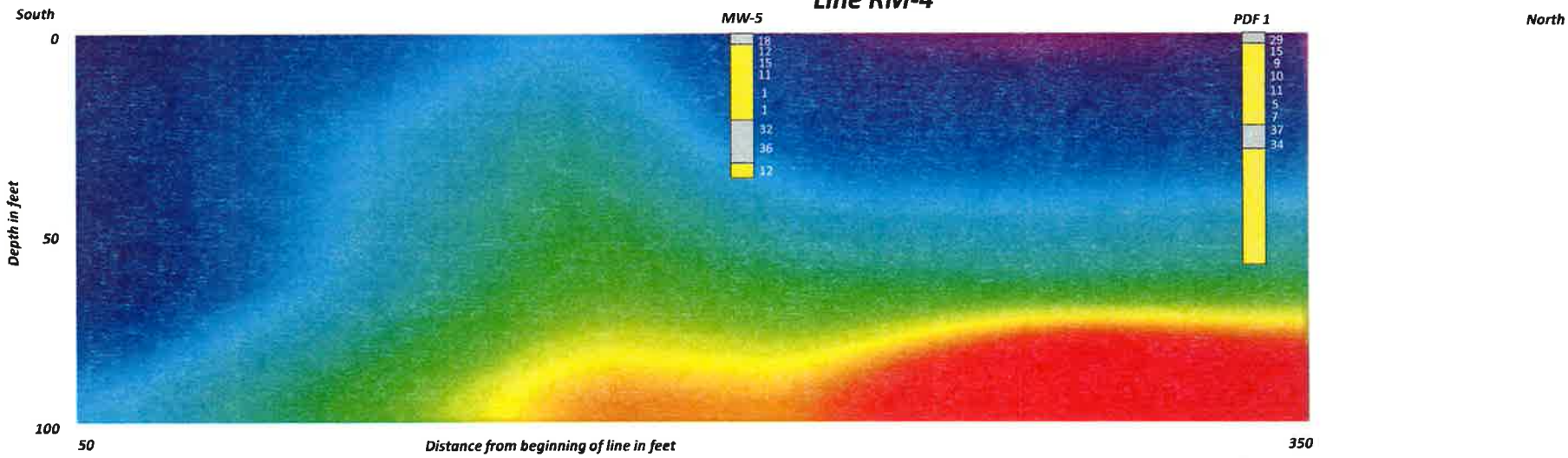

Line RM-2
South
North
SS – R5
SS – R4
17
5
3
3
>52
>77
>66
9
12
9
7
5
24
9
11
4
>50
>50
>50
>50
>50
33
4
0
50
100
Depth in feet
50
410
Distance from beginning of line in feet

Potentially liquefiable
Silt/Clay
Silty/Clayey Gravel
Calcine Tailings
Sand/Silty sand

## Line RM-3



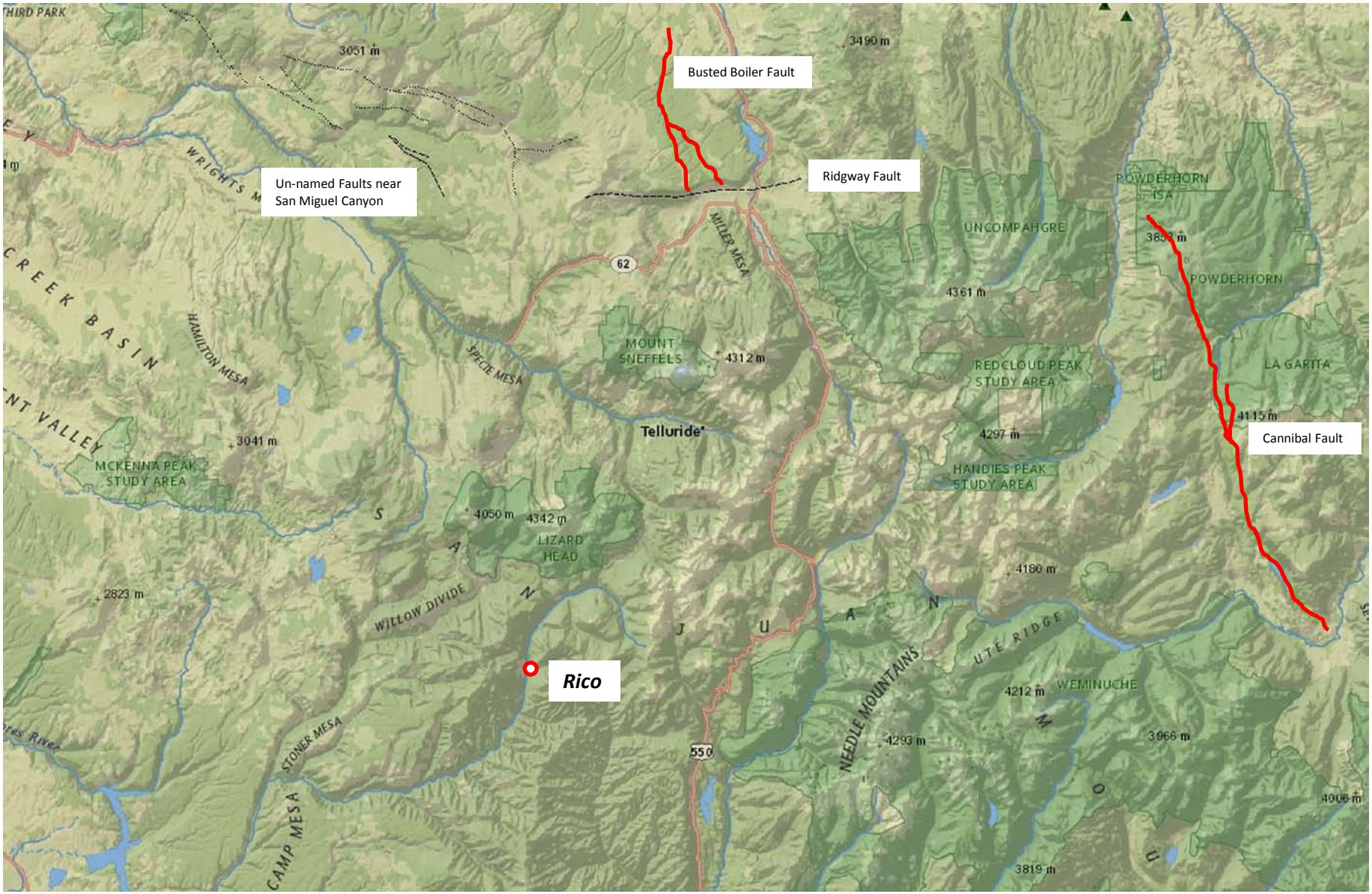

## Line RM-4



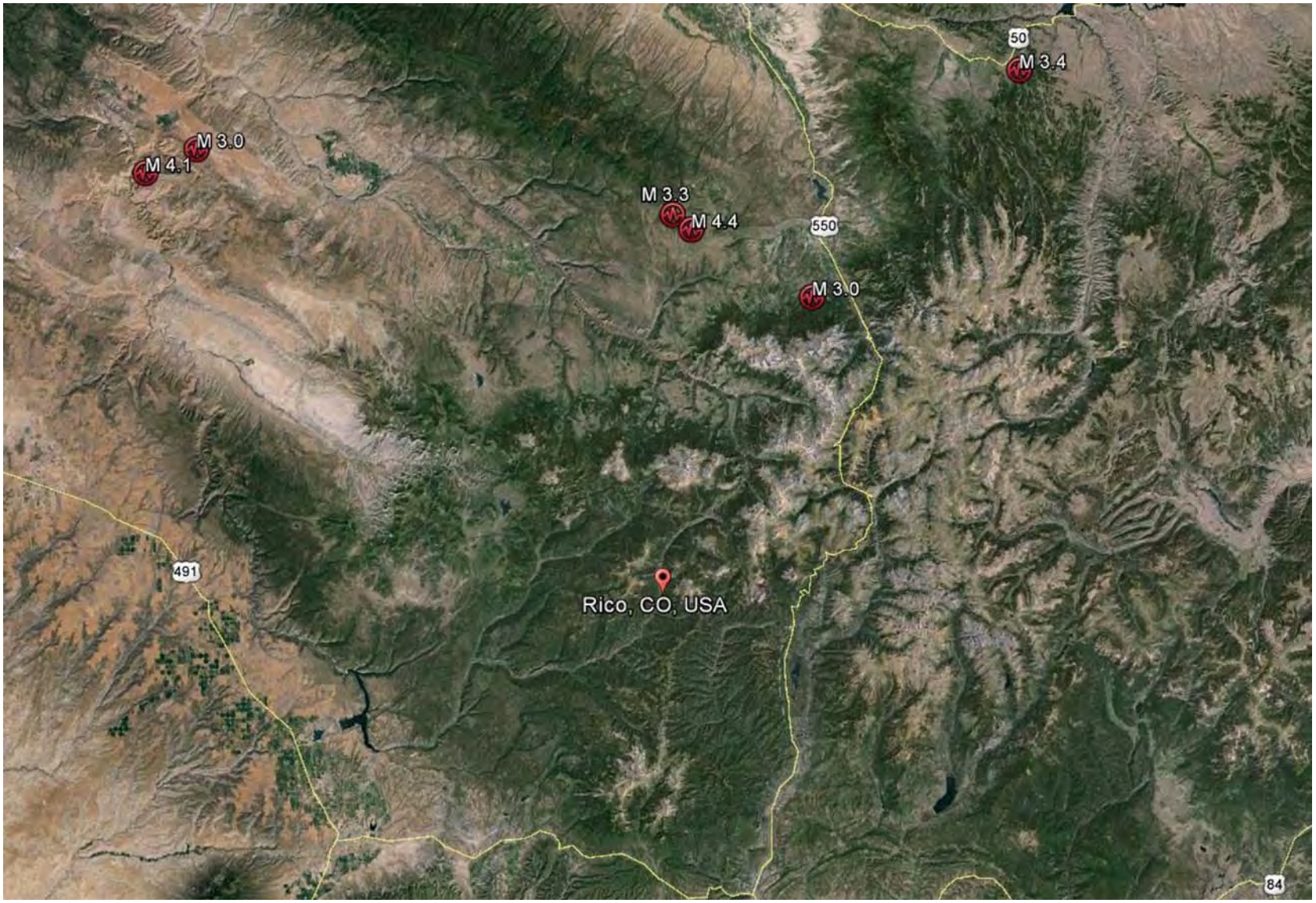
# Appendix C

# Seismotectonic Data

# Quaternary Faults in the Vicinity of Rico, Colorado



# Earthquake Epicenters in the Vicinity of Rico, Colorado



**Earthquake Hazards Program**

# Database Search

## Complete Report for Busted Boiler fault (Class A) No. 2274

Brief Report ||Partial Report

Compiled in cooperation with the Colorado Geological Survey

*citation for this record:* Widmann, B.L., compiler, 1998, Fault number 2274, Busted Boiler fault, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 11/26/2013 12:50 PM.

**Synopsis** The Busted Boiler fault is at the southwest margin of the Uncompahgre Uplift. It extends north (perpendicular) from the Ridgway fault [2276]. The fault is marked by a 5- to 25-m-high fault scarp, abandoned and/or diverted streams, and ponded sediment. Late Quaternary deposits are offset across the fault trace.

**Name comments** The Busted Boiler fault extends north from and perpendicular to the Ridgway fault [2276]. The fault dies out to the north between Horsefly Creek and Polores Creek. The fault is northwest of the town of Ridgway and west of Highway 550.

**Fault ID Comments:**
Fault number Q24 of Widman and others (1998 #3441).

**County(s) and State(s)** OURAY COUNTY, COLORADO

**Physiographic province(s)** COLORADO PLATEAUS

**Reliability of location** Good
Compiled at 1:250,000 scale.

*Comments:* The fault was mapped by Sullivan and others (1980 #2756), Steven and Hail (1989 #2747) at a scale of 1:100,000, and Tweto and others (1976 #2774) and Lettis and others (1996 #4453) at a scale of 1:250,000. The fault trace used herein is from Lettis and others (1996 #4453).

**Geologic setting** The Busted Boiler fault is on the southeast margin of the Uncompahgre Uplift, which is a northwest-trending, east-tilted fault block. The Busted Boiler is a high-angle normal fault, downthrown to the west. It forms the eastern margin of a discontinuous graben.

**Length (km)** 18 km.

**Average strike** N5°W

**Sense of movement** Normal

*Comments:* Lettis and others (1996 #4453) reported normal movement on the fault.

**Dip Direction** W

**Paleoseismology studies**

**Geomorphic expression** The fault is marked by a prominent west-facing scarp that is 5- to 25-m-high. Diversion and/or abandonment of local streams is reported, and Holocene sediment is ponded against the fault (Lettis and others, 1996 #4453).

**Age of faulted surficial deposits** Sullivan and others (1980 #2756) and Lettis and others (1996) reported offset of late Quaternary sediment. The fault is almost entirely within the Cretaceous Dakota Sandstone, with less than 5 percent of the fault extending through or beneath Quaternary deposits.

**Historic earthquake**

**Most recent prehistoric deformation** Late Quaternary (<130 ka)

*Comments:* Sullivan and others (1980 #2756) and Lettis and others (1996 #4453) reported late Pleistocene and possibly even Holocene movement on the fault. Evidence for Holocene movement is non-definitive, therefore, the most recent paleoevent on the fault is herein considered to have occurred during the late Quaternary (<130 ka).

**Recurrence interval**

**Slip-rate category** Less than 0.2 mm/yr

*Comments:* Widmann and others (1998 #3441) placed this structure within the <0.2 mm/yr slip-rate category.

**Date and Compiler(s)** 1998
Beth L. Widmann, Colorado Geological Survey

**References**

#4453 Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project-Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: Technical report to U.S. Bureau of Reclamation, Denver, Colorado, 177 p.

#2747 Steven, T.A., and Hail, W.J., Jr., 1989, Geologic map of the Montrose 30' x 60' quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-1939.

#2756 Sullivan, J.T., Meeder, C.A., Martin, R.A., and West, M.W., 1980, Seismic hazard evaluation-Ridgway dam and reservoir site-Dallas Creek project Colorado: U.S. Water and Power Resources Service, Seismotectonic Section, report, 43 p.

#2774 Tweto, O., Steven, T.A., Hail, W.J., Jr., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1° x 2° quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-761.

#3441 Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p., 1 pl., scale 1:500,000.

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# Database Search

## Complete Report for Cannibal fault (Class A) No. 2337

Brief Report ||Partial Report

Compiled in cooperation with the Colorado Geological Survey

*citation for this record:* Widmann, B.L., compiler, 1999, Fault number 2337, Cannibal fault, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 11/26/2013 12:48 PM.

**Synopsis** The Cannibal fault is in the San Juan Mountains between two major middle or late Cenozoic volcanic centers; the nested Lake City and Uncompahgre calderas to the west and the nested La Garita and San Luis calderas to the east (Steven and Hail, 1989 #2747). Although previously considered a late Cenozoic fault by Kirkham and Rogers (1981 #792) and Colman (1985 #1953), more recent investigation by Lettis and others (1996 #4453) indicated probable Quaternary fault movement on the Cannibal fault. They reported numerous lineations in late Pleistocene glacial deposits along the fault and a strong geomorphic expression in the Clear Creek graben. They concluded that the Cannibal fault is potentially active. Based on the work of Lettis and others (1996 #4453), the Cannibal fault is herein considered to have last moved during the late Quaternary.

**Name comments** The Cannibal fault is in the San Juan Mountains, east of Lake City. It trends generally southeast from the mouth of Fourth of July Creek, near the Hinsdale/Gunnison County line, to Antelope Spring southeast of Santa Maria Lake. The fault was named by Lettis and others (1996 #4453).

**Fault ID Comments:**
Fault 96 in Kirkham and Rogers (1981 #792).

**County(s) and State(s)** GUNNISON COUNTY, COLORADO
MINERAL COUNTY, COLORADO
HINSDALE COUNTY, COLORADO

**Physiographic province(s)** SOUTHERN ROCKY MOUNTAINS

**Reliability of location** Good
Compiled at 1:250,000 scale.

*Comments:* The north half of the Cannibal fault was mapped at a scale of 1:100,000 Steven and Hail (1989 #2747), 1:250,000 by Tweto and others (1976 #2774), 1:500,000 by Kirkham and Rogers (1981 #792), and 1:1,000,000 by Colman (1985 #1953). The south half of the fault was mapped at a scale of 1:250,000 by Steven and others (1974). The entire length of the fault was mapped at a scale of 1:250,000 by Lettis and others (1996 #4553) and 1:250,000 and 1:500,000 by Widmann and others (1998 #3441). The trace used herein is from Lettis and others (1996 #4553).

**Geologic setting** The Cannibal fault is in the San Juan Mountains, an area characterized by extensive middle and late Tertiary volcanism. Steven and others (1974 #2748) outlined as many as 15 collapsed and nested calderas in the San Juan Mountains. Many of the faults in this area are related to collapse of these volcanic calderas. However, the Cannibal fault lies between two large volcanic centers; the nested Lake City and Uncompahgre calderas to the west and the nested La Garita and San Luis calderas to the east. It is a normal down-to-west fault and forms the northeast margin of the Clear Creek graben, south of Spring Creek Pass.

**Length (km)** 49 km.

**Average strike** N20°W

**Sense of movement** Normal

*Comments:* Lettis and others (1996 #4453) suggested normal movement on a west-dipping fault plane.

**Dip Direction** W

**Paleoseismology studies**

**Geomorphic expression** Lineaments in late Pleistocene glacial deposits along the fault were reported by Lettis and others (1996 #4453).

**Age of faulted surficial deposits** Rocks of the Miocene Hinsdale Formation are offset by the northern end of this fault (Steven and Hail, 1989 #2747). Kirkham and Rogers (1981 #792) reported 100 m of offset in Miocene volcanic rocks, based on oral communication with T.A. Steven. Quaternary deposits were not mapped as offset by the fault by Steven and Hail

(1989 #2747) or Steven and others (1974 #2748), but Lettis and others (1996 #4453) noted several lineaments in older Pinedale (late Pleistocene) to Bull Lake (late middle Pleistocene) moraine deposits.

**Historic earthquake**

**Most recent prehistoric deformation** Late Quaternary (<130 ka)

*Comments:* This fault has been active since the Miocene, based on offset of Miocene volcanic rocks (Kirkham and Rogers, 1981 #792; Steven and Hail, 1989 #2747). Lettis and others (1996 #4453) reported "topographic, lithologic, and vegetation lineaments suggestive of recent fault activity" in older Pinedale to Bull Lake (late Pleistocene) moraine deposits. They concluded that the Cannibal fault is a potentially active fault based on these lineaments and "its strong geomorphic expression within the Clear Creek graben..." The most recent paleoevent is herein tentatively considered to have occurred during the late Quaternary.

**Recurrence interval**

**Slip-rate category** Less than 0.2 mm/yr

*Comments:* The compiler placed this fault within the <0.2 mm/yr slip-rate category.

**Date and Compiler(s)** 1999
Beth L. Widmann, Colorado Geological Survey

**References**

#1953 Colman, S.M., 1985, Map showing tectonic features of late Cenozoic origin in Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-1566, 1 sheet, scale 1:1,000,000.

#792 Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p., 3 pls.

#4453 Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project-Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: Technical report to U.S. Bureau of Reclamation, Denver, Colorado, 177 p.

#2747 Steven, T.A., and Hail, W.J., Jr., 1989, Geologic map of the Montrose 30' x 60' quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-1939.

#2748 Steven, T.A., Lipman, P.W., Hail, W.J., Jr., Barker, F., and Luedke, R.G., 1974, Geologic map of the Durango quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-764.

#2774 Tweto, O., Steven, T.A., Hail, W.J., Jr., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1° x 2° quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-761.

#3441 Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p., 1 pl., scale 1:500,000.

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# Database Search

## Complete Report for Ridgway fault (Class A) No. 2276

Brief Report ||Partial Report

Compiled in cooperation with the Colorado Geological Survey

*citation for this record:* Widmann, B.L., compiler, 1997, Fault number 2276, Ridgway fault, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 11/26/2013 12:53 PM.

**Synopsis** The Ridgway fault is an east-west-oriented fault on the southwest margin of the Uncomphagre Uplift. The fault is defined by a 300-m-high fault-line scarp, but there is no observable surface rupture or offset of middle to late Quaternary deposits. Sullivan and others (1980 #2756) reported possible offset of Kansan (early middle Quaternary) to early Wisconsin (late Quaternary) glacial deposits. Micorseismic studies in the area reveal a close spatial association of seismicity to the Ridgway fault. The fault was considered to be potentially active by Kirkham and Rogers (1981 #792), Sullivan and others (1980 #2756) and Lettis and others (1996 #4453).

**Name comments** The Ridgway fault extends east from the Ouray/Montrose County line, runs parallel to and north of Pleasant Valley Creek, and ends northeast of the town of Ridgway.

**Fault ID Comments:**
Fault 179 in Kirkham and Rogers (1981 #792) and fault number Q26 of Widman and others (1998 #3441).

**County(s) and State(s)** MONTROSE COUNTY, COLORADO
OURAY COUNTY, COLORADO

**Physiographic province(s)** COLORADO PLATEAUS
SOUTHERN ROCKY MOUNTAINS

**Reliability of location** Good
Compiled at 1:250,000 scale.

*Comments:* The Ridgway fault was mapped at a scale of 1:24,000 by Hail (1988 #2692; 1989 #2693) and Lettis and others (1996 #4453), 1:100,000 by Steven and Hail (1989 #2747), and 1:250,000 by Tweto and others (1976 #2774). The trace used herein is from Lettis and others (1996 #4453).

**Geologic setting** The Ridgway fault lies on the southwest margin of the Uncompahgre Uplift, which is a northwest-trending, east-tilted fault block. The Ridgway fault is a high-angle normal fault that is down to the south.

**Length (km)** 24 km.

**Average strike** N87°E

**Sense of movement** Normal

*Comments:* Sullivan and others (1980 #2756) and Sullivan and Martin (1986 #2755) reported a south-dipping fault plane based on microseismicity studies. Down- to-the-south movement on a south-dipping fault plane indicates normal movement.

**Dip Direction** S

**Paleoseismology studies**

**Geomorphic expression** Sullivan and others (1980 #2756) described a south-facing, 300-m-high fault-line scarp along the Ridgway fault. However, Lettis and others (1996 #4453) reported that there has not been any documented surface rupture in at least 140 k.y., which is supported by the general lack of geomorphic features such as scarps or lineaments along the fault.

**Age of faulted surficial deposits** Sullivan and others (1980 #2756) postulated that Kansan (early middle Quaternary) to early Wisconsin (late Quaternary) glacial deposits may be offset by the Ridway fault. However, Lettis and others (1996 #4453) and Ake and others (1997 #2105) reported that pre-Bull Lake (middle Pleistocene) to Pinedale (10 to 40 ka) deposits are not offset by the fault. Lettis and others (1996 #4453) further stated that Holocene non-glacial deposits are not offset by the fault based on the absense of geomorphic features indicative of youthful faulting. Maxium stratigraphic throw on the Ridway fault is about 150 m, most of which is believed to have occurred during the Laramide (Sullivan and others, 1980 #2756).

**Historic earthquake**

Quaternary (<1.6 Ma)

**Most recent prehistoric deformation** *Comments:* Sullivan and others (1980 #2756) examined glacial deposits and attempted to correlate them across the fault. They postulated that elevation differences in these glacial deposits across the fault could suggest Quaternary movement on the Ridgway fault. Microseismicity studies by Sullivan and others (1980 #2756) and Martin (1987 #2722) reported that seismicity is associated with the Ridgway fault. Kirkham and Rogers (1981 #792) and Colman (1985 #1953) indicated Quaternary movement on the fault. Lettis and others (1996) reported no observable surface rupture since at least 140 ka. They also suggested that either the seismicity is being produced by the Ridgway fault itself but without surface rupture since 140 ka, or that the seismicity is induced by the filling of Ridgway Reservoir and is occurring on the Ridgway fault and/or associated branch faults in the region. The most recent paleoevent on the Ridway fault is herein conservatively considered to have occurred during the Quaternary (<1.6 Ma) based on possible offset of Quaternary glacial deposits and microseismicity data cited by Sullivan and others (1980 #2756).

**Recurrence interval**

**Slip-rate category** Less than 0.2 mm/yr

*Comments:* Based on the lack of geomorphic evidence to support recent fault activity, and the lack of any observable surface rupture, Widmann and others (1998 #3441) placed this structure within the <0.2 mm/yr slip-rate category.

**Date and Compiler(s)** 1997
Beth L. Widmann, Colorado Geological Survey

**References**

#2105 Ake, J.P., Vetter, U., and Hawkins, F., 1997, Seismicity and Quaternary faulting near Ridgway, Colorado: Colorado Geological Survey Geohazards Conference field trip guidebook.

#1953 Colman, S.M., 1985, Map showing tectonic features of late Cenozoic origin in Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-1566, 1 sheet, scale 1:1,000,000.

#2692 Hail, W.J., Jr., 1988, Reconnaissance geologic map of the Horsefly Peak quadrangle, Ouray, Montrose, and San Miguel Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2059.

#2693 Hail, W.J., Jr., 1989, Reconnaissance geologic map of the Ridgway quadrangle, Ouray County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2100.

#792 Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p., 3 pls.

#4453 Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project-Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: Technical report to U.S. Bureau of Reclamation, Denver, Colorado, 177 p.

#2722 Martin, R.A., Jr., 1987, Preliminary results of network operation for the period June 4, 1985 through April 30, 1987, Ridgway seismic network: U.S. Bureau of Reclamation Seismotectonic Report 87-1.

#2747 Steven, T.A., and Hail, W.J., Jr., 1989, Geologic map of the Montrose 30' x 60' quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations I-1939.

#2755 Sullivan, J.T., and Martin, R.A., 1986, Seismic hazard studies for Ridgway dam site, Colorado, in Colorado tectonics, seismicity and earthquake hazards--Proceedings and field trip guide: Colorado Geological Survey Special Publication 19, p. 30-31.

#2756 Sullivan, J.T., Meeder, C.A., Martin, R.A., and West, M.W., 1980, Seismic hazard evaluation-Ridgway dam and reservoir site-Dallas Creek project Colorado: U.S. Water and Power Resources Service, Seismotectonic Section, report, 43 p.

#2774 Tweto, O., Steven, T.A., Hail, W.J., Jr., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1° x 2° quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-761.

#3441 Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p., 1 pl., scale 1:500,000.

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**Earthquake Hazards Program**

# Database Search

## Complete Report for Unnamed faults near San Miguel Canyon (Class B) No. 2284

Brief Report ||Partial Report

Compiled in cooperation with the Colorado Geological Survey

*citation for this record:* Widmann, B.L., compiler, 1998, Fault number 2284, Unnamed faults near San Miguel Canyon, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 11/26/2013 03:24 PM.

**Synopsis** This group of faults lies on the south end of the Uncompahgre Uplift. Although there was no reported evidence of Quaternary offset along these faults they were mapped as Quaternary faults by Lettis and others (1996 #4453; plate 2). They attributed fault activity to salt tectonism, and thus are considered to be Class B structures. The most recent movement on the faults herein considered to have occurred during the Quaternary based on the work of Lettis and others (1996 #4453).

**Name comments** This unnamed group of faults includes 14 faults that generally trend northwest parallel to the San Miguel River. The faults are on the southeast end of the Uncompahgre Uplift.

**Fault ID Comments:**
Fault number Q34 of Widman and others (1998 #3441).

**County(s) and State(s)** MONTROSE COUNTY, COLORADO
SAN MIGUEL COUNTY, COLORADO

**Physiographic province(s)** COLORADO PLATEAUS

**Reliability of location** Good
Compiled at 1:250,000 scale.

*Comments:* The faults were mapped at a scale of 1:250,000 by Williams (1964 #2789) and Lettis and others (1996). The fault trace used herein is from Lettis and others (1996 #4453).

**Geologic setting** This group of faults are on the southeast end of the Uncompahgre Uplift, which is a northwest-trending, east-tilted fault block. These faults are down both to the northeast and southwest, and are considered to be salt-related rather than tectonic features (Lettis and others, 1996 #4453).

**Length (km)** 32 km.

*Comments:*

The cumulative fault length is about 101 km owing to the large number of fault traces in this group.

**Average strike** N53°W

**Sense of movement** Normal .

**Dip Direction** SW; NE

**Paleoseismology studies**

**Geomorphic expression** No information is available about the Quaternary geomorphic expression of the fault.

**Age of faulted surficial deposits** Faults in this group offset Jurassic to Cretaceous bedrock (Williams, 1964 #2789). Less than 1 percent of the cumulative fault length (100 km) extends through or beneath Quaternary deposits. Although there is no evidence of faulted Quaternary deposits along these faults, Lettis and others (1996 #4453) concluded they moved during the Quaternary but were related to salt tectonism.

**Historic earthquake**

**Most recent prehistoric deformation** Quaternary (<1.6 Ma)

*Comments:* Although there is no direct evidence of faulted Quaternary deposits along these faults, they were mapped as Quaternary faults related to salt tectonism by Lettis and others (1996 #4453; plate 2).

**Recurrence interval**

**Slip-rate category** Less than 0.2 mm/yr

*Comments:* Widmann and others (1998 #3441) placed these structures within the <0.2 mm/yr slip-rate category.

**Date and Compiler(s)** 1998
Beth L. Widmann, Colorado Geological Survey

**References**

#4453 Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project-Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: Technical report to U.S. Bureau of Reclamation, Denver, Colorado, 177 p.

#3441 Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p., 1 pl., scale 1:500,000.

#2789 Williams, P.L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Geologic Investigations I-360.

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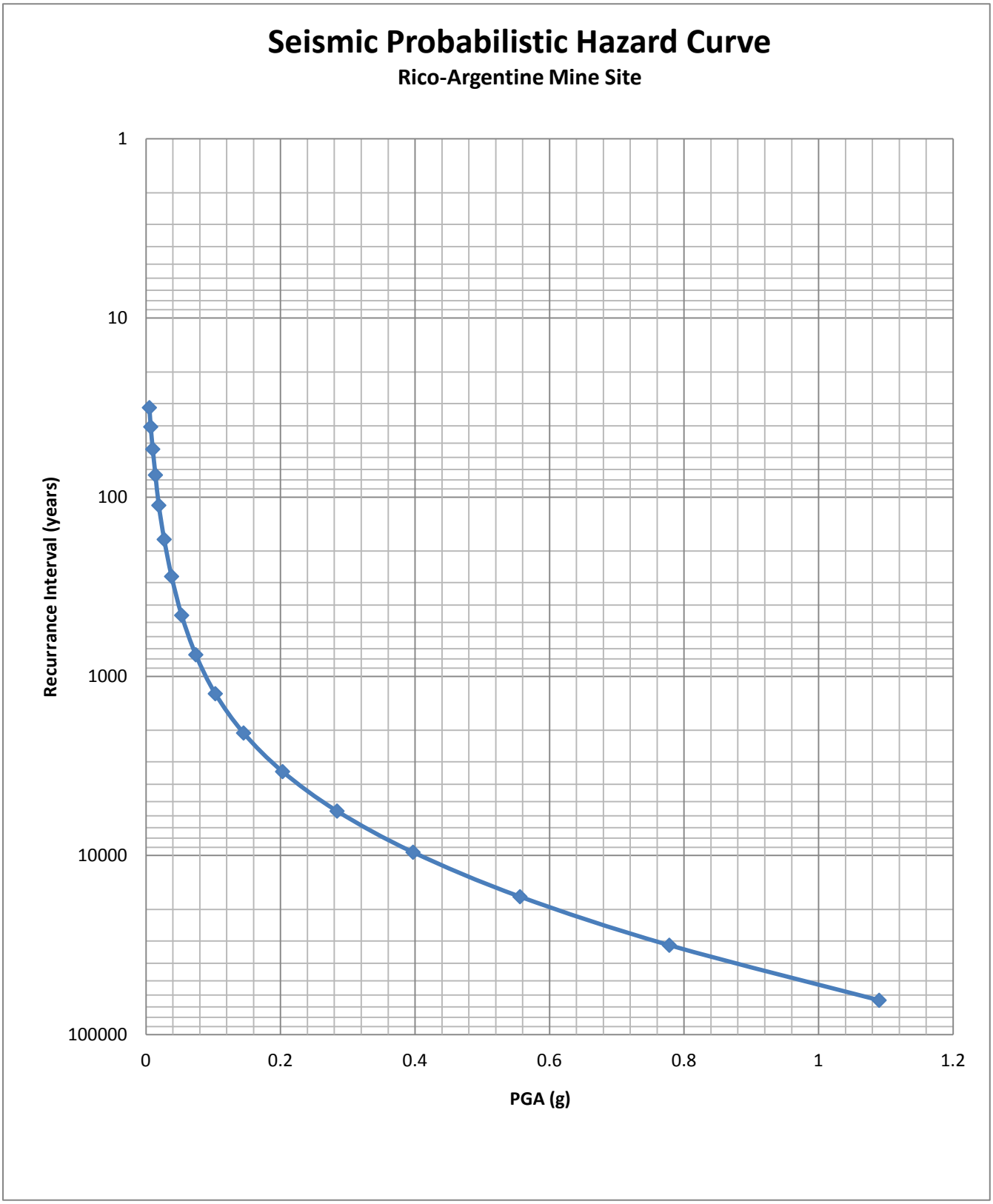
Seismic Probabilistic Hazard Curve
Rico-Argentine Mine Site
Recurrance Interval (years)
1
10
100
1000
10000
100000
0
0.2
0.4
0.6
0.8
1
1.2
PGA (g)

# Appendix D

# Sampling and Analysis Plan for Surface Water and Groundwater (On CD)

Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
Atlantic Richfield Company
May 23, 2013

# Sampling and Analysis Plan
# For Surface Water and Groundwater

# Rico-Argentine Mine Site – Rico Tunnels
# Operable Unit OU01
# Rico, Colorado

This document is the property of BP – Atlantic Richfield Company and was prepared by Anderson Engineering Company, Inc., and AECOM Technical Services, Inc. It is provided on the condition that it will be used solely for the intended purpose and will be used solely for the execution and review of the engineering, remediation, or construction of the subject project.

| Revision | Prepared By | Reviewed By | Approved By | Date | Pages Affected |
|---|---|---|---|---|---|
| **0** | **AECI / AECOM** | | | **May 23, 2013** | **All** |
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| | | | | | |
| | | | | | |

# Atlantic Richfield Company

**Anthony R. Brown**
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May 23, 2013

***VIA EMAIL AND OVERNIGHT COURIER***

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
US EPA Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

**Subject: Sampling and Analysis Plan (SAP) Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01 Rico, Colorado**

Dear Mr. Way,

A digital file in PDF format of the updated *Sampling and Analysis Plan (SAP) – Rico Tunnels Operable Unit OU01 Rico, Colorado* dated May 23, 2013, is being submitted to you today via email. Three (3) hardcopies of the report will also be sent by overnight courier to your office.

Atlantic Richfield Company (AR) is submitting this updated SAP responsive to requirements in Section 5.1 of the Removal Action Work Plan accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, Colorado, U.S. EPA Region 8, Docket No. CERCLA-08-2011-0005.

If you have any questions or comments, please feel free to contact me at (714) 228-6770 or via email at Anthony.Brown@bp.com

Sincerely,

Anthony R. Brown

Anthony Brown
Project Manager
Atlantic Richfield Company

Enclosures (Sampling and Analysis Plan, Rico-Argentine Mine Site)

cc: Terry Moore, Atlantic Richfield
Sandy Riese, EnSci
Chris Sanchez, AECI
Dave McCarthy, Copper Environmental
Tom Kreutz, AECOM
Doug Yadon, AECOM
Mark Lombardi, AMEC
Spencer Archer, AMEC

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# SAMPLING AND ANALYSIS PLAN FOR SURFACE AND GROUNDWATER WATER SAMPLING RICO, COLORADO

# May 2013

## 1.0 Introduction

This Sampling and Analysis Plan (SAP) delineates surface water, groundwater, and St. Louis Tunnel discharge water quality sampling, as well as flow rate and groundwater elevation measurement activities within the upper Dolores River basin near the Town of Rico, Colorado. The sampling locations and parameters for analysis for this sampling program have been selected to respond to the requirements identified in the Unilateral Administrative Order (UAO) issued to Atlantic Richfield Company (AR) by the Environmental Protection Agency (EPA), Region 8, dated March 23, 2011. These locations will provide data on the St. Louis Tunnel discharge, flows at selected locations within the St. Louis settling ponds system, at the system discharge to the Dolores River (collectively referred to as the St. Louis Ponds system), previously sampled locations along the main stem Dolores River and groundwater at and below the St. Louis Ponds system.

Surface water flow and groundwater elevation measurements will be performed at each sampling site in conjunction with the water quality sampling. Section 3.0 lists the sampling station locations and site descriptions. Additionally, continuous flow measurements will be taken at the St. Louis Tunnel adit and at the St. Louis Ponds system discharge to the Dolores River. Figures 1, 2, and 3 illustrate the location of the various sampling stations.

## 2.0 Sampling Objectives/Frequency

Analytical sampling will provide water quality data, including trace metals concentrations, in order to update the Water Quality Assessment in cooperation with the Colorado Department of Public Health and Environment (CDPHE), and evaluate potential remedial water treatment options for the St. Louis Tunnel discharge. The objective of this data collection is to provide the following information:

- Elevation and quality of groundwater in the St. Louis Ponds area (the project site)
- Quality and flow rate of surface water as it passes through the project site
- Quality and flow rate of water released into the river, and both upstream and downstream water quality and flow rate of the Dolores River
- Information to support analysis of the stability of pond embankments

To achieve this objective, routine monthly measurement and sampling will occur at several locations and sample points as shown in Table 2-1. In addition to the locations, Table 2-1 also identifies the rationale for collection at each sample point – either required, background, data gap, or for informational purposes:

**Table 2-1: Sampling Locations and Design Rationale**

| Location ID | Matrix | Depth (feet) | Analytical | Concentration Level | No. of Samples | Sampling SOP | Rationale |
|---|---|---|---|---|---|---|---|
| DR-1 | SW | Varies | M/WQ | Low | 2 | 3-1 | Background Upstream |
| DR-1A | SW | Varies | None | NA | 1 | NA | Background Upstream |
| DR-2 | SW | Varies | M/WQ | Low | 2 | 3-1 | Upstream |
| DR-2A | SW | Varies | None | NA | 1 | NA | Outfall |
| DR-3 | SW | Varies | M/WQ | Low | 1 | 3-1 | Influent |
| DR-3A | SW | Varies | None | NA | 1 | NA | Background |
| DR-4 | SW | Varies | M/WQ | Low | 1 | 3-1 | Representative |
| DR-5 | SW | Varies | M/WQ | Low | 1 | 3-1 | Representative |
| DR-6 | SW | Varies | M/WQ | Low | 1 | 3-1 | Outfall |
| DR-4-SW | SW | Varies | M/WQ | Low | 2 | 3-1 | Background Downstream |
| DR-7 | SW | Varies | M/WQ | Low | 2 | 3-1 | Downstream |
| DR-G | SW | Varies | M/WQ | Low | 1 | 3-1 | Representative |
| GW-1 | GW | 5-10 | M/WQ | Low | 1 | 4-1 | Background |
| GW-3 | GW | 10-15 | M/WQ | Low | 1 | 4-1 | Representative |
| GW-4 | GW | 10-15 | M/WQ | Low | 1 | 4-1 | Representative |
| GW-5 | GW | 20-25 | M/WQ | Low | 1 | 4-1 | Representative |
| GW-6 | GW | 20-25 | M/WQ | Low | 1 | 4-1 | Representative |
| GW-7 | GW | 20-30 | M/WQ | Low | 1 | 4-1 | Representative |
| EB-1 | GW | 20-25 | M/WQ | Low | 1 | 4-1 | Representative |
| EB-2 | GW | 15-20 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-1 SHALLOW | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |

| Location ID | Matrix | Depth (feet) | Analytical | Concentration Level | No. of Samples | Sampling SOP | Rationale |
|---|---|---|---|---|---|---|---|
| MW-1 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-2 SHALLOW | GW | 10-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-2 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-2 SHALLOW | GW | 10-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-3 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-4 SHALLOW | GW | 15-20 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-4 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-5 SHALLOW | GW | 15-20 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-5 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-6 SHALLOW | GW | 20-30 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-6 DEEP | GW | 5-15 | M/WQ | Low | 2 | 4-1 | Representative |
| MW-101 | GW | 25-30 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-102 | GW | 25-30 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-103 | GW | 5-10 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-104 | GW | 5-10 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-202 | GW | 35 | M/WQ | Low | 1 | 4-1 | Representative |
| MW-204 | GW | 15-20 | M/WQ | Low | 1 | 4-1 | Representative |
| P13-102 | GW | 10-15 | M/WQ | Low | 1 | 4-1 | Representative |
| P13-103 | GW | 10-15 | M/WQ | Low | 1 | 4-1 | Representative |
| AT-2 | GW | 10-20 | M/WQ | Low | 1 | 4-1 | Representative |
| BAH-01 | GW | 200 – 230 | M/WQ | Los | 1 | 4-1 | Representative |
| CHV-101 S | GW | 48 | M/WQ | Los | 1 | 4-1 | Representative |
| DG-1 | To be installed 2013 | | | | | 4-1 | Data Gap |
| DG-2 | To be installed 2013 | | | | | 4-1 | Data Gap |
| DG-3 | To be installed 2013 | | | | | 4-1 | Data Gap |
| MW-105 | To be installed 2013 | | | | | 4-1 | Representative |
| P19-101 | To be installed 2013 | | | | | 4-1 | Representative |
| P19-102 | To be installed 2013 | | | | | 4-1 | Representative |
| CHV-101 D | To be installed 2013 | | | | | 4-1 | Representative |
| MW-201 | To be installed 2013 | | | | | 4-1 | Representative |
| MW-203 | To be installed 2013 | | | | | 4-1 | Representative |
| MW-205 | To be installed 2013 | | | | | 4-1 | Representative |
| MW-206 | To be installed 2013 | | | | | 4-1 | Representative |

| Location ID | Matrix | Depth (feet) | Analytical | Concentration Level | No. of Samples | Sampling SOP | Rationale |
|---|---|---|---|---|---|---|---|
| MW-207 | To be installed 2013 | | | | | 4-1 | Representative |
| CHI-101 | To be installed 2013 | | | | | 4-1 | Representative |
| CHI-102C | To be installed 2013 | | | | | 4-1 | Representative |
| CHI-103 | To be installed 2013 | | | | | 4-1 | Representative |

M/WQ – Metals/Other Water Quality Parameters as dictated in Table 4-2.

The completion of twelve monitoring wells is expected in 2013, and will be monitored on a monthly basis. Three angle boreholes (CHI-101, CHI-102C, and CHI-103) are expected to be completed in 2013. Water level measurements only will be collected on a monthly basis at these three angle boreholes. Table 2-1 lists all wells and boreholes to be completed in 2013.

In addition to the above locations, there may be periodic sampling of additional points that may be required on a one-time, short-term or occasional basis. These sample points and measurements will be collected in accordance with the parameters set forth in this plan and the project Quality Assurance Project Plan for Surface and Groundwater Sampling (QAPP). If it is necessary for these additional locations to be part of the monthly/routine sampling events, they will be added and the applicable plans revised.

The data collected from this sampling program will assist the project team and regulatory agencies with development of long-term strategies for the project site, including:

- Remediation design for mining/milling byproducts and surface waters
- Pond and embankment design
- Long-term water quality assessment and objectives for the Dolores River

The data from the water samples will be used to characterize the water quality of the tunnel discharge, flows related to the St. Louis Ponds system, groundwater, and conditions along the main stem of the Dolores River (the receiving stream for the ponds system discharge). A primary objective of this sampling program is to collect samples and develop water quality data over an entire annual cycle at minimum, including seasonal low-flow periods. The sampling program will also provide data to support design and implementation of an effective water treatment system for the St. Louis Tunnel discharge, and support evaluation and design of mine discharge hydraulic controls.

The final pond discharge enters a segment of the Dolores River that is described as “the main stem of the Dolores River from a point immediately above the confluence with Horse Creek to a point immediately above the confluence with Bear Creek” in Colorado state regulations, 5 CCR 1002-34, Regulation No. 34.6(4). These regulations establish classifications and water quality standards for streams in the San Juan and Dolores River Basins. The stream segment associated with the St. Louis Tunnel discharge (stream segment #COSJDO03) is classified for Cold Water Aquatic Life 1, Class E Recreation, and Agriculture uses. These uses determine specific numeric water quality standards for physical, biological, inorganic, and metal parameters.

The selection of parameters for water sample analyses was primarily driven by these water quality standards. The data collected will be utilized to determine the impact of the final discharge on the Dolores River’s compliance with applicable water quality standards. EPA guidance (40 CFR 136) will be applied in determining sample collection and analysis methodologies and standard quality assurance/control (QA/QC) protocols (such as sample blanks, duplicates, and spiking) will also be followed to ensure accuracy and reliability of results; refer to the project QAPP for more detail.

Atlantic Richfield (AR) initiated surface water sampling under the UAO in December 2010 and will collect samples on a monthly schedule through 2014, or until a date agreed upon by the project team and regulatory agencies when it is determined that monthly sampling is no longer required. After this date, sampling and analyses will continue on a seasonal basis as required in the UAO and summarized as follows:

- Peak Flow (April/May)
- Moderate to Low Flow (October/November)
- Low Flow (January/February)

# 3.0 Water Quality, Sampling, Flow, and Elevation Measurement Sampling Locations

Water quality samples will be collected from each sampling location discussed in this section. Both surface water and groundwater samples will be analyzed for parameters listed in Table A5.4-1 in the QAPP. Field water quality measurements will be conducted and recorded for each sample collected. Dolores River samples will be collected starting with the most downstream sampling site and progressing upstream, as feasible, given flow and access conditions (ice cap over river, high flows, etc.). Additionally, two field blanks will be collected during each trip and one blind duplicate sample will be collected for every 10 samples (see QAPP for more details). Flow measurements and water elevations will be taken at all Dolores River sampling locations and at various locations throughout the St. Louis Ponds site as water depth, velocity, and weather permit. All pond water surface elevation data to date is summarized in Appendix A.

All water sampling activities will be guided by the following Standard Operating Procedures (SOPs). The SOPs are listed below in Table 3-1 by reference, with a copy provided in Appendix B of this SAP A copy of the EPA Method 1669 is included as Appendix C. A copy of the Water Measurement Manual is included as Appendix D. Anderson Engineering Co., Inc. (AECI) has been retained by AR to complete the surface and groundwater sampling and surface water flow measurements. Each AECI SOP is industry compliant and reviewed and updated on an annual basis, with each member of the sampling team trained and proficient in the listed techniques. EPA Method 1669 is revised as the EPA deems necessary.

**Table 3-1: Water Sampling Activities Standard Operating Procedures**

| SOP No. | Revision | Date | Matrix | Description | Regulatory Citation | Modifications |
|---|---|---|---|---|---|---|
| 1-6 | 0 | 2007 | GW, SW | Sample Custody and Documentation | Method 1669 | None |
| 1-11 | 0 | 2007 | GW, SW | Packaging and Shipment of Field Samples | Method 1669 | None |
| 2-9 | 0 | 2008 | GW, SW | Field Water Quality Measurement | None | None |
| 3-1 | 0 | 2001 | SW | Surface Water and Sediment Sampling | Method 1669 | None |
| 3-4 | 0 | 2002 | SW | Streamflow Measurement | Method 1669 | None |
| 3-6 | 0 | 2011 | SW | Streamflow Measurement with a Portable Meter | WMM | None |
| 3-7 | 0 | 2012 | SW | Streamflow Measurement with Ice Present | Method 1669 | None |
| 3-8 | 0 | 2013 | SW | Collection of Cross Channel Surface Water Samples | Method 1669 | None |
| 4-1 | 0 | 2007 | GW | Groundwater Sampling | Method 1669 | None |
| 4-9 | 0 | 2008 | GW | Well Purging | Method 1669 | None |
| E1669 | 0 | 1996 | GW | US EPA Guidance - Sampling Ambient Water for Trace Metals | Method 1669 | None |
| WMM | 3 | 2001 | SW | US Department of Interior, Bureau of Reclamation – Water Measurement Manual | WMM | 3rd Revision |

On-site Telemetry

In order to provide access to real time data from remote locations, telemetry systems are being considered for installation at data collection locations throughout the site. Possible telemetry locations being considered on the Dolores River are DR-1, DR-2, DR-7, DR-4-SW, and DR-G. Possible locations on the St. Louis Ponds site are at the two Parshall flumes DR-3 and DR-6, at the Pond 15 discharge, DR-4, and at the southern end of the planned demonstration wetland. Telemetry systems at these locations would allow those personnel involved with the water sampling to remotely monitor conditions and parameters at flow monitoring locations, such as weather and flowrates. Decisions on whether or not to install telemetry systems are still forthcoming and will be left to the discretion of site management, with consideration given to safety and security of installing and maintaining such systems.

## 3.1 Surface Water Sampling Locations

There will be a total of nine surface water sample locations within the St. Louis Ponds system and on the Dolores River. Typical flow measurement devices and methods are also provided. All surface water grab and composite locations are further identified on Figures 1, 2, and 3. The methods for collection, grab, and composite sampling are defined in SOP 3-8, Collection of Cross-Channel Surface Water Samples. Field water quality parameters will be collected for each river compartment corresponding to each aliquot, and for the total composite.

**DR-1. Dolores River above St. Louis settling ponds system.** The sampling/flow measurement location is on the Dolores River approximately 50 feet upstream of the Rico Ranger Station. Flow measurement will be accomplished by flowmeter when the river is safely accessible. Flow measurements will be obtained by the flotation method during periods of peak flows. Both a grab and composite sample will be collected at this location.

**DR-2. Dolores River immediately above the St. Louis settling ponds system outfall.** Sampling/flow measurement location is on the Dolores River just above the discharge outfall, and upstream of the hot tub discharge. The site is located directly adjacent to the thermal discharge which supplies the outdoor hot tub. Flow measurement will be accomplished by flowmeter when the river is safely accessible. Flow measurements will be obtained by the flotation method during periods of peak flows. Both a grab and composite sample will be collected at this location.

**DR-3. St. Louis Tunnel discharge at adit entrance.** Sampling location is at the Parshall flume located approximately 50 feet west of the cinder block structure at the former adit entrance. Flow measurement by installed 9-inch flume downstream at sampling location and by installed water level monitoring equipment (see Section 5.0). A grab sample will be collected at this location.

**DR-4. Discharge of Pond 15.** The sampling location is at the outlet of the upper discharge pipe located on the midpoint of the Pond 15 south embankment. Flow measurement will be accomplished by flowmeter and pipe flow depth measurements. A grab sample will be collected from this location.

**DR-5. Discharge of Pond 8.** The sampling location is at the inlet of the discharge spillway located at the southwest corner of Pond 8. Flow measurement will be accomplished by flowmeter or water balance estimates if flow cannot be measured accurately. A grab sample will be collected from this location.

**DR-6**. **St. Louis settling ponds system outfall to the Dolores River (previous permit Outfall 002).** Sample location is at installed 9-inch Parshall flume. Flow measurement by installed 9-inch flume and by installed water level monitoring equipment (see Section 5.0). A grab sample will be collected from this location.

**DR-7. Dolores River below St. Louis settling ponds system outfall.** Sampling/flow measurement location is located just off the entrance road to the St. Louis Ponds site where the Dolores River is adjacent to the entrance road. The site is located approximately 75 feet downstream of a large bend in the river that first brings the Dolores adjacent to the entrance road. Flow measurement will be accomplished by flowmeter when the river is

safely accessible. Flow measurements will be obtained by the flotation method during periods of peak flows. Both a grab and composite sample will be collected from this location.

**DR-4-SW. Dolores River below Silver Swan.** Sampling/flow measurement location is on the Dolores River below the Silver Swan site just downstream of a bend in the river and below a cemetery on the east bank. Flow measurement will be accomplished by flowmeter when the river is safely accessible. Flow measurements will be obtained by the flotation method during periods of peak flows. Both a grab and composite sample will be collected from this location.

**DR-G.** Located approximately 3.5 miles downstream of the Silver Swan site, at the USGS gauging station #09165000 immediately downstream of the bridge at this location. Flow measurement will be accomplished by flowmeter when the river is safely accessible. Flow measurements will be obtained by the flotation method during periods of peak flows. A grab sample will be collected from this location.

## 3.2 Groundwater Sampling Locations

There will be a total of 41 groundwater wells and five angle boreholes sampled within the St. Louis Ponds site area. They will be collected and processed in accordance with the SOPs as identified in Table 3-1 above at locations summarized below; each location is described, including sampling devices and methods used for sample collection. All groundwater wells are located as shown on Figures 1, 2, and 3:

**GW-1.** Well is located on the north end of the site, approximately a quarter-mile north of the northern edge of Pond 18 and approximately 75 feet North east of DR-1. Sampling by bailer.

**GW-3** Well is located approximately 200 feet north of the northern edge of Pond 18, and approximately 60 feet west of the main access road. Sampling by bailer.

**GW-4.** Well is located on the western flood dike of Pond 18, approximately midway along the dike. Sampling by bailer.

**GW-5.** Well is located on the northern edge of the former Pond 17 area, or on the northern dike of the newly constructed Drying Cell 1. Sampling by bailer.

**GW-6.** Well is located on the middle of the former Pond 17 area, or on the western edge of the south dike of the newly constructed Drying Cell 1. Sampling by bailer.

**GW-7.** Well is located on the eastern edge of the access road directly across from the former Pond 17, or directly across from the newly constructed Drying Cell 2. Sampling by bailer.

**EB-1.** Well is located on the northern edge of the former Pond 17 area, or on the northern dike of the newly constructed Drying Cell 1. It is within 10 feet of GW-5. Sampling by bailer.

**EB-2.** Well is located on the southern portion of the former Pond 16 area, or on the western edge of the south dike of the newly constructed Drying Cell 3. Sampling by bailer.

**MW-1 Shallow/Deep**. Both wells are located approximately 4 feet apart on the western embankment of Pond 13 at the division between Pond 11 and Pond 12. Sampling by bailer.

**MW-2 Shallow/Deep.** Both wells are located approximately 4 feet apart on the western flood embankment of Pond 12, about mid-way along the pond. Sampling by bailer.

**MW-3 Shallow/Deep** Both wells are located approximately 4 feet apart on the western flood embankment of Pond 15, on the southern half of the embankment. Sampling by bailer.

**MW-4 Shallow/Deep.** Both wells are located approximately 4 feet apart on the southern embankment of Pond 13, approximately 60 west of the main east access road. Sampling by bailer.

**MW-5 Shallow/Deep.** Both wells are located approximately 4 feet apart on the western dike of Drying Cell 3. Sampling by bailer.

**MW-6 Shallow/Deep.** Both wells are located approximately 4 feet apart on northern embankment of Pond 13, approximately 75 feet west of the main east access road. Sampling by bailer.

**MW-101.** Well is located approximately 200 feet south of the lime plant building in a large open clearing. Sampling by bailer.

**MW-102.** Well is located approximately 150 feet southeast of well GW-7 at the point that the access road splits in two directions. Sampling by bailer.

**MW-103.** Well is located at the southwest corner of Pond 7 on the flood-control dike adjacent to the Dolores River. Sampling by bailer.

**MW-104.** Well is located approximately midway along the west flood-control dike of Pond 9. Sampling by bailer.

**MW-202.** Well is located approximately 25 feet southeast of the cinder block structure at the former adit entrance. Sampling by bailer.

**MW-204.** Well is located approximately 200 feet east of the cinder block structure at the former adit entrance, adjacent to the collapsed tunnel. Sampling by bailer.

**P13-102.** Well is located at approximately the southeast end of the newly constructed dike at the southwest corner of Pond 13. Sampling by bailer.

**P13-103.** Well is located approximately midway along the newly constructed dike at the south corner of Pond 13. Sampling by bailer.

**CHV-101 Shallow.** Well is located approximately 125 feet east of the cinder block structure at the former adit entrance, adjacent to the collapsed tunnel. Sampling by bailer.

**AT-2.** Angle borehole casing is located approximately 220 feet east of the cinder block structure at the former adit entrance, adjacent to the collapsed tunnel. Sampling by bailer.

**BAH-01**. Angle borehole casing which accesses the mine tunnel.

Twelve additional monitoring wells and three additional angle boreholes will be installed in 2013 to assist with update of data gaps that exist for the project site. The new wells are DG-1, DG-2, DG-3, MW-105, P19-101, P19-102.CHV-101 Deep, MW-201, MW-203, MW-205, MW-206, and MW-207. The new angle boreholes are CHI-101, CHI-102C, and CHI-103. Samples will not be collected monthly from the three new angle boreholes. Monthly depth to water measurements will be completed on all new angle boreholes.

There may be additional locations that require monitoring or sampling on a one-time, short-term, or occasional basis. These locations would be sampled using the processes and methods as outlined in the SOPs. If these non-routine locations are added to the program, then they will be described as the others above and added to this plan, through a plan revision.

Prior to collection of groundwater samples, all groundwater wells will be purged in accordance with procedures outlined in SOP 4-9: Well Purging – Pumping Method. However, bailers will be used in place of a pump in order to purge the wells. A bailer used to purge one well will not be used to purge and/or sample from another well. A bailer may be left at a particular well to be used multiple times as long as it is permanently dedicated to that well

and is not used on other wells. Bailers left at a well should be kept inside the well, suspended above the water surface, with a cap covering the well opening and the cord secured and placed in a plastic bag to prevent inadvertent contamination from the surrounding environment and ground. Wells will be sampled as weather and well conditions permit. Groundwater elevation and well depth readings will also be measured and recorded at the time of sampling, immediately prior to purging of the well. Well casings elevations and a summary of groundwater elevations to date is provided in Appendix E.

Purging will be conducted with water quality measurements collected, using a field meter, at each well volume, for pH, temperature, and electric conductivity, for a total of three well volumes. Each well volume will be measured and collected into a graduated bucket. All purge water will be contained and disposed of within the existing ponds system.

## 4.0 Sampling and Analysis Parameters and Methods

Water samples will be analyzed for the parameters listed in Table 5.4-1 of the QAPP. All samples will be collected as grab samples, with the exception of DR-1, DR-2, DR-7, and DR-4-SW, where both grab and composite samples will be collected. Care will be exercised to collect samples from well-mixed locations which are representative of conditions within the flow stream. Clean hands - dirty hands procedures will be followed throughout all sample collection activities, as defined in EPA Guidance Document 1669. For quality control purposes, one blind duplicate sample will be collected every 10 samples, and two field blanks will be included in addition to the water samples being submitted to the laboratory for analysis.

Lab-certified bottles will be used to collect all water samples. All sample water will first be collected from a stream, flume, or groundwater well into clean plastic jugs or bottles and then separated into sample bottles. A separate collection jug will be used for each sample and then disposed of after collection. The following sample bottles will be used for collection and analysis (all samples collected without filtration unless otherwise indicated):

**Table 4-0: Containers Used for Certain Analyses with Recommended Holding Times**

| Analysis | No. of Containers | Container Type | Container Size | Preservative | Minumum Holding Times |
|---|---|---|---|---|---|
| Sample Transfer | 1 | HDPE jug | 1 gallon | None | None |
| Alkalinity<br>Total Dissolved Solids (TDS)<br>Total Suspended Solids (TSS)<br>Chloride<br>Sulfate Analysis | 1 | HDPE bottle | 500 mL | None | 7 days because of TDS and TSS |
| Salinity | 1 | HDPE bottle | 250 mL | None | 6 months |
| Total Metals<br>Silica<br>Water Hardness | 1 | HDPE bottle | 250 mL | $HNO_3$ | 28 days because of Hg |
| Dissolved Metals (field-filtered using 0.45µm filter) | 1 | HDPE bottle | 250 mL | $HNO_3$ | 28 days because of Hg |
| Potentially Dissolved Metals | 1 | HDPE bottle | 250mL | $HNO_3$ | 28 days because of Hg |
| Sulfide | 1 | HDPE bottle | 250 mL | NaOH and Zn Acetate | 7 days |
| Cyanide | 1 | HDPE bottle | 250 mL | NaOH | 14 days |
| Total Organic Carbon (TOC)<br>Nitrate Analysis | 1 | Amber glass | 250 mL | $H_2SO_4$ | 28 days |

The field parameter readings for all groundwater samples will be measured external to the sample location, using the container provided with the instrument. The surface water field parameters will be measured directly from the stream, or surface water source (in situ). Field measurement data for pH, temperature, electrical conductivity, dissolved oxygen, and Oxidation-Reduction Potential (ORP) will be recorded on the Field Water Sampling Form, an example of which is provided in Appendix F. To measure these parameters, a Hanna Instruments HI 9828 Multiparameter Meter or equivalent will be used. Well purge volumes will be measured for pH, temperature, and electric conductivity using an ExTech instrument, or equivalent. Field instruments will be calibrated each sample day prior to starting work activities, using standard solutions, and consistent with manufacturer's instructions. Weather parameters, including temperature and precipitation, will be obtained and recorded in the logbook or on the Daily Toolbox form. Field testing will be performed in accordance with AECI Standard Operating Procedures 2-9: Field Water Quality Measurements.

All sample bottles will be labeled to identify the sample number, date and time of collection, type of analysis, and appropriate preservative. The sample number will be created as follows:

**MW-2-DEEP_20130207**
**Sample Location_Date (date as YYYYMMDD)**

In addition, sample analysis / chain of custody forms will be completed and processed at the time of sample collection. Original chain of custody forms will be signed, dated, and placed in the sample shipment container prior to sealing the container for shipment. For information regarding specific sampling procedures, see AECI Standard Operating Procedures 1-6: Sample Custody and Documentation, 1-11: Packaging and Shipment of Field Samples, and 3-1: Surface Water and Sediment Sampling.

## 4.1 Sampling Handling

Each analytical sample is placed on ice immediately upon collection within a cooler. The coolers are transported from the field lab building on-site to the Rico office in town, at which point they are packaged for shipment, secured with packaging tape, and prepared for shipment with the necessary shipping labels. Table A5.4-1 of the QAPP lists holding times for each method; samples will be shipped to the laboratory with sufficient time for the laboratory to analyze the sample within the required holding time.

For each cooler that is shipped or transported to an analytical laboratory, a 100mL bottle of distilled water will be included that is marked “temperature blank.” This blank will be used by the sample custodian to check the temperature of samples upon receipt. A temperature blank is provided by the lab with each cooler.

All water samples will be placed in a cooled container and sent to Pace Analytical Laboratory. Sample analyses will be performed according to methods specified in 40 CFR, Part 136, or other methods approved by EPA. Laboratory methods, detection limits, and reporting limits for all parameters are presented in Table A5.4-1 of the QAPP. Laboratory results will be supported by sufficient backup data and QA results to enable reviewers to conclusively determine the quality of the data in accordance with the accompanying QAPP. The analytical report package will include reference to the analytical methods used, detection limits, and quality control data.

## 4.2 Sample Custody Documentation

See AECI Standard Operating Procedures No. 1-6 and 1-11 for all sampling handling, delivery, and custody procedures. A chain of custody (COC) form, which is provided in Appendix G of this plan, is completed daily for each set of samples.

COC procedures will be followed as indicated in Section B3 of the QAPP.

Samples will be analyzed in the laboratory within the holding times specified by the lab. Holding times for all parameters are listed in Table 4-0 above. If all samples are shipped together to be analyzed at the same time, then they must be shipped within the lowest holding time. Samples will always be shipped by overnight courier service to prevent ice in the coolers from melting. If the lab is not open the day following shipment, coolers must be kept on ice and shipped on a day when they can be received the following day at the lab.

## 5.0 Flow Measurement Methods

Discharge (flow) measurements will be conducted in accordance with the measurement procedures adapted for use during the previous Rico site monitoring, as well as USGS and USBR standard discharge measurement procedures, where applicable. An STI Ultrasonic IRU-5180 automated water level detector has been installed on the St. Louis Tunnel discharge, at the existing Parshall flume (DR-3). Additionally, an OTT PLS submersible pressure transducer has also been installed at the same flume. An OTT Orpheus Mini submersible pressure transducer has been installed at the existing Parshall flume at the final ponds system outfall discharge to the Dolores River (DR-6). These water level detectors are connected to data recorders which maintain hourly water level (i.e., stage) data that will be downloaded monthly to a laptop computer. The stage data will be converted to flow values using an appropriate flume-rating table or the following flume equation:

$$Q = CHa^n$$

Q = Flowrate (ft/s)
C = Free Flow Coefficient = 3.07 for 9” throat width
Ha = Measuring Head (depth of flow), measured at 2/3 the distance from the start of the throat to the beginning of the wall of one side of the converging section (see Figure 1)
n = Exponent = 1.53 for 9” throat width

*(Source: U.S. Bureau of Reclamation Water Measurement Manual Manual, Chapter 8, Section 10)*

A plan and section of a typical Parshall flume showing the key flume dimensions are shown on Figure 4

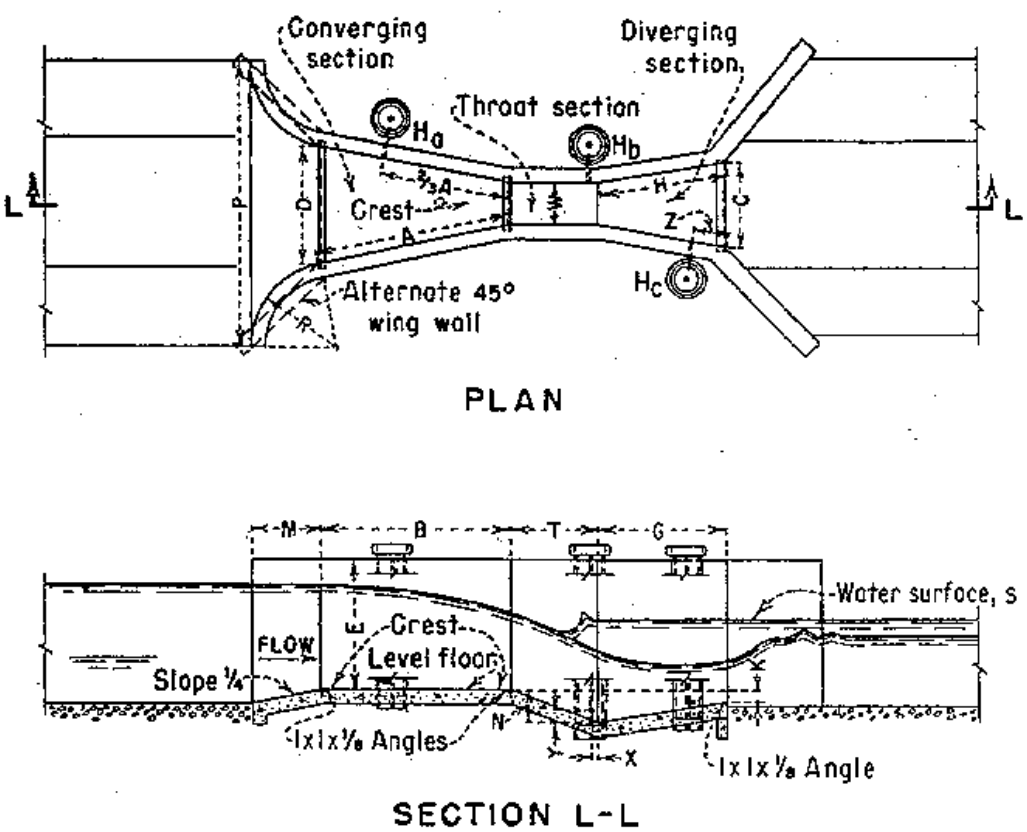


Figure 4. Parshall Flume Dimensions (*Source: USBR Water Measurement Manual, Ch. 10, Sec. 8)*

When monthly water quality samples are collected, flows will also be manually measured at the existing Parshall flumes. Manual measurements will also be taken if routine inspections identify any condition(s) that may affect

the accuracy of the automated data collection system. Water depth measurements will be taken at the location in the flume described above in the flume equation. Staff gages are present in the appropriate location at each flume to facilitate manual depth measurements. This water depth will then be used to read the flow rate from a flume-rating table, or will be used in the calculation of the flowrate from equations. The flow measurements will be recorded in a logbook or on sampling forms and the discharges calculated in the office. This information will be utilized to check and calibrate the automated stage measurement installations. Additionally, water levels of all active ponds will be recorded monthly by survey of elevations of pond water surface. Pond water levels to date are presented in Appendix F.

Flow velocity readings and flowrate calculations will be performed in accordance with AECI Standard Operating Procedures 3-4: Stream Flow Measurements and 3-6: Stream Flow Measurements with Portable Flowmeter. River flow measurements will be collected at Dolores River cross-sections DR-1, DR-2, DR-7, DR-4_SW, and DR-G. Each month, velocity readings will be taken at each cross-section using a Hach FH950 Portable Velocity Meter or equivalent. This method uses the velocity at six-tenths of the depth as the mean velocity, as identified in SOP 3-6, Appendix B. The average velocity will be taken at sub-sections along the cross-section, facing upstream. The width and depth of each subsection will also be measured and recorded. The flow meter will be set to the 5-second fixed-period average mode. Each average velocity will be multiplied by the area of the sub-section of the cross-section to obtain the flowrate for that portion. The sum of these flowrates will represent the total flowrate at that river cross-section. Additionally, the river water level (stage) will be gauged by survey or reference to a staff gage at the respective stations and recorded in the field logbook.

As control of work/safety are critical concerns of AR and the Rico team, obtaining river cross-sections during high flow and winter months poses safety issues. River bed geometry surveys will be conducted during lower-flow seasons when it is observed, suspected, or known that changes in river bed geometry may have occurred. This river bed survey will be used only in situations where high, fast flows prevent safe access and flow approximations are needed. If a new survey is needed, the river bed will be surveyed as soon as flows permit safe access and allow for an accurate survey to be performed. No adjustments to previous data at the re-surveyed location will be applied, though any data collected during high flow seasons thereafter will be compared to the newly surveyed river bed geometry to estimate flowrates. Stream sections will be selected with the desired characteristics of parallel flows, smooth streambed with minimal obstructions, a straight channel, and a flat streambed. The river water level will be gauged by survey or reference to a staff gage at the respective stations each month as far as safe access to the bank permits during periods of high flow and ice cover. The method of measurement will be noted for all data collected.

During winter months, ice and snow build-up create safety concerns for accessing and entering Dolores River sampling stations to retrieve samples and obtain flow measurements. If conditions, due to ice, snow, and avalanche dangers, prevent safe access to or within the river, these areas will not be sampled. Standard Operating Procedure 3-7 discusses the method to be used for Streamflow Measurement with Ice.

During high-flow periods, sampling technicians will not be permitted to enter the Dolores River cross-sections where flow velocity exceeds 7.5 feet per second and water depths exceed 3 feet, or where river depth and velocity make it too difficult for a sampling technician to stand. Such conditions generally occur during peak flow months. During these peak flow periods, river velocities may be estimated by the flotation method. This method involves measuring off a 20-foot section of ground along the bank parallel to the flow of the river. An object is released in the river upstream of the start of the 20-foot measured interval, as close to the center of the flow stream as possible. Due to high flows, an object can be carefully tossed from a safe location on the bank of the river, upstream of the start of the 20-foot interval. Once the object reaches the start of the 20-foot interval, a stopwatch is used to record the time required for the object to float on the surface of the river for the 20-foot length. A minimum of three trials are conducted and recorded in the field log book. An average is taken of the three trials and divided by 20 feet in order to obtain the average surface velocity in the center of the flow stream. This velocity is then multiplied by a factor of 0.8 (see Appendix H) in order to obtain an average vertical velocity for the stream. To increase accuracy, this procedure will be done along three flow paths in the stream: through the middle of each half of the stream and along the centerline. The total cross-sectional area is calculated based on previous river bed geometry surveys and a survey of the current river stage. This area is multiplied by the average stream center velocity to obtain a flow estimate for the river at that cross-section.

## 6.0 Potential for Sample Variability

Inconsistency and variability can potentially occur while completing groundwater and surface water sampling. These variables can impact both the field and laboratory portions of the project cycle. The following table details sources of variability and mitigations to limit variability.

**Table 6-1: Field Analysis Variability**

| Steps | Sources of Variability | Overcoming Variability |
|---|---|---|
| Establishing a Sample Point | Improper well construction/placement; inappropriate materials | Place wells strategically; observe and log construction; use appropriate materials. |
| Field Measurements | Instrument malfunction; operator error | Calibrate equipment; keep documentation calibration records; maintain and update equipment as recommended by manufacturer; perform hands-on “mentor” training of all sample personnel to confirm proper usage of equipment. |
| Sample Collection | Sampling mechanism bias; operator error | Use hands-on “mentor” training approach with all field sampling personnel; use standard operating procedures for all sampling tasks and to generate consistency in collection method. See Table 3-1 above for SOP list. |
| Sample Delivery and Transfer | Sampling mechanism bias; sample exposure; degassing; oxygenations; field conditions | Use hands-on “mentor” training approach for all field sampling personnel; use SOPs for sample handling and custody methods; use QC sample methods for review of field conditions and equipment conditions. |
| Field Blanks and Standards | Operator error; matrix interferences | Use QC sample methods (field and equipment blanks, duplicates, trip blanks, and others) for review of field conditions and any bias created by sample process. |
| Field Determination | Instrument malfunction; operator error | Calibrate and maintain field equipment; maintain field calibration logs; use SOPs to guide field monitoring |
| Preservation and Storage | Matrix interferences; handling/labeling errors | Use SOP to guide sample handling and storage |
| Transportation | Delay; sample loss | Follow custody and lab procedures regarding transportation and packaging of samples |

See Laboratory QA manuals for discussion of lab procedures, sources of error, and mitigation techniques.
.

## 7.0 Report

After review, the monthly report will be posted in PDF format on the project SharePoint site. Laboratory analytical data, field parameter measurements, flow values, and groundwater elevations will be maintained in the project EQuIS database as described in the QAPP. Data, including laboratory analytical, field parameters, flow measurements, and groundwater levels, will also be exported from the EQuIS database after QA/QC reviews are completed and provided in Excel format on the SharePoint site. Data management procedures, review, and QA/QC of data are described in detail in the QAPP.

If additional samples are collected beyond those normally sampled as part of the monthly sampling program, a brief description of these samples will be included in the monthly report. This section of the monthly report will list the location(s) where samples were collected, a short description of the type of location (e.g., well, pond discharge), the matrix (e.g., surface water, groundwater), and a short narrative explaining the purpose for collecting the sample.

# Figures

# 1 NORTHERN ST. LOUIS PONDS SAMPLING LOCATIONS

SCALE - 1" = 200'

General Notes

SCALE IN FEET
0 175 350

| No. | Revision/Issue | Date |
|---|---|---|
| | | |
| | | |

BP

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ENGINEERING COMPANY, INC.
977 WEST 2100 SOUTH
SALT LAKE CITY, UTAH 84119
(801) 972-6222

RICO WATER SAMPLING

NORTHERN ST. LOUIS PONDS SAMPLING LOCATIONS

RICO, COLORADO

| | |
|---|---|
| DRAWN BY: | MAD |
| ENGINEER: | MAD |
| APPROVED: | MAD |

| Project | Sheet |
|---|---|
| Date 9-Jan-13 | 1 |
| Scale 1" = 200' | |

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P:\SAP and QAPP Figures\20150109 Sampling Locations.dwg

**2** **SOUTHERN ST. LOUIS PONDS SAMPLING LOCATIONS**

SCALE - 1" = 200'

General Notes

SCALE IN FEET
0 100 200

| No. | Revision/Issue | Date |
|---|---|---|
| | | |
| | | |
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SALT LAKE CITY, UTAH 84119
(801) 972-6222

RICO WATER SAMPLING

SOUTHERN ST. LOUIS PONDS
SAMPLING LOCATIONS

RICO,
COLORADO

| | |
|---|---|
| DRAWN BY: | MAD |
| ENGINEER: | MAD |
| APPROVED: | MAD |

| Project | Sheet |
|---|---|
| Date 9-Jan-13 | 2 |
| Scale 1" = 200' | |

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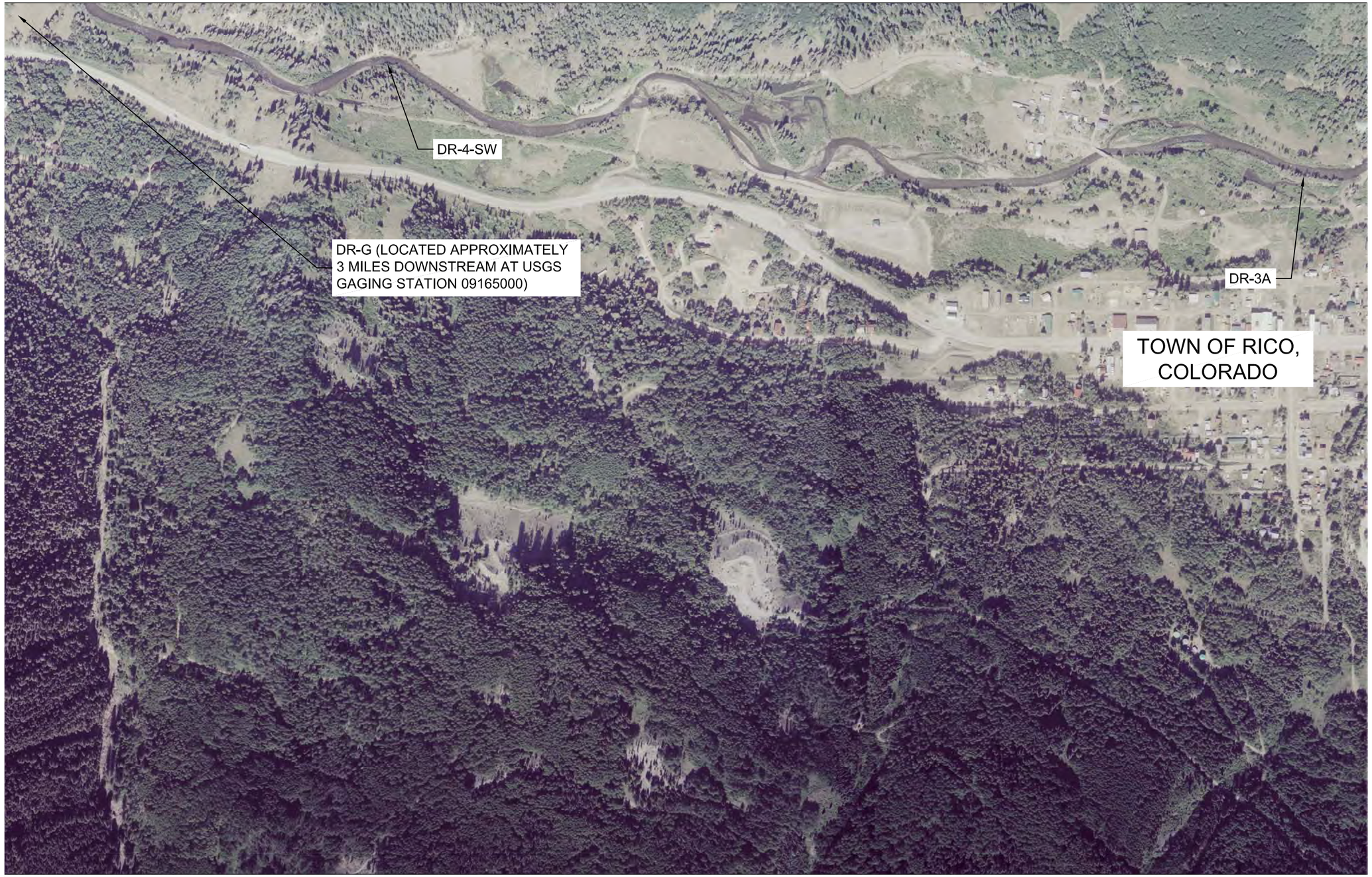


**3** **SAMPLING LOCATIONS SOUTH OF RICO, CO**

SCALE - 1" = 500'

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General Notes

SCALE IN FEET
0 250 500

| No. | Revision/Issue | Date |
|---|---|---|
| | | |
| | | |

BP / ARCO

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SALT LAKE CITY, UTAH 84119
(801) 972-6222

RICO SURFACE WATER SAMOPLING

SAMPLING LOCATIONS SOUTH OF RICO, CO

RICO, COLORADO

| | |
|---|---|
| DRAWN BY: | MAD |
| ENGINEER: | MAD |
| APPROVED: | CES |

| | |
|---|---|
| Project | Sheet 3 |
| Date 5-Apr-12 | |
| Scale 1" = 500' | |

F:\SAP and QAPP figures\20130109 South of Rico Sampling.dwg

# **Appendix A**

Pond Water Elevations

Appendix A - St. Louis Pond Water Levels

| | Pond Water Elevation (ft) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey Date | Pond 1 | Pond 2 | Pond 3 | Pond 4 | Pond 5 | Pond 6 | Pond 7 | Pond 8 | Pond 9 | Pond 10 | Pond 11 | Pond 12 | Pond 13 | Pond 14 | Pond 15 | Pond 18 | Comments |
| 6/1/2012 | 8769.53 | 8772.05 | 8773.70 | 8775.47 | 8778.24 | 8781.14 | 8785.36 | 8788.70 | 8792.91 | 8794.95 | 8806.22 | 8806.83 | - | 8808.22 | 8818.02 | - | |
| 6/20/2012 | 8769.11 | 8771.75 | 8773.50 | 8775.40 | 8780.18 | 8781.15 | 8785.35 | 8788.72 | 8792.92 | 8794.70 | 8806.27 | 8806.84 | - | 8808.24 | 8818.11 | - | *Pond 5 elevation may have been influenced by daily build-up of beaver dams at south flume |
| 7/18/2012 | 8769.09 | 8771.79 | 8773.51 | 8775.09 | 8779.21 | 8781.14 | 8785.40 | 8788.80 | 8792.93 | 8794.77 | 8806.32 | 8806.85 | - | 8808.27 | 8818.19 | - | |
| 8/28/2012 | 8769.18 | 8771.84 | 8773.64 | 8775.40 | 8779.45 | 8781.49 | 8785.44 | 8788.82 | 8792.94 | 8794.80 | 8806.49 | 8806.86 | - | 8808.21 | 8817.98 | | Note: Beaver dams found in ponds 5, 6, and 8 |
| 9/20/2012 | 8768.97 | 8771.61 | 8773.53 | 8775.37 | 8779.26 | 8781.46 | 8785.41 | 8788.78 | 8792.90 | 8794.62 | 8806.47 | 8806.75 | - | 8808.04 | 8818.04 | | |
| 10/19/2012 | 8769.08 | 8771.77 | 8773.62 | 8775.51 | 8778.99 | 8781.32 | 8786.15 | 8789.62 | 8792.76 | 8793.94 | 8806.01 | - | 8806.58 | 8807.95 | - | | BM 14/15 was removed during drilling operations in October 2012. BM 12/14 will be used to obtain water levels from Pond 15 from henceforth |
| 11/30/2012 | 8769.26 | 8771.91 | 8773.75 | 8775.68 | 8779.24 | 8781.41 | 8785.31 | 8788.66 | 8792.89 | 8794.89 | 8806.03 | 8806.81 | - | 8808.15 | 8817.95 | - | Ice cover present on a certain varying percentages of the surface of several ponds (ponds not listed below had no ice formation present):<br>Pond 1 - 90% frozen<br>Pond 2 - 90% frozen<br>Pond 4 - 20% frozen<br>Pond 5 - 40% frozen<br>Pond 6 - 75% frozen<br>Pond 7 - 90% frozen<br>Pond 8 - 50% frozen<br>Pond 9 - 40 % lightly frozen (thin ice)<br>Pond 10 - 99% frozen |
| Pond water levels not collected in December 2012 due to unsafe weather and site conditions, excessive ice builbup in ponds, and unsafe access conditions on pond embankments | | | | | | | | | | | | | | | | | |
| Pond water levels not collected in January 2013 due to unsafe weather and site conditions, excessive ice builbup in ponds, and unsafe access conditions on pond embankments | | | | | | | | | | | | | | | | | |
| Pond water levels not collected in February 2013 due to unsafe weather and site conditions, excessive ice builbup in ponds, and unsafe access conditions on pond embankments | | | | | | | | | | | | | | | | | |
| Pond water levels not collected in March 2013 due to unsafe weather and site conditions, excessive ice builbup in ponds, and unsafe access conditions on pond embankments | | | | | | | | | | | | | | | | | |
| 4/3/2013 | 8769.74 | 8772.05 | 8773.72 | 8775.66 | 8779.20 | 8781.26 | 8785.26 | 8788.67 | 8792.86 | 8795.03 | 8806.00 | 8806.78 | - | 8808.12 | 8817.93 | - | |

**Appendix B**

AECI Standard Operating Procedures

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1.0 PURPOSE ---------- Page 2
2.0 SCOPE ---------- Page 2
3.0 REQUIREMENTS ---------- Page 2
4.0 REFERENCES ---------- Page 2
5.0 DEFINITIONS ---------- Page 2
6.0 RESPONSIBILITIES ---------- Page 2
7.0 EQUIPMENT ---------- Page 2
8.0 PROCEDURE ---------- Page 3

# SAMPLE CUSTODY AND DOCUMENTATION

## 1.0 PURPOSE

The purpose of this procedure is to define the requirements necessary for Sample Custody and Documentation.

## 2.0 SCOPE

A stringent, established program of sample chain-of-custody procedures shall be followed during field sample collection and handling activities and transfer of the samples to the analytical laboratory.

## 3.0 REQUIREMENTS

Whenever possible, preprinted labels should be used to ensure that necessary information is retained with the sample.

## 4.0 REFERENCES

None

## 5.0 DEFINITIONS

None

## 6.0 RESPONSIBILITIES

### Field Project Leader

The Field Project Leader has overall responsibility for the correct implementation of sampling activities, including review of the sampling plan and any necessary training of the sampling technician(s). The actual collection, packaging documentation (sample label and log sheet, chain-of-custody recorded, Contract Lab reports, etc.) and initial custody of samples will be the responsibility of the sampling technician(s).

## 7.0 EQUIPMENT

Sample Label

Field Sample Data Sheet

Chain-of-Custody Record

## 8.0 PROCEDURE

### 8.1 Sample Label

Each sample shall be labeled, and the following information recorded on the label:

1. Sample identification;
2. Laboratory analyses;
3. Date and time sample was taken;
4. Preservative added; and storage (cooler/ice)
5. Remarks, including pertinent field observations.

### 8.2 Chain-of-Custody Record

Chain-of-custody (COC) records ensure that samples are traceable from the time of collection until they are received and analyzed by the analytical laboratory. An example COC is attached. If the samples are shipped via commercial shipper, the COC shall be sealed in the sample-shipping container, and the shipping agent or courier is not required to sign the COC. Upon arrival at the lab, the sample custodian checks the custody seals on the sample shipping container, opens the container and signs as receiving the sample.

A sample is in a person's custody if one of the following criteria is met:

1. It is in the person's possession;
2. It is in the person's view after being in possession;
3. It has been locked up to prevent tampering after it was in the person's possession; or
4. It was in the person's possession and was then transferred to a designated secure area.

The COC record is completed and signed by the individual physically in charge of its custody. The sampler is personally responsible for the care and custody of the sample until it is or relinquished to a carrier to transport to the laboratory.

When transferring possession of the samples, the individuals relinquishing and receiving the sample shall sign, date, and write the time of day on the COC record. Samples in separate coolers shall not be included in the same COC record. The COC record is enclosed with the samples in each given cooler after it has been signed by the sampler. The COC record also serves as the laboratory request form.

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Salt Lake City, UT
84119
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FAX (801) 972-6235

# CHAIN OF CUSTODY RECORD

COC# _____
Page _____ of _____

Client: _____
Project: _____
_____
AECI Contact _____

Lab Name: _____
Lab Contact: _____
Lab Address: _____
_____

Matrix Codes
(W) Water
(S) Soil
(L) Liquid

QC: (circle one)
I II III IV

| Field Location | Field Sample ID Number | Date | Time | Matrix | No. of Containers | Analysis Requested | | | | | | | | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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| Relinquished By: *signature* | Date | Time | Received By: *signature* | Date | Time | Special Instructions |
|---|---|---|---|---|---|---|
| | | | | | | |
| Relinquished By: *signature* | Date | Time | Received By: *signature* | Date | Time | |
| | | | | | | |
| Relinquished By: *signature* | Date | Time | Received By: *signature* | Date | Time | |
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| Relinquished By: *signature* | Date | Time | Received By: *signature* | Date | Time | |
| | | | | | | |

# TECHNICAL STANDARD OPERATING PROCEDURE No. 1-11

PACKAGING AND SHIPMENT OF FIELD SAMPLES

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2.0 SCOPE ---------- Page 2

3.0 REQUIREMENTS ---------- Page 2

4.0 REFERENCES ---------- Page 2

5.0 DEFINITIONS ---------- Page 2

6.0 RESPONSIBILITIES ---------- Page 3

7.0 EQUIPMENT ---------- Page 3

8.0 PROCEDURE ---------- Page 4

# PACKAGING AND SHIPMENT OF FIELD SAMPLES

## 1.0 PURPOSE

The purpose of this procedure is to define the requirements necessary for sample packaging and information on chain-of-custody records used in sample transfer. Site specific deviations from the procedures outlined in this document must be approved by the Project Manager or the Client Project Manager.

## 2.0 SCOPE

This procedure applies to the packaging, shipping and documentation of samples being transferred from the field to the laboratory for analysis.

## 3.0 REQUIREMENTS

Careful packaging, shipping and documentation are necessary to insure that all samples received are undamaged and authentic.

Sample packaging is to be in accordance with ultra clean sampling procedures defined in EPA method 1669.

## 4.0 REFERENCES

HAZWRAP, July 1990. *Quality Control Requirements for Field Methods*, DOE/HWP-69/R1.

HAZWRAP, July 1988. *Requirements for Quality Assurance of Analytical Data*, DOE/HWP-65, Rev. 0, July 1988.

U.S. Department of Transportation, 1983. *Hazardous Materials Regulations*, 49 CFR 171-177.

United States Environmental Protection Agency, 1984. *User's Guide to the Contract Laboratory Program, Office of Emergency and Remedial Response*, Washington, DC.

USAEC, May 1993. *U.S. Army Environmental Center Guidelines for Implementation of ER 1110-1-263 for USAEC Projects.*

USATHAMA, January 1990. *U.S. Army Toxic and Hazardous Materials Agency Quality Assurance Program*, USATHAMA PAM 11-41.

EPA Method 1669, *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels*, July 1996, Office of Water Engineering and Analysis Division, Washington, DC.

## 5.0 DEFINITIONS

**Carrier -** A person or firm engaged in the transportation of passengers or property.

**Chain-of-Custody Record Form -** A Chain-of-Custody Record Form is a printed form that accompanies a sample or group of samples as custody of the sample(s) is transferred from one custodian to the

subsequent custodian. Chain-of-Custody Record Form is a controlled document. One copy of the form must be retained in the project file.

**Custodian -** The person responsible for the custody of samples at a particular time, until custody is transferred to another person (and so documented), who then becomes custodian. A sample is under your custody if:

- You possess the sample.
- It is in your view, after being in your physical possession.
- It was in your physical possession and then you locked it up to prevent tampering.
- You have designated and identified a secure area to store the sample.

**Environmental Sample -** A low concentration sample typically collected offsite and not requiring DOT hazardous waste labeling as a high hazard sample.

**Packaging -** The assembly of one or more containers and any other components necessary to insure that all samples received are undamaged and authentic.

**Sample -** A sample is physical evidence collected from a facility or the environment, which is representative of conditions at the point and time that it was collected.

**Clean Hands –** All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handles by the individual designated as “clean hands”.

**Dirty Hands –** All operations involving preparations of the sampler (except the sample container itself), operation of any machinery, and for all other activities that do not involve direct contact with the sample.

**Holding Time** – The time from the moment the sample is taken from the source until analysis is performed on that sample in the lab.

## 6.0 RESPONSIBILITIES

**Field Project Leader -** Responsible for determining that samples are properly packaged and shipped, and for determining that the chain-of-custody procedures are implemented from the time the samples are collected to their release to the shippers.

**Field Samplers -** Responsible for implementing the packaging and shipping requirements and for initiating the chain-of-custody records until they are relinquished to another custodian, to the shipper, or to the carrier.

## 7.0 EQUIPMENT

1. Bubble Pack
2. Sampling Gloves
3. Reclosable Plastic Bags
4. Permanent Felt Tip Marker

5. Shipping Coolers
6. Ice or Blue Ice.
7. Ziploc plastic bags (appropriate size for samples).

## 8.0 PROCEDURE

### 8.1 Sample Packaging and Shipping

Samples collected for shipment from a site should be classified as environmental samples and in general, are not expected to be grossly contaminated with high levels of hazardous materials.

Upon arrival at the sampling site, one member of the two-person sampling team is designated as "dirty hands"; the second member is designated as "clean hands." This is in accordance with EPA method 1669.

### 8.2 Environmental Samples

#### 8.2.1 Packaging

Environmental samples may be packaged as follows:

- Place each sample within a Ziploc bag, then place that sample with bag into a second Ziploc bag. In accordance with EPA Method 1669 "clean hands, dirty hands" method. (to prevent sample labels from becoming saturated due to ice within the sample cooler)
- Place samples in a cooler.
- Pack with enough cushioning materials to minimize the possibility of container breakage.
- If sample preservation methods call for it, place ice which has been bagged in ziplock bags (or blue ice) in the cooler to maintain the proper preservative temperature of 4 degrees C
- Seal cooler with packing tape or duct tape if cooler is being shipped though commercial shipper to laboratory.
- Always ship samples overnight in order to prevent ice in coolers from melting before reaching the lab.

### 8.3 Holding Times

Samples must be analyzed in the laboratory within the holding times specified by the lab. For metals (except mercury) the holding time is 6 month. For mercury, it's 28 days; for alkalinity and cyanide analysis, it's 14 days; for sulfate and salinity, it's 28 days; for hardness, it's 6 months; and for TDS and TSS, the holding time is 7 days. If all samples are being shipped together to be analyzed at the same time, then all must be shipped within the lowest holding time, which will generally be 7 days.

### 8.4 Chain-of-Custody

See SOP 1-6 (Sample Custody and Documentation) for Chain of Custody guidelines.

# TECHNICAL STANDARD OPERATING PROCEDURES No. 2-9

FIELD WATER QUALITY MEASUREMENTS


1.0 PURPOSE ---------- Page 2

2.0 SCOPE ---------- Page 2

3.0 REQUIREMENTS ---------- Page 2

4.0 REFERENCES ---------- Page 2

5.0 DEFINITIONS ---------- Page 2

6.0 RESPONSIBILITIES ---------- Page 2

7.0 EQUIPMENT ---------- Page 2

8.0 PROCEDURES ---------- Page 3

# FIELD WATER QUALITY MEASUREMENTS

## 1.0 PURPOSE

The purpose of this procedure is to define the requirements for the standard operating procedure of taking field water quality measurements, including pH, temperature, oxidation-reduction potential, turbidity, dissolved oxygen, and conductivity.

## 2.0 SCOPE

This procedure applies to the calibration, operation, and maintenance of an EXTECH DO610 combo meter kit, which measures pH, temperature, conductivity and dissolved oxygen (DO).

## 3.0 REQUIREMENTS

Electrical conductance of a substance is its ability to conduct an electrical current. Chemically pure water has a low electrical conductance; while water that contains dissolved inorganic solids (chloride, phosphate, etc.) has a higher electrical conductance. Consequently, the greater the amount of dissolved solids in groundwater or surface water the greater the water's electrical conductivity.

## 4.0 REFERENCES

EXTECH Instruments DO610 ExStik II D*O/pH/Conductivity Kit Instruction Manual*

## 5.0 DEFINITIONS

None.

## 6.0 RESPONSIBILITIES

### Field Project Leader (FPL)

The FPL is responsible for overseeing the sampling activities and ensuring the proper calibration and maintenance of field water quality instruments.

## 7.0 EQUIPMENT

The instruments to be used for testing water quality in the field include the following:

- EXTECH DO610 DO/pH/Conductivity Meter Kit
- Hanna Instruments HI 9828 Multiparameter Meter

## 8.0 PROCEDURE

The manufacturers instructions included with the units are to be followed for initial and continuing calibration, and maintenance of the instruments. Instruction manuals are to be on-site with the instruments and are to be reviewed by the field personnel at the beginning of the sampling event. Instrument calibration of pH and conductivity should be done with standards that bracket the expected range of measured values.

Instruments are to be calibrated daily at or before the first sampling location of the day. Calibration information is to be recorded in the field log book.

Specific instructions on operating the equipment properly are given in detail in the HI 9828 Multiparameter instruction manual, which will always accompany the equipment. The DO610 combo kit will also be available at all times to serve as a redundant measurement system. It will be maintained and operated in accordance with the DO610 instruction manual, which will also always accompany the equipment.

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# SURFACE WATER AND SEDIMENT SAMPLING

## 1.0 PURPOSE

The purpose of this procedure is to define the requirements necessary for surface water and sediment sampling. This SOP presents a discussion of the recommended methods and frequency of sample collection as a guide to developing site-specific sampling programs. This procedure describes the methods and equipment commonly used for collecting environmental samples of surface water and sediment samples for either on-site examination and testing, or for laboratory analysis. Site-specific deviations from the procedures outlined in this document must be approved by the AECI Project Manager or the Client Project Manager prior to initiation of the sampling activity.

## 2.0 SCOPE

Surface water and sediment sampling is applicable to almost any site that has surface drainages on it or located hydraulically downgradient from it.

## 3.0 REQUIREMENTS

Many factors must be considered in developing a sampling program for surface water or sediments, including study objectives; accessibility; site topography; flow, mixing, and other physical characteristics of the water body; point and diffuse sources of contamination; and personnel and equipment available to conduct the study. For waterborne constituents, dispersion depends on the vertical and lateral mixing within the body of water. For sediments, dispersion depends on bottom current or flow characteristics, sediment characteristics (density, size) and geochemical properties. Ultra clean methods will be followed for sampling activities.

## 4.0 REFERENCES

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United States Environmental Protection Agency, 1980. *Standard Operating Procedures and Quality Assurance Manual*. Water Surveillance Branch, USEPA Surveillance and Analytical Division, Athens, Georgia.

U.S. Geological Survey, 1977. *National Handbook of Recommended Methods for Water-Data Acquisition*. Office of Water Data Coordination, USGS, Reston, Virginia.

EPA Method 1669, *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels*, July 1996, Office of Water Engineering and Analysis Division, Washington, DC.

## 5.0 DEFINITIONS

**Environmental Sample -** Low concentration sample typically collected offsite and not requiring DOT hazardous waste labeling as a high hazard sample.

**Sediment –** Sediment generally refers to solid material such as sand, silt, clay, and gravel, which is deposited by fluvial or alluvial processes.

**Clean Hands –** All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handles by the individual designated as "clean hands".

**Dirty Hands –** All operations involving preparations of the sampler (except the sample container itself), operation of any machinery, and for all other activities that do not involve direct contact with the sample.

## 6.0 RESPONSIBILITIES

### Project Manager

The Project Manager is responsible for the selection of the appropriate methodology, technique and field procedure for conducting the sampling.

### Field Project Leader (FPL)

May be an AECI employee or contractor who is responsible for overseeing the sampling activities. The FPL is also responsible for checking all work performed and verifying that the work satisfies the specific tasks outlined by this SOP and the Project Plan.

## 7.0 EQUIPMENT

1. Sampling Bottles (treated with preservatives, if necessary)
2. Specific Conductivity Meter
3. Dissolved Oxygen Meter
4. Turbidity Meter
5. Oxidation-Reduction Meter
6. pH Meter
7. Thermometer or temperature meter
8. Stainless Steel Bowl and Spoon
9. Stainless Steel Hand Augers, Shovel, or Spoon
10. Filtering Equipment (if analyzing for metals in water)
11. Peristaltic Pump
12. Decontamination Equipment and Supplies
13. Sampling nontalc gloves
14. Ziploc bags (appropriate size)

## 8.0 PROCEDURE

### 8.1 General Procedures for Surface Water Sampling

- In order to meet the sample handling and preservation requirements, several separate collection bottles will be used at each location, and together will comprise the "sample."

The sample will consist of preserved and non-preserved bottles. Preservatives may include nitric acid for metals analysis, sodium hydroxide for cyanide analysis, sulfuric acid for nitrates and total organic carbon analysis, sodium hydroxide and zinc acetate for sulfide analysis, or other appropriate preservatives for the required analysis. Non-preserved HDPE bottles will be used for inorganic analyses, such as alkalinity, salinity, total dissolved solids, etc.

- Upon arrival at the sampling site, one member of the two-person sampling team is designated as “dirty hands”; the second member is designated as “clean hands.” This is in accordance with EPA method 1669 for ultra clean sampling procedure.
- Care should be taken to insure that the grab sample is collected from a point that appears well-mixed, both laterally and vertically, and in the mid-stream of the flow. Backwater or stagnant areas should be avoided.
- If possible, the sampler should stand on the banks of the stream, avoiding sloughing into the stream channel. However, if it is not possible to reach a well-mixed, mid-stream flow from the banks, the sampler should wade into the stream wearing clean waterproof boots. Feet should be placed downstream of the collection point, with the sampler facing upstream. Care should be taken not to dislodge or stir up bed material or fine settled material coating the bed material.
- The lab-certified, pre-cleaned raw water bottle, which does not contain preservatives, may be used as a collection container for all sub-samples in the set. Pre-preserved bottles should not be immersed in the stream channel.
- The sampler should wear a clean, new pair of disposable gloves while lowering the collection container into the stream. The bottle mouth should face upstream, and be held under the surface. Depending upon the depth of the flow column, the bottle can be lowered below the water surface to mid-depth, but not so far as to collect or stir up bottom sediments.
- The collected water should be carefully poured into the acidified bottle designated for total metals without overflowing.
- Another batch of water can be similarly collected in the raw water bottle, from which a filtered sample for dissolved metals can be obtained. The dissolved metals portion, as well as all other portions needed for all analyses, should however be taken from the same original collected raw sample as the total metals portion. The peristaltic pump equipped with new, disposable tubing is used to pump water from the raw water bottle through the new, disposable 0.45 micron filter, and into a second acidified bottle for dissolved metals analysis. Alternately, the intake tubing for the pump may be lowered into the stream flow and the water pumped directly through the filter and into the acidified bottle for dissolved metals analysis.
- After collection at each sample site, the tubing and filter should be discarded.
- The raw water bottle used for collection purposes is then refilled if necessary and sealed for the remaining analytical sample.

## 8.2 General Procedures for Sediment Sampling

The following section outlines commonly used procedures for collecting surface water and sediment samples. Criteria for choosing the correct piece of sampling equipment is also covered in this section. All sampling equipment should be cleaned and decontaminated prior to use in accordance with SOP 1-9.

- In general, whenever sampling surface water and sediments from the same location, the surface water samples should be collected first and sediments second to minimize collection of sediment with the water samples.
- In general, the stream flow measuring is performed after the surface water and sediment samples have been collected.
- Protective clothing and proper equipment specified in the site-specific Health and Safety Plan should be worn and used.
- The sampling sequence shall begin at downstream locations and progress upstream to prevent cross-contamination from one location to another.
- Prior to sampling sediments in a stream, the sampling devise shall be rinsed with stream water at a point downstream from the sampling location. Twigs, leaves, pebbles, and debris that are not integral components of the matrix of interest must be removed by the sampling team. Prior to sampling sediments in a pond or lagoon, the sampling devise shall be triple rinsed with water near the sampling point. However, caution must be exercised to avoid disturbing the sediments at the sampling point by the rinsing activities.

The sediment sample should be mixed and homogenized in a stainless-steel bowl prior to placement in the sample container. Duplicates and split samples shall be collected from the same bowl as the sample.

## 8.3 Surface Water Collection Techniques

### 8.3.1 Dip Sampling

A dip or grab sample should be collected over a period of not exceeding 15 minutes. Water is often sampled by filling a container, either attached to a pole or held directly, from just beneath the surface of the water (i.e., a dip or grab sample).

### 8.3.2 Weighted Bottle Sampling

A grab sample can also be taken using a weighted holder that allows a sample to be lowered to any desired depth, opened for filling, closed, and returned to the surface. This allows discrete sampling with depth. Several of these samples can be combined to provide a vertical composite. Alternatively, an open bottle can be lowered to the bottom and raised to the surface at a uniform rate so that the bottle collects sample throughout the total depth and is just filled on reaching the surface. The resulting sample using either method will roughly approach a depth-integrated sample.

A closed weighted bottle sampler consists of a stoppered glass or plastic bottle, weight and/or holding device, and lines to open the stopper and to lower or raise the bottle.

#### 8.3.3 Pumps

A peristaltic pump may be used both for collection of a surface water sample and to pump water through a filter for dissolved metals analytical sample.

Tubing used for the pump shall be nonreactive (preferably Teflon® or Tygon®). The tubing shall be disposed of after one use.

When sampling, the tubing is weighted and lowered to the desired depth. The sample is then obtained by operation of the pump.

### 8.4 Underwater Sediment Collection Options

Sediment samples are generally collected at the same locations as the water samples. If only one sediment sample is to be collected, the site shall be approximately at the center of the water body. This is particularly true for reservoirs that are formed by the impoundment of rivers or streams. Generally, the coarser grained sediments are deposited near the headwaters of the reservoir. Bed sediments near the center will be composed of fine-grained materials which may, because of their lower porosity and greater surface area available for adsorption, contain greater concentrations of contaminants. The shape, flow pattern, depth distribution, and water circulation patterns must all be considered when selecting sediment, sampling sites. In streams, areas likely to have sediment accumulation (i.e., bends, behind islands or boulders, quiet shallow areas or very deep, low-velocity areas) shall be sampled while areas likely to show net erosion (i.e., high-velocity, turbulent areas) and suspension of fine solid materials shall be avoided.

Chemical constituents associated with bottom material may reflect an integration of chemical and biological processes. Bottom samples reflect the historical input to streams, lakes, and estuaries with respect to time, application of chemicals, and land use. Bottom sediments, especially fine-grained material, may help act as a sink or reservoir for adsorbed heavy metals, even if the water column concentrations are below detection limits. It is important to minimize the loss of low-density "fines" during any sampling process.

#### 8.4.1 Scoop Sampler

A scoop sampler may consist simply of a stainless steel spoon if the water is shallow enough (generally less than 8 inches deep) or a pole to which a jar or scoop is attached for deeper water. The pole may be made of bamboo, plastic, wood, or aluminum, and be either telescoping or of fixed length. A stainless steel scoop or glass jar at the end of the pole is usually attached using a clamp.

If the water body can be sampled from the shore or if it can be waded, the easiest and "cleanest" way to collect a sediment sample is to use a scoop sampler. This reduces the potential for cross-contamination. This method is accomplished by reaching over or wading into the water body and, while facing upstream (i.e., into the current), scooping the sample along the bottom in the upstream direction. It is very difficult not to disturb fine-grained materials of the sediment-water interface when using this method.

#### 8.4.2 Core Samplers

Core samplers are used to sample vertical columns of sediment. They are useful when a historical record of sediment deposition is desired, for they preserve the sequential layering of the deposit. Also, the sample is withdrawn intact, permitting the removal of only those

layers of interest. Core liners manufactured of glass, Teflon®, brass, or stainless steel. In addition, samples are easily delivered to the lab for analysis in the tube in which they are collected. The disadvantage of coring devices is that a relatively small surface area and sample size is obtained necessitating repetitive sampling to obtain large amounts of sample needed for some analyses.

Many types of coring devices have been developed to address varying depths of water from which the sample is to be obtained, the nature of the bottom material, and the length of the core to be collected. In shallow wade-able waters, the direct use of a core liner is recommended. The liner material shall be chosen based upon the analytical parameters required.

Core sampler tubes or liners shall be approximately 12 inches long since only recently deposited sediments, eight inches or less, are to be sampled. Soft or semi-consolidated sediments such as mud and clays have a greater adherence to the inside of the tube and thus can be sampled with larger diameter tubes. However, because coarse or unconsolidated sediments such as sand and gravel will tend to fall out of the tube, a small diameter is required. A tube about 2 inches in diameter is usually sufficient. The wall thickness of the tube shall be about 1/3 inches for either Teflon® or glass. The end of the tube may be tapered by filing it down to facilitate entry of the liner into the substrate.

### 8.5 Dry Channel Sediment Collection

Sediment samples collected from dry channels shall be collected according to the protocols listed in SOP 5.2 – Soil Sampling. Sediment collected from dry channels shall be collected from separate depths of 0-2 inches and 2-6 inches.

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# STREAM FLOW MEASUREMENTS

## 1.0 PURPOSE

The purpose of this procedure is to describe methods, sequence of operations, and equipment necessary to determine the cross-sectional area and flow of a stream. . Site-specific deviations from the procedures outlined in this document must be approved by the AECI Project Manager or the Client Project Manager prior to initiation of the sampling activity.

## 2.0 SCOPE

An essential part of any remedial investigation is knowing the quantities of stream flow across the site being investigated. This knowledge serves as an aid in determining proper remedial actions. Stream flow measurement is to be conducted concurrently with stream sampling. The flow should be measured immediately after the water quality sample is collected and in the same location.

## 3.0 REQUIREMENTS

Since the physical characteristics that streams exhibit vary widely, it is necessary to present several methods and techniques that can be used to calculate channel areas and flow rates.

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## 5.0 DEFINITIONS

**Flow (or volumetric flow rate) -** The volume of water that passes through a cross-sectional plane in some unit of time.

**Flume -** An artificial channel used for constricting the flow of water in order to promote laminar flow for the purpose of measuring flow volume.

**Stage -** The height of a water surface above an arbitrarily established datum plane.

**Weir -** A levee or dam-type structure containing a notch through which the flow of water can be measured and regulated.

## 6.0 RESPONSIBILITIES

### Project Manager

The Project Manager is responsible for the selection of the appropriate methodology, technique and field procedure for conducting the flow measurements.

### Field Project Leader

The Field Project Leader is responsible for the execution of the field test to determine flow in an open channel. The Field Project Leader is also responsible for inspection of equipment to ensure its adequacy for performance, and preparation of the site.

## 7.0 EQUIPMENT

Equipment required will vary depending upon method of cross-sectioning and flow measuring selected.

## 8.0 PROCEDURE

### 8.1 General

The discussion below addresses the various methods and techniques used to measure cross-section and stream velocities with respect to the velocity-area open channel technique of stream flow measurement. These techniques should be applied whenever stream gauging information is not available. When possible, stream gauging station information will be utilized because real time flow information can be obtained from the authority responsible for the station.

The most common method of open channel flow determination is the velocity-area method. In this method, a flow or discharge measurement is computed as the summation of the products of partial areas of the flow cross-section and their respective average velocities as determined by a current meter. This calculation is represented by the formula:

$Q = \Sigma V * \Sigma A$ where:

Q = total discharge,

A = individual partial cross-sectional area

V = corresponding mean velocity normal to the partial area

$\Sigma$ = summation of individual measurements

Alternately, the portable control section method may be used, which uses a pre-calibrated control structure such as a flume or weir. These methods are discussed below.

### 8.2 Cross-Sectional Area Determination

#### 8.2.1 Width Determination

Width determination for narrow, shallow streams and brooks is accomplished by a simple tape measurement; however, for large streams, alternatives may be required. Bridges are convenient avenues across which measurements can be made. An equally acceptable method of determining width will be by transit and stadia survey techniques.

#### 8.2.2 Depth Determinations

Most often, depth measurements are taken directly with a measured rod or sounding weight. The mass of the weight suspended at the end of the tape should be sufficient to keep the tape essentially vertical. For high velocity streams or excessively deep channels, a sonic sounder is most appropriate, since some can be adapted to produce a continuous strip chart profile of the channel depth.

### 8.3 Velocity/Flow Determinations

As a general practice, the actual measurement of depth, width and velocity would normally occur concurrently. When flow measurement is to be performed concurrently with analytical sampling, the analytical samples are to collected prior to measuring the flow in order to avoid compromising

the sample with stream sediment. The main parameters to be collected for open channel flow determinations will be cross-sectional area and stream velocity.

### 8.3.1 Current Meters

Current meters provide a quick and relatively accurate method of determining flow under existing site conditions. They are generally not used for long-term determinations. There are many types of current meters: mechanical, electrical, vertical shaft, and horizontal shaft. The types preferred for open channel stream measurement are those which have a vertical shaft. The basic concept of a current meter is that a rotating element at the end of the vertical shaft (or, in some cases, stationary electrodes) is submerged beneath the stream's surface where the flow of water rotates the element (or passes between the electrodes). The speed of rotation of the element (or flow between the electrodes) measured directly by the current meter which is then correlated to stream flow velocity through the meter's own electronic circuitry or by graphs or charts which accompany the instrument. Speed is normally measured in meters/second or feet/second. Current meters will generally measure flow down to 0.03 meters/sec (0.1 ft/second). Current meters that use electrodes may be utilized for measuring streams that have weedy growths emanating from the stream bottom which would affect the rotation element. The depth to which current meters can be used will only be limited by the ability to hold the unit rigid at depth. Once a current meter value is taken, the measurement will be averaged with other measurements taken along a vertical transect of the stream at that point to determine the mean velocity along that vertical transect. In a wide stream, several vertical transects can be constructed such that less than 10 percent of the volume of the stream will be represented by each transect. The mean stream velocity can be calculated as the average of the individual average vertical velocities of each transect, with each average velocity weighted by the cross-sectioned area of the stream that it represents.

The Standard Operating Procedures regarding current meters for the IS&R/Carr Fork site shall follow all guidelines as discussed in SOP 3-6, “Streamflow Measurement with Portable Meter.”

### 8.3.2 Flumes

A considerably more sophisticated method of determining stream flow is through the installation of artificial, pre-calibrated control structures such as a flume. A flume is basically a constricted flow structure that provides a uniform cross-section for measurement of flow. Flow should be determined within the superficial section within the throat of the constriction. For a detailed discussion of weirs and flumes, see U.S. Geological Survey (1977), Volume 1, Chapter 1, pp. 1-65 to 1-77.

A flume is a specially shaped, open channel flow section which restricts the channel area and/or changes channel slope. This configuration results in an increased velocity and change in the level of the liquid flowing through the flume. The volumetric flow through the flume is determined by measuring the liquid level in the flume at a gage point, usually at some point downstream from the flume inlet. The liquid level/ flow rate relationship for a flume is defined by either test data (calibration curves) or by an empirically derived formula. This relationship s typically supplied by the manufacturers. Flumes are used when hydraulic head loss through the channel must be minimized,

sediments or solids are present in the stream flow, and stream flow rates vary.

The selected flume location for open channel flow measurement shall be accessible in all weather conditions with an inlet approach that is level, straight, and of sufficient length to allow for smooth and uniform flow. In all cases, manufacturer's recommendations for installation, calibration, and instrumentation shall be followed.

To measure the quantity of flow using a flume, the depth of flow from the water surface to the flume floor is obtained at a gage point in the converging section of the flume structure. Liquid levels in the flume relate directly to flow quantity by a mathematical formula specific to a particular flume geometry. In all cases, the manufacturer will supply the flow quantity formula to be used.

For fluid flow height measurement, a staff gauge shall be permanently mounted in the converging section of the flume according to manufacturer's recommendations. If manual flow levels are used, several levels shall be read. All data shall be recorded in the bound field logbook (see SOP 1-5).

If fluid levels in a flume are measured electronically, an ultrasonic water-level transmitter or equivalent device shall be used. This device will measure the liquid level in the flume and provide output signals to a data recorder for flow rate and volumetric flow totals. If an ultrasonic transmitter is used, it shall be installed, calibrated, and maintained according to manufacturer's recommendations.

### 8.3.3 Weirs

A weir is a dam or obstruction placed across an open channel with an opening on top through which the measured liquid flows. Stream flow should be determined by measuring the height of flow through the weir, which is a function of potential energy behind the overfall. Weirs are classified according to the shape of the weir plate opening. The most common types of weirs are the rectangular weir, the V-notch weir, and the trapezoidal weir.

The volumetric flow through a weir may be determined by measuring the liquid level at a prescribed distance upstream from the weir plate. Characteristic head versus flow relationships are governed by the geometry of the weir plate. All level measurements are made relative to the crest elevation. Weirs are not suitable for flat-sloped channel installations where head loss must be considered and for water carrying excessive solid materials or silt.

To measure the quantity of flow using a weir. the head or vertical distance from the crest of the weir plate to the liquid surface is measured in the pool upstream from the crest. Once the head is known, the quantity of flow can be determined using the known head-flow rate relationship of the particular weir (i.e., V-notch, rectangular. etc.).

For the head measurement, a staff gage shall be permanently mounted in the pool upstream from the weir crest. If manual head measurements are used, several levels shall be read. All data shall be recorded in the bound field logbook (see SOP 1-5).

If head levels in a weir are measured electronically, an ultrasonic water-level transmitter or equivalent device shall be used. This device will measure the liquid level and provide

output signals to a data recorder for flow rate and volumetric flow totals. If an ultrasonic water-level transmitter is used, it shall be installed, calibrated, and maintained according to manufacturer's recommendations.

### 8.3.4 Instrumentation

Flow measurements can be recorded either manually or electronically. A flow totalizer for recording the quantity of water shall be installed at all electronically instrumented measurement locations.

All flow recording instruments shall be protected from weather and vandalism, and shall be checked on a regular basis to ensure the data recorder (totalizer or chart) is functioning properly. Manually recorded flow quantities shall be entered in the bound field logbook. Original charts from electronically recorded flow quantities shall be kept in central files for future reference.

### 8.3.5 Calculations

Calculations related to flow measurement shall be completed using established procedures as listed in SOP 3-6. Results from calculations shall be checked and verified before use or permanent storage.

### 8.3.6 Records

All records associated with flow measurement including charts, graphs, and field logs, shall be placed in a calculation brief format, checked, and verified prior to use or permanent storage.

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# STREAMFLOW MEASUREMENT WITH PORTABLE METER

## 1.0 PURPOSE

The objective of streamflow measurement is to determine the discharge (volume/time = flow velocity x area) by dividing a representative stream cross section into smaller sections, measuring flow velocity and area of each smaller section, and summing the measured discharge of each smaller section to provide the total stream discharge. This SOP is to be used by employees of AECI and/or contractors/subcontractors. Site-specific deviations from the procedures outlined in this document must be approved by the AECI Project Manager or the Client Project Manager prior to initiation of the sampling activity. This SOP relates directly to SOP 3-4: Stream Flow Measurements, and acts as a subsection of that SOP. Field team shall be familiar with Both SOPs.

## 2.0 SCOPE

An essential part of any remedial investigation is knowing the quantities of stream flow across the site being investigated. This knowledge serves as an aid in determining proper remedial actions.

## 3.0 REQUIREMENTS

None

## 4.0 REFERENCES

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Wilson, James F., Jr., 1968. "Fluorometric Procedures for Dye Tracing," *U.S. Geological Survey Techniques Water-Resources Investigation*, Book 3, Chapter A12, p. 31.

## 5.0 DEFINITIONS

**Flow (or volumetric flow rate) -** The volume of water that passes through a cross-sectional plane in some unit of time.

## 6.0 RESPONSIBILITIES

### Project Manager

The Project Manager is responsible for the selection of the appropriate methodology, technique and field procedure for conducting the flow measurements.

### Field Project Leader (FPL)

May be an AECI employee or contractor who is responsible for overseeing the sampling activities. The FPL is also responsible for checking all work performed and verifying that the work satisfies the specific tasks outlined by this SOP and the Project Plan.

## 7.0 EQUIPMENT

1. Portable flow meter (Marsh-McBirney Model 2000 or equivalent), or Global Water Flow Probe propeller type flowmeter.
2. Flow meter wading rod, calibrated in .1-foot intervals
3. Measuring tape or equivalent

## 8.0 PROCEDURE

1. Select a stream section (metering section) where flows are mostly parallel, there are no sharp turns in water direction, and the bottom is reasonably smooth; the velocity measurements will be more accurate. The metering section can be smoothed by reshaping the edges, removing rocks from the bottom, removing aquatic weeds, etc. It is usually not possible to satisfy all of these conditions. Select the best possible metering section using these criteria.
2. Record the metering section location, time date, recorder and other pertinent information in the field log book.
3. Set a measuring tape or equivalent across the metering section as perpendicular to the flow as possible. Anchor both ends securely to wooden stakes, trees, rocks, etc. This placement will allow accurate placement of the flowmeter across the metering section.
4. Divide the metering section into sections (no more than two feet wide). For streams wider than 5 feet, not more than 10% of the flow can be included in any one vertical section.
5. Velocity measurements begin at the initial point at either the left or right bank of the metering section. The initial point is usually defined as the measuring tape reading at the contact of the water line and stream bank. However, in some cases, there may be no flow for some distance from the stream bank, due to stagnant water or backwater effects. In such a case, the initial point begins where positive flow can be measured. Record the initial point reading in the field log book.
6. Attach the flow meter probe to the wading rod. Turn on the flow meter.
7. Position the flow meter in the center of the first vertical section.
8. Measure the water depth using the wading rod. Record the total water depth in the field log book. Water depth is determined from calibrations on the wading rod. Three marks signify 1-foot intervals, two marks signify 0.5-foot intervals and one mark signifies 0.1-foot intervals. Depth measurements on the Global Water Flow Probe can be read directly from attached measuring tape. Read stream depths ignoring the “pile-up” effect of water on the upstream side of the wading rod.
9. Position the flow meter to six-tenths of the total depth (from the surface) of the vertical section and pointing directly into the flow. This depth can be obtained using the wading rod by aligning the total depth marks on the rod to the 0.6 mark on the wading rod handle. Allow the flow meter to stabilize for 10 seconds. Measure the velocity for 30 seconds. Record this value in the field log book. This value is the velocity used to determine the flow within the vertical section being measured.

   This method will be best utilized when the depth of the stream is less than 0.8 meters (2.6 feet) but greater than 0.1 meters (0.3 feet). In this method, each measurement within each vertical section should be taken three times and the result averaged to determine the mean velocity. This method will reduce the effects of aberrant measurements.

11. Calculate the area (feet squared) of vertical section by multiplying the width by the total depth.
12. Calculate the flow (cubic feet per second) of each vertical section by multiplying the area by the average velocity.
13. Calculate the total flow of the metering section by summing all the flows of each vertical section. Record this value in the field log book.

## 9.0 PRECAUTIONS

The limit for wading is set by health and safety considerations of the field personnel. The amount of water that can be waded safely varies slightly with each individual, but is principally a function of velocity, depth, and substrate stability and slickness. Field personnel shall not take chances in gauging streams that cannot be easily waded.

The wading position taken by the field personnel when making stream flow measurements can affect the velocity of the water passing the flow meter probe. The best position to stand in the stream is approximately 18 inches or more to the side of the wading rod and flow meter probe. This allows the water to flow around the flow meter freely without the potential back water effects a downstream wader may cause.

## 10.0 QUALITY CONTROL

Because flow is not a direct measurement (velocity, depth, width, and area are measured first), the accuracy of the method cannot be determined. With selection of good cross-sections, and careful measurements of depth and velocity, measured flow should be within ±10 percent of true flow.

Precision of the method (and technique of the investigator) can be determined by measuring total flow several times along the same cross-section.

Peak instrument performance can be ensured by conducting the periodic maintenance tasks detailed in the Instruction Manual. These tasks include cleaning of the probe, checking the meter zero, and checking the condition of batteries.

## 11.0 SPECIAL INSTRUCTIONS

Because total flow determination in an open channel is a summation or integration process, the overall accuracy of the measurement is generally increased by increasing the number of partial cross-sections. Generally, 10 to 20 cross-sections are adequate depending on the variability and complexity of the cross-sectional shape and flow patterns. With a smooth cross-section and good velocity distribution, or with narrow stream channels, fewer sections may be used.

Occasionally, flows are not perpendicular to the established cross section for its entire width. If high or low flows change flow patterns at an established cross-section, consideration should be given to temporarily or permanently moving a cross-section rather than using a substandard, established one.

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# STREAMFLOW MEASUREMENT WITH ICE PRESENT USING PORTABLE METER

## 1.0 PURPOSE

During the winter season, ice and or snow may partially or completely cover sampling and flow monitoring locations along the Dolores River and the St. Louis settling ponds system. Obtaining samples and flow measurements during winter conditions presents additional safety hazards and requires allowances for restricted surface flow measurements and calculations. This SOP covers collecting flow measurements in surface waters no deeper than three feet below the top of ice cover. Therefore, previous knowledge of the cross section locations is required to know the approximate depth of the water when ice and snow cover is present. Attached to this SOP are cross section measurements obtained when no ice cover was present.

The objective of stream flow measurement is to determine the discharge (volume/time = flow velocity x area) by dividing a representative stream cross section into smaller sections, measuring flow velocity and area of each smaller section, and summing the measured discharge of each smaller section to provide the total stream discharge. When ice cover is present a coefficient multiplier is included into the flow calculation to account for reduced velocity caused by surface friction from the bottom of the ice cover.

This SOP is to be used by employees of AECI and/or contractors/subcontractors. Site-specific deviations from the procedures outlined in this document must be approved by the AECI Project Manager or the Client Project Manager prior to initiation of the sampling activity. This SOP relates directly to SOP 3-4: Stream Flow Measurements, and acts as a subsection of that SOP. Field team members shall be familiar with both SOPs.

## 2.0 SCOPE

Many remedial investigations require evaluation of hydrological data including cross sections and flow measurements of flowing surface water through and adjacent to the investigation site. Capturing low flow measurements during the winter season may require field teams to access partially or completely ice and or snow covered rivers or streams.

## 3.0 REQUIREMENTS

None

## 4.0 REFERENCES

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Wilson, James F., Jr., 1968. "Fluorometric Procedures for Dye Tracing," *U.S. Geological Survey Techniques Water-Resources Investigation*, Book 3, Chapter A12, p. 31.

## 5.0 DEFINITIONS

**Flow (or volumetric flow rate) -** The volume of water that passes through a cross-sectional plane in some unit of time.

## 6.0 RESPONSIBILITIES

### Project Manager

The Project Manager is responsible for the selection of the appropriate methodology, technique and field procedure for conducting the flow measurements.

**Field Project Leader (FPL)**

May be an AECI employee or contractor who is responsible for overseeing the sampling activities. The FPL is also responsible for checking all work performed and verifying that the work satisfies the specific tasks outlined by this SOP and the Project Plan.

## 7.0 EQUIPMENT

1. Portable flow meter suitable for measuring flows with ice present, user manual
2. Flow meter wading rod, calibrated in 0.1-foot intervals
3. Measuring tape or equivalent
4. Ice stick or flow meter wading rod suitable for measuring thickness of ice cover.
5. Hip boots or waders
6. Ice chisel
7. Ice auger if ice is too thick to allow chiseling access holes
8. Ice strainer – to remove ice chips from measuring holes
9. Snow shovel
10. Ice creepers (boot sole traction attachments to provide stable footing on ice)
11. Winter clothing that conforms with Cold Stress Anderson Defined Practice

## 8.0 PRECAUTIONS

The limit for wading is set by health and safety considerations of the field personnel. The amount of water that can be waded safely varies slightly with each individual, but is principally a function of velocity, depth, and substrate stability and slickness. Field personnel shall not take chances in gauging streams that cannot be easily waded.

The danger of working on ice-covered streams should never be underestimated. The fact that water is flowing under the ice means that falling through the ice will likely result in an extremely dangerous situation. This SOP covers collecting flow measurements in surface waters no deeper than three feet below the top of ice cover. Therefore, previous knowledge of the cross section locations is required to know the approximate depth of the water. Attached to this SOP are cross section measurements obtained when no ice cover was present along the Dolores River.

When working on frozen streams you should be aware that ice thickness may be irregular, especially late in the season when a thick snow cover may act as an insulator. Also, keep in mind that water just above freezing can slowly melt the underside of the ice, creating thin spots and that ice bridged above the water may be weak, even though most of the ice is relatively thick. Ice creepers are traction devices that can be strapped on the bottom of boots or waders to help prevent slipping on ice-covered streams.

When crossing the stream, the field team should test the strength of the ice with solid blows from a sharp ice chisel. You should make sure you have a strong hold on the ice chisel, so if it does go through the ice it won't slip out of your hand.

When considering between a power or hand auger, a power auger may be the best choice if numerous holes are required in ice thicker than 8-inches. Keep in mind when drilling holes that the weight of the ice can place the water under pressure. You should be prepared for the fact that water may rise in the hole when it is drilled.

## 9.0 PROCEDURE

1. When selecting a current meter consider models with no moving parts or use an ice meter equipped with polymer bucket wheels mounted on a round ice rod. Polymer bucket wheels are approved by the United State Geological Survey (USGS) for ice measurements because their solid construction reduces the effect of slush on the meter. Polymer bucket wheels are not approved by the USGS for normal open-channel measurements.
2. Select a stream section (metering section) where flows are mostly parallel, there are no sharp turns in water direction, and the bottom is reasonably smooth; the velocity measurements will be more accurate. The metering section can be smoothed by reshaping the edges, removing rocks from the bottom, removing aquatic weeds, etc. It is usually not possible to satisfy all of these conditions. The upstream end of a riffle, which will be the downstream end of a pool, is usually a good location to make an ice measurement because that is where slush ice should be at a minimum. Slush is usually thickest at the upstream end of a pool. Velocity measurements made at shallower depths than 1.5 feet should have the accuracy estimate of the measurement downgrade, because the velocity measurement will be affected by proximity to the stream bed and water surface. If most depths are less than 1.5 feet, you should try to find another section that has larger depths. Select the best possible metering section using these criteria.
3. Record the metering section location, time, date, recorder and other pertinent information in the field log book or forms.
4. To prepare the cross section for drilling or chipping access holes, the field team should test the strength of the ice with solid blows from a sharp ice chisel with every step across the river. Although it is not always necessary, you may prefer to shovel snow from the cross section prior to drilling holes.

   After you prepare the cross section you will need to drill holes where the majority of flow is located. If ice is thin an ice chisel can be used to cut holes. If the ice/snow cover does not bridge completely across the river or the cover is mostly snow, you may choose stand on the stream bed and shovel or chip away the surface snow and ice creating a channel wide enough to stand in across the stream.

   Reference the previously completed cross section drawings attached to this SOP and choose locations to drill several exploratory holes.
5. As with open channel measurements, velocity and depth should be measured at least 20 locations along the cross section. No more than 10% of the total flow should be measured at any one subsection. With a smooth cross section and good velocity distribution, or with narrow stream channels, fewer sections may be used.
6. Set a measuring tape or equivalent across the metering section as perpendicular to the flow as possible. Anchor both ends securely to wooden stakes, trees, rocks,

etc. This placement will allow accurate measurements of flow monitoring locations across the metering section.

7. Measure water and ice depth and calculate effective depth. Total water depth is determined by reading the depth on an ice rod or stick when held on the stream bottom. Read stream depths ignoring the "pile-up" effect of water on the upstream side of the wading rod. The thickness of ice below the water surface is then determined by raising the ice rod, wading rod with base plate, or stick to hook the bottom of the ice and reading the depth.

   You can also measure depths using an ice rod and attached hook. Using an ice stick, rather than the ice rod, will help prevent the meter, which will probably be attached to the ice rod, from being damaged or frozen before it is needed to measure velocity.

   Effective depth is the total depth of water minus the distance from the water surface to the bottom of the ice (the ice thickness). Effective depth = total depth of water – thickness of submerged ice.

   Slush ice, which can jam meters, is often present in flow under ice. Small amounts of slush and auger cuttings can be removed from holes. This facilitates reading depths and eliminates the possibility it will clog the meter. It will be impossible to remove large amounts of stream borne slush.

   When slush ice is present in a hole, effective depth becomes the total depth of flow minus the distance from the water surface to the interface between water and slush. The interface between water and slush can be determined by raising the current meter to a point were slush prevents the meter from turning.

   It might be easiest to measure depths in all holes before measuring velocity. This is especially true when cross sections are not too wide.

8. Velocity should be measured after depths are measured and effective depth determined for each hole. Effective depth is used to determine the proper position for measuring velocity. Velocity is measured at 0.2 and 0.8 depth when effective depths are greater than 2.5 feet and at 0.6 depth when the effective depth is less than 2.5 feet.

   The proper meter location for measuring velocity can be computing using the formulas shown below. For example, the meter can be set at 0.2 of the depth by holding the meter at depth equal to the thickness of ice plus 0.2 the effective depth as measured from the top of the ice surface.

   - 0.2-depth setting = ice thickness + 0.2(effective depth)
   - 0.8-depth setting = total depth - 0.2(effective depth)
   - 0.6-depth setting = total depth - 0.4(effective depth)

   When measuring velocity, effects of water pulsating in the hole can be reduced by keeping the meter as far upstream as possible, while still keeping the meter vertical. You should minimize the amount of time the meter is out of the water when you move from hole to hole. This helps prevents the meter from freezing up while you are using it. In addition, it is a good idea to keep the meter in the first hole you drill until you are ready to use it. This prevents the meter from super cooling prior to use.

Velocity profiles under ice differ from open-channel profiles. The roughness of the ice bottom causes the thread of maximum velocity to be farther below the surface than during non-ice measurements. Velocity measurements made at shallower depths than 1.5 feet should have the accuracy estimate of the measurement downgraded (e.g. to poor), because the velocity measurement will be affected by proximity to the stream bed and water surface below the ice. Ice measurements are inherently less accurate than open-channel measurements and are seldom rated better than fair.

When depths are relatively large (greater than 2.5 feet), average water velocity in the vertical can be estimated by averaging velocity measured at 0.2 and 0.8 the depth. When depths are less than 2.5 feet, deformation of the velocity profile by ice cover makes it necessary to apply a coefficient of 0.92 to velocities which are measured at 0.6 depth.

When cross sections are only partially frozen, stream discharge can be measured by combining open-water methods with methods used to measure under ice. However, if measurements are taken in close proximity to ice cover, the ice may still have an effect on the velocity distribution in the narrow open-water section, and you may decide to use only the methods to measure flow under ice.

The wading position taken by the field personnel when making stream flow measurements can affect the velocity of the water passing the flow meter probe. The best position to stand in the stream is approximately 18 inches or more to the side of the wading rod and flow meter probe. This allows the water to flow around the flow meter freely without the potential back water effects a downstream wader may cause.

Velocity measurements begin at the initial point at either the left or right bank of the metering section. The initial point is usually defined as the measuring tape reading at the contact of the water line and stream bank. However, in some cases, there may be no flow for some distance from the stream bank, due to stagnant water or backwater effects. In such a case, the initial point begins where positive flow can be measured. Record the initial point reading in the field log book.

Allow the flow meter to stabilize for 10 seconds. Measure the velocity for 30 seconds. Record this value in the field log book. This value is the velocity used to determine the flow within the vertical section being measured. Each measurement within each vertical section should be taken three times and the result averaged to determine the mean velocity. If the flow meter model used provides an average flow per unit of time, monitor the flow for 30 sections and record a consistent average flow. This method will reduce the effects of aberrant measurements.

11. Calculate the area (feet squared) of vertical section by multiplying the width by the total depth.
12. Calculate the flow (cubic feet per second) of each vertical section by multiplying the area by the average velocity. When depths are relatively large, average water velocity in the vertical can be estimated by averaging velocity measured at 0.2 and 0.8 the depth. When depths are less than 2.5 feet, deformation of the velocity profile by ice cover makes it necessary to apply a coefficient of 0.92 to velocities which are measured at 0.6 depth.
13. Calculate the total flow of the metering section by summing all the flows of each vertical section. Record this value in the field log book or field forms.

## 10.0 QUALITY CONTROL

Because flow is not a direct measurement (velocity, depth, width, and area are measured first), the accuracy of the method cannot be determined. With selection of good cross-sections, and careful measurements of depth and velocity, measured flow should be within ±10 percent of true flow.

Precision of the method (and technique of the investigator) can be determined by measuring total flow several times along the same cross-section.

Peak instrument performance can be ensured by conducting the periodic maintenance tasks detailed in the Instruction Manual. These tasks include cleaning of the probe, checking the meter zero, and checking the condition of batteries.

## 11.0 SPECIAL INSTRUCTIONS

Because total flow determination in an open channel is a summation or integration process, the overall accuracy of the measurement is generally increased by increasing the number of partial cross-sections. Generally, 10 to 20 cross-sections are adequate depending on the variability and complexity of the cross-sectional shape and flow patterns. With a smooth cross-section and good velocity distribution, or with narrow stream channels, fewer sections may be used.

Occasionally, flows are not perpendicular to the established cross section for its entire width. If high or low flows change flow patterns at an established cross-section, consideration should be given to temporarily or permanently moving a cross-section rather than using a substandard, established one.

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## 1.0 PURPOSE

This standard operating procedure (SOP) describes the requirements and process for collecting surface water samples from multiple locations across the channel of a wadeable stream. Collecting multiple samples along a transect perpendicular to the stream flow will provide information on the homogeneity of water chemistry across the channel (if samples are analyzed independently) or will provide a representative sample of stream water chemistry (if individual samples are composited before analysis). This procedure can be used wherever it is possible to wade completely across the channel. Where the water is too deep for wading, these procedures maybe modified to be used from a stable boat. Samples collected using this method may be analyzed on-site or transported to a laboratory. Proper preservation techniques may vary depending on the target analytes. Site-specific deviations from this SOP must be approved by the AECI Project Manager or the Client Project Manager prior to initiation of the sampling activity.

## 2.0 SCOPE

Surface water sampling is applicable to most study sites with surface drainages directly on the site or that are located hydraulically downgradient from such drainages.

## 3.0 REQUIREMENTS

Factors that may affect the ability to collect cross-channel samples include channel width, water depth, water velocity, channel bed stability and composition of the substrata. For successful completion of this procedure, a site must be safely accessible by sampling personnel access to the entire width of the stream channel must be possible. Ultra clean methods shall be followed for sampling activities.

### 3.1 Health and Safety

Stream substrata, or bed material, can be highly variable, even within a small stream section, and may pose a risk to those working in the stream. Large rocks with significant algal growth can be slick and those pose a fall risk. Rocks and sand can shift when weight is applied to them. Sharp rocks, sticks and artificial debris (broken bottles, metals, barbed wire) can puncture boots and skin. Before wading into a new area of the stream, examine the area visually, if possible, and use one foot to gently probe and stream bottom for suitable footing. If necessary, use a wading staff for stability.

**PPE:** Waders, nitrile or similar gloves.

Operational or safety issues associated with this procedure shall be reported to the on-site supervisor, AECI Project Manager, SH&E Coordinator, or their designees for resolution. Employees and contractors are required to stop work when they believe work conditions are unsafe.

## 4.0 REFERENCES

USGS. 1999. *National Field Manual for the Collection of Water-Quality Data, Chapter A4. Collection of Water Samples*.

USEPA. *Water: Monitoring and Assessment*. Chapter 5 Water Quality Conditions. (website)

USEPA. 1999. Rapid *Bioassessment Protocols for use in Wadeable Streams and Rivers*. EPA 841-B-99-002.

USEPA. 1996. *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels.* EPA Method 1669. Office of Water, Engineering and Analysis Division, Washington, DC.

USGS. 1985. *Study and Interpretation of the Chemical Characteristics of Natural Water*. USGS Water Supply Paper 2254.

## 5.0 DEFINITIONS

**Environmental Sample** – Low concentration sample typically collected offsite and not requiring DOT hazardous waste labeling as a high hazard sample.

**Clean Hands** – All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handled by the individual designated as "clean hands."

**Dirty Hands** – All operations involving preparation of the sampler (except the sample container itself), operation of any machinery and all other activities that do not involve direct contact with the sample, shall be performed by the individual designated as "dirty hands."

## 6.0 RESPONSIBILITIES

**Project Manager**

The Project Manager (PM) is responsible for the selection of the appropriate methodology, technique and field procedure for conducting the sampling.

**Field Project Leader**

The Field Project Leader (FPL) may be an AECI employee or contractor who is responsible for overseeing the sampling activities. The FPL is also responsible for making on-site decisions as to slight shifts in the cross-channel sampling location in order to ensure a safe working environment and that representative samples will be collected. The FPL provides oversight for all work performed and verification that the activity satisfies the requirements of this SOP and the Project Plan.

## 7.0 EQUIPMENT

1. Sampling bottles (certified clean and pre-treated with preservatives, if necessary)
2. Large (~2 L to 5 gallon) mixing bottles (e.g., a clean cubitainer)
3. Decontamination equipment and supplies
4. Nitrile gloves
5. Shoulder-length gloves
6. Peristaltic sump, clean tubing and 0.45 µm inline filters, or
7. 60 cc syringes and 0.45 µm syringe filters
8. Labels
9. Sharpies® or other indelible markers
10. 100-foot tape measure or rope with accurately-marked intervals
11. ≥ 3 foot rebar or wooden stakes
12. Orange plastic flagging
13. Hammer

## 8.0 PROCEDURE

### 8.1 General Procedures for Collection of Cross-Channel Water Samples

- Determine whether the multiple samples collected across the channel will be composited into a single sample, or analyzed independently. If the latter, then sufficient volume must be collected at each site for all analyses.
- Acquire the necessary number and type of sample containers for all samples. A "sample" (composite or multiple individual samples) will consist of five (5) bottles, including two 250-mL acidified (to ≤ 2 pH with nitric acid) high density polyethylene (HDPE) bottles (one non-filtered for total metals and hardness analysis, and one filtered (0.45 µm) for dissolved metals analysis), one 250-mL HPDE bottle with NaOH (for cyanide analysis), one 250-mL HDPE bottle (unpreserved) for salinity, and one 500-mL HDPE bottle (unpreserved) for the remaining inorganic analyses.
- Upon arrival at the site, one member of the sampling shall be designated as "dirty hands" and a second member shall be designated as "clean hands."
- The cross-channel samples shall follow the general USGS procedure of equal-width-increment (EWI) sampling. Each stream section to be sampled will be of approximately equal width.
- If samples are to be collected at multiple transects, begin work at the furthest downstream location.
- Select the sampling transect location. One person shall stand at the edge of one bank of the stream holding the tape or rope and a second person shall carry the end of the tape or rope across the stream. As much as possible, minimize disturbance of the stream bottom and limit the area of travel to a narrow corridor. Samples shall always be collected upstream of the disturbed area.
- With the tape or rope as taut as possible, secure the tape/rope to stakes on each bank.
- Determine the number of sampling compartments (sections). See Figure 1 of this SOP and follow this general guidance:
    - Small stream (≤25 ft in width): 4-6 compartments
    - Intermediate stream (>25 – 50 ft in width): 6-12 compartments
    - Large stream (>50 ft in width): ≥ 12 compartments
- Stream features should also be used in determining the number of compartments. IT may be appropriate to place different features (pools, runs, ripples, eddies) into separate compartments. A seemingly homogenous reach (e.g., a consistent run) will probably require fewer compartments.
- Using the hammer, drive a stake into the stream bed marking the center of the compartment. Tie an orange flag at the top of each stake to make them more visible.

### 8.2 Collection of Independent Samples in each Compartment

- One of the unpreserved sample bottles may be used to collect water from the stream at each staked location, or a separate container may be used. As 1500 mL are needed for all analyses, a 2 L collection bottle would be adequate for collecting the individual compartment samples (new bottle for each compartment).
- Don clean gloves. Nitrile gloves are acceptable, however, for deeper water wear clean, shoulder-length gloves.
- Approach the location from the downstream side. Once in position, wait approximately 30 seconds (or longer if needed) for any disturbed fine sediment to be carried downstream.

- At the midpoint of the compartment, where the stake is located, rinse the bottle three times with stream water. Just upstream of the stake, place the sampling bottle into the water, gently lowering it through the water column. The mouth of the bottle should be facing generally upstream, but the bottle should be angled upward at ~20-45° to allow air to escape as the bottle fills. Do not touch the bottom of the stream, as that may disturb sediment. Raise the bottle slowly back up through the water column. The bottle should be full when it is lifted from the water.
- Securely replace the bottle cap and hand the filled bottle to another staff member (or place it on a rock or other location where it will not be carried downstream). Each bottle should be appropriately marked with the correct compartment number.
- Go to the next compartment, again approaching from the downstream side, and repeat the collection process.
- Divide the sample into the appropriate preserved and unpreserved bottles (see Section 8.4 of this SOP).

### 8.3 Collection of a Composite Sample

- Before collecting samples for analysis, determine in which compartment a sample bottle will fill the fastest when lowered and raised through the water column (e.g., 1 minute, 30 seconds, etc.). This will be the Transit time. Use this same Transit time at all compartments, even if a bottle is not completely filled when brought back to the surface.
- As 1500 mL are needed for all analyses, a 1 L collection bottle should be adequate for collecting the individual compartment samples, which will be mixed as a composite sample before being subdivided for analyses. Use a new bottle for each compartment.
- Don clean gloves. Nitrile gloves are acceptable, however, for deeper water wear clean, shoulder-length gloves.
- Approach the location from the downstream side. Once in position, wait approximately 30 seconds (or longer if needed) for any disturbed fine sediment to be carried downstream.
- At the midpoint of the compartment, where the stake is located, rinse the bottle three times with stream water. Just upstream of the stake, gently lower and raise the sampling bottle into the water within the pre-determined Transit time. The mouth of the bottle should be facing generally upstream, but the bottle should be angled upward at ~20-45° to allow air to escape as the bottle fills. Do not touch the bottom of the stream, as that may disturb sediment. The bottle may not be completely full when it is lifted from the water.
- Securely replace the bottle cap and hand the filled bottle to another staff member (or place it on a rock or other location where it will not be carried downstream). Each bottle should be appropriately marked with the correct compartment number.
- Go to the next compartment, again approaching from the downstream side, and repeat the collection process.

- When all compartment samples have been collected, mix each by vigorously inverting them no less than three times, and immediately emptying them into the large mixing bottle. Make sure the mixing bottle is large enough to contain the water collected.
- Cap the mixing bottle and homogenize the composite sample by vigorously and repeatedly swirling and inverting the bottle for no less than one minute.
- Divide the sample into the appropriate preserved and unpreserved bottles (see Section 8.4 of this SOP). Some sample may remain in the mixing bottle.

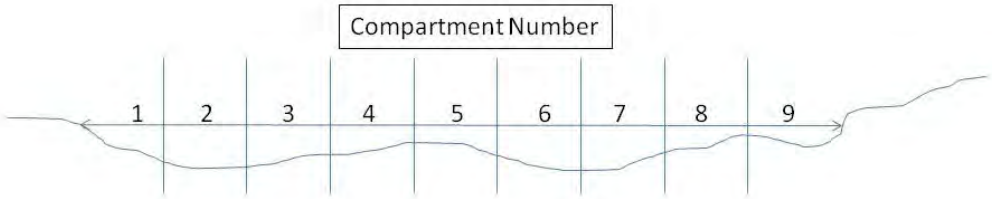
### 8.4 Dividing a Sample to Individual Analyte Bottles

- Fill all containers, <u>except</u> the one for dissolved metals, with the raw water sample, either the individual compartment samples, or the composite.
- <u>Do not</u> overfill the bottles that already contain preservative.
- For the dissolved metals sample, filter 250 mL of the raw water sample using a 1) peristaltic pump equipped with new, disposable tubing and a new, 0.45 µm filter, or 2) new, 60 cc syringe and 0.45 µm filter syringes.
- If using a pump, tubing and filter, place the intake tube into the raw sample and the outlet tube into the 250 mL sample bottle with preservative. Activate the pump and filter enough water to fill the sample bottle, without overfilling.
- If using a syringe and syringe filters, draw approximately 60 cc of the raw water sample into the syringe <u>before</u> the filter is attached. Attach the filter and depress the plunger while holding the syringe filter outlet over the preserved sample bottle. It may be necessary to stop and replace the filter if the raw water contains a high level of solids.
- Make sure all sample bottles are securely capped and labeled.

## 9.0 DOCUMENTATION/VERIFICATION

A record of field activities, including the number and type of samples collected, shall be recorded on field data sheets or in a field log. The log shall be reviewed by the FPL to verify the accuracy of the data.

**Figure 1. Example of the general placement of the cross-channel sampling compartments for the equal-width-increment (EWI) sampling procedure.**



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# GROUNDWATER SAMPLING

## 1.0 PURPOSE

The purpose of this procedure is to obtain groundwater samples that are representative of the source from which they are taken and minimize sampler exposure to groundwater contaminants. The methods and equipment described are for the collection of water samples from the saturated zone of the substrata. Site-specific deviations from the procedures outlined in this document must be approved by the Project Manager prior to initiation of the sampling activity.

## 2.0 SCOPE

This procedure provides information on proper equipment and techniques for groundwater sampling. Review of the information contained herein will facilitate planning of the field sampling effort by describing standard sampling techniques. The techniques described should be followed whenever applicable, noting the site-specific conditions adjustments in methodology.

## 3.0 REQUIREMENTS

Generally, wells should be sampled within three hours of purging. However, wells with poor recharge should be sampled within 24 hours of purging. Poor recharge wells are defined as those that cannot recharge 80 percent of the original volume within 24 hours. All sampling equipment must be decontaminated before commencement of sampling.

## 4.0 REFERENCES

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EPA SW-846.

USEPA, 1987. *Ground Water Handbook*, EPA/625/6-87/016.

USEPA, 1987. *A Compendium of Superfund Field Operations Methods*, EPA/540/P-87/001.

USEPA, September 1986. *Resource Conservation and Recovery Act (RCRA) Ground Monitoring Technical Enforcement Guidance Document*, OSWER-9950.1.

USATHAMA, January 1990. *U.S. Army Toxic and Hazardous Materials Agency Quality Assurance Program*, USATHAMA PAM 11-41.

## 5.0 DEFINITIONS

None

## 6.0 RESPONSIBILITIES

**Field Project Leader (FPL) –** The FPL is responsible for overseeing the sampling activities. The FPL is also responsible for checking all work performed and verifying that the work satisfies the specific tasks outlined by this SOP and the Project Plan.

## 7.0 EQUIPMENT

Sample containers shall conform with EPA regulations for preservation of appropriate contaminants (see SOP 2-8 “Preservation and Handling of Aqueous Samples”). The sample withdrawal equipment most commonly used are discussed in SOP 4-9 “Well Purging-Pumping Methods”. The following items may be needed to collect groundwater samples:

1. Sample Containers
2. Coolers for Sample Shipping and Cooling
3. Appropriate Packing Cartons and Filler
4. Labels
5. Chain-of-Custody Documents
6. Temperature Meter
7. pH Meter
8. Dissolved Oxygen Meter
9. Specific Conductivity Meter
10. Turbidity Meter

11. Oxygen/Reduction Potential (ORP) Meter
12. Water-Level Indicator
13. Appropriate Sampling Gloves
14. Field Sampling Logbook
15. Plastic Trash Bags
16. Indelible Marking Pens
17. Shallow-Well Pumps (centrifugal, positive displacement or peristaltic pumps where applicable)
18. Deep-Well Pumps (submersible pump and electrical power generating unit or bladder pump with compressed air source, where applicable)
19. Sample Tubing Such as Teflon®, Polyethylene and Polypropylene (tubing type shall be selected based on specific site requirements and must be chemically inert to groundwater being sampled)
20. Teflon® or Polyethylene Bailers
21. Teflon®-Coated Wire, Stainless Steel Single Strand Wire, Polypropylene Monofilament Line, or One-Quarter Inch Nylon Rope and Tripod-Pulley Assemble (if necessary)
22. Pails (plastic, graduated)
23. Decontamination Solutions (distilled water, Alconox or Liquinox, where applicable)
24. Volatile organic vapor detection equipment (such as PID, OVM, or HnU)

## 8.0 PROCEDURE

### 8.1 General

To be useful and accurate, a groundwater sample must be representative of the particular saturated zone of the substrata being sampled. The method described in SOP 4-9 for purging wells prior to sampling consists of the use of pumps. The procedures described in SOP 4-9 will be used for purging wells prior to sampling.

#### 8.1.1 Sampling Methods

The collection of a groundwater sample is made up of the following steps.

1. Fill out sample labels for each of the required sample containers. The following information must be included on the sample label:
    - site name
    - field identification or sample station number
    - date and time of sample collection
    - designation of the sample as grab or composite
    - sample preservative used

- types of analyses to be performed.

If a sample is split with another party, sample labels with identical information should be attached to each of the sample containers.

2. If organic vapors are suspected in the well, based on known site contaminants, then the well casing shall be checked for organic vapors after removing the well cap using an organic vapor monitor.
3. Sound the well for total depth and water level (using decontaminated equipment) and record these data in the field notebook.
4. Calculate depth from the casing top to the groundwater surface.
5. An initial measurement of purge water for physical parameters including pH, conductivity, turbidity, dissolved oxygen, and oxidation-reduction potential shall be recorded on the Groundwater Sampling Form and in the Field Logbook.
6. Lower purging equipment into the well to a short distance below the water level and begin water removal. If resistance is encountered when lowering the device into the well, withdraw the device from the well and inform the Field Operations Leader. Purge the well in accordance with SOP 4-9.
7. To ensure that groundwater samples are representative of actual conditions, samplers must work efficiently to minimize the loss of groundwater contaminants and the introduction of foreign contaminants. To prevent contamination of samples, the sample bottles should be opened only when receiving groundwater samples and closed immediately afterwards. To prevent introduction of foreign contaminants into the well, sample bottles should be held away from the well opening and discharge pipe when receiving samples and the bailing rope (if used) should not be allowed to touch the ground, or other potentially contaminating objects.
8. When a sample bottle is filled, the bottle must be tightly capped as soon as possible. (If sampling for volatile organic compounds, it must be endured that the sample does not contain any air bubbles before securing the cap.) SOP 2-8 details the sample containers to be used for specific analysis.
9. As soon as all samples are collected, prepare the samples for shipment in accordance with SOP 1-11 “Packaging and Shipment of Field Samples.”
10. Record all sampling information in the Field Logbook.
11. Decontaminate equipment in accordance with SOPs 1-8.

### 8.1.2 Collection of Split Sample or Field Duplicates

Whenever field duplicates are collected or samples are split with another organization the additional samples for identical analyses will be collected along with the original sample.

### 8.1.3 Sample Containers

For most samples and analytical parameters, either glass or plastic containers are satisfactory. SOP 2-8 describes the required sampling containers for various analytes at various concentrations.

#### 8.1.4 Preservation of Samples and Sample Volume Requirements

Sample preservation techniques and volume requirements depend on the type and concentration of the contaminant and on the type of analysis to be performed. SOP 2-8 describes the sample preservation and volume requirements for most of the chemicals that will be encountered during site investigations.

#### 8.1.5 Field Filtration

For sites at which metals are the primary constituent of concern, the collected water should be carefully poured into the acidified bottle (nitric acid to pH of 2) designated for total metals without overflowing.

Another batch of water should be similarly collected in the raw water bottle or in an empty (clean) distilled water jug, from which a filtered sample for dissolved metals can be obtained. The peristaltic pump equipped with new, disposable tubing is used to pump water from the raw water bottle through the new, disposable 0.45 micron filter, and into a second acidified bottle for dissolved metals analysis. Alternately, the disposable filter may be attached directly to a submersible pump discharge port and the water pumped directly through the filter and into the acidified bottle for dissolved metals analysis. Another option is to attach the filter and tubing to a disposable pressurized bailer.

After collection at each sample site, the tubing and filter should be discarded.

The raw water bottle used for collection purposes is then refilled and sealed for the remaining analytical sample, such as for anions and physical parameters.

Refer to SOP 2-8: Preservation and Handling of Aqueous Samples for specific information regarding sample preservation and handling.

#### 8.1.6 Handling and Transporting Samples

After collection, samples should be handled as little as possible. Ice should be bagged and steps taken to ensure that the melted ice does not cause sample containers to be submerged and thus the possibility of cross-contaminated. All sample containers should be enclosed in plastic bags to prevent cross-contamination.

Samples should be secured in the ice chest to prevent movement of sample containers and possible breakage (especially if glass containers are used). Sample packing and transportation requirements are described in SOP 1-11.

#### 8.1.7 Sample Holding Times

Holding times, allowed time between sample collection and analysis for routine samples, are discussed in SOP 2-8.

### 8.2 Records

Records will be maintained for each sample that is taken, including the following information:

- Sample identification (site name, location, project number; sample name/number and location; time and date; sampler's identity).
- Sample source and source description.
- Field observations and measurements (appearance; field chemistry; sampling method).
- Sample disposition (analyses to be run; number and size of bottle; preservatives added).
- Additional remarks (e.g., sampled in conjunction with state, county, local regulatory authorities; etc.).

### 8.3 Chain of Custody

Proper chain-of-custody procedures play a crucial role in data gathering. SOP 1-6 “Sample Custody and Documentation” describes the requirements for a correct chain-of-custody.

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# WELL PURGING—PUMPING METHOD

## 1.0 PURPOSE

The purpose of this procedure is to provide general reference information on well purging by the pumping method prior to the sampling of groundwater wells. The methods and equipment described are for the purging of water samples from the saturated zone of the substrata. Site-specific deviations from the procedures outlined in this document must be approved by the Project Manager prior to initiation of the sampling activity.

## 2.0 SCOPE

This procedure applies to purging relatively large volumes of water prior to sampling.

## 3.0 REQUIREMENTS

Methods for purging from completed wells include the use of pumps, bailers, and various types of samplers. The primary considerations in obtaining a representative sample of the groundwater are to avoid collection of stagnant (standing) water in the well and to avoid physical or chemical alteration of the water due to purging and sampling techniques. In a non-pumping well, there will be little or no vertical mixing of water in the well pipe or casing, and stratification will occur. The well water in the screened section will mix with the groundwater due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant.

## 4.0 REFERENCES

HAZWRAP, July 1990. *Quality Control Requirements for Field Methods*, DOE/HWP-69/R1.

USAEC, May 1993. *U.S. Army Environmental Center Guidelines for Implementation of ER 1110-1-263 for USAEC Projects.*

USATHAMA, January 1990. *U.S. Army Toxic and Hazardous Materials Agency Quality Assurance Program*, USATHAMA PAM 11-41.

United States Environmental Protection Agency, 1987. *Ground Water Handbook*, EPA/625/6-87/016.

United States Environmental Protection Agency, September 1986. *Resource Conservation and Recovery Act (RCRA) Ground Monitoring Technical Enforcement Guidance Document*, OSWER-9950.1.

## 5.0 DEFINITIONS

None

## 6.0 RESPONSIBILITIES

**Project Manager** - The Project Manager is responsible for reviewing the purging procedures used by the field crew and for performing in-field spot checks for proper purging procedures.

**Field Project Leader (FPL)** - The Field Project Leader is responsible for selecting and detailing the specific well purging techniques and equipment to be used, documenting these in the Field Logbook, and properly briefing the site sampling personnel. The FPL will be responsible for purging of wells, performing necessary physical measurements and observations, and containment of purged water. The FPL must record pertinent information including amount of water purged, pH, specific conductivity, temperature, and turbidity in the Field Logbook.

## 7.0 EQUIPMENT

The following equipment may be needed for the completion of this work.

1. Purge Pump
    a. A Peristaltic pump creates a vacuum in a flexible polymer tube that is capable of drawing water out of a well from approximately 30 feet deep. The tubing runs through the pump's roller-bearing housing, which cyclically squeezes it, forcing water out the top and drawing water in the bottom. The pump sits at the surface, only the tubing is lowered into the well. The pump can draw water very slowly and steadily with a minimum of agitation, making it ideal for the development, purging and sampling of slow recharge wells less than 30 feet deep.
    b. Submersible pumps take in water and push the sample up a sample tube to the surface. The power sources of these samplers may be compressed gas or electricity. The operation principles vary and the displacement of the sample can be by an inflatable bladder, sliding piston, or impeller. Pumps are available for 2-inch diameter wells and larger. These pumps can lift water from considerable depths (several hundred feet).
2. Power Source
3. Water Level Indicator
4. pH Meter
5. Specific Conductance Meter
6. Temperature Meter
7. Turbidity Meter
10. Tank(s) or Container(s) to Contain the Purge Water (if required)
11. Field Logbook

10. Calculator

## 8.0 PROCEDURE

### 8.1 General

- The amount of water to be purged from a well is generally considered to be three casing volumes. A well will not be sampled until a minimum three casing volumes of water are removed.
- Water quality parameters of the purge water, which include temperature, pH, conductivity, turbidity, dissolved oxygen, and oxidation-reduction potential, will be monitored during the purging operation in order to gauge when the parameters have stabilized.
- When feasible, and especially on sites where wells have known high contaminant levels, upgradient and background wells should be sampled first in order to prevent cross-contamination.

### 8.2 Calculations of Well Volume

To ensure that the proper volume of water has been removed from the well prior to sampling, it is first necessary to determine the volume of standing water in the well casing. The volume can be easily calculated by the following method. Calculations shall be entered in the Field Logbook:

1. Obtain all available information on well construction (location, casing, screens, etc.).
2. Determine well casing diameter.
3. Measure and record static water level (depth below ground level or top of casing reference point).
4. Determine depth of well (if not known from past records) by sounding, using a clean, decontaminated, weighted tape measure or water level indicator.
5. Calculate number of linear feet of static water (total depth or length of well pipe minus the depth to static water level).
6. Calculate the volume of water in the casing:

   $$Vc = \pi (di/2)^2 (TD-H)$$

   $$Vt = (Vc)(7.48)$$

   where:

   Vc = volume of water in casing, $ft^3$

   Vt = total volume, gal

   di = inside diameter of casing, ft

   TD = total depth of well, ft

   H = depth to water, ft, from ground surface
7. Multiply the calculated casing volume by three.

### 8.3 Specific Procedure

- Open the well casing cover, remove the well cap (if present).
- Measure the "depth to water" in the well.

  Calculate the volume of water in the well. Record this information in the Field Logbook and calculate the volume of water required to be purged. Normally, the well will be purged of three volumes of water and until the field parameters have stabilized (see discussion on requirements for stabilization below).
- Water quality parameter measurements shall be recorded in the Field Logbook.
- Lower the purge pump into the well until it is submerged.

  *NOTE: If resistance is encountered when lowering the pump into the well, WITHDRAW THE PUMP FROM THE WELL and inform the Field Project Leader.
- Direct the pump discharge hose into the receptor vessel and start the pump in accordance with the pump's operation manual. Purging will continue until a minimum of three well volumes are removed and water quality parameters have stabilized. During well purging, monitor indicator field parameters (turbidity, temperature, specific conductance, pH) every three to five minutes (or less frequently, if appropriate). Purging is considered complete and sampling may begin when all the above indicator field parameters have stabilized. Stabilization is considered to be achieved when three consecutive readings, taken at three (3) to five (5) minute intervals, are within the following limits:
  - turbidity (10% for values greater than 1 NTU)
  - specific conductance (3%)
  - temperature (3%)
  - pH (± 0.1 unit)
- In addition, dissolved oxygen (DO) and oxygen-reduction potential (ORP) should be recorded on the groundwater sampling log sheet, but these are to be considered for informational purposes only.
- If the well pumps dry and will not yield 3 purge volumes, wait 24 hours to sample. Samples may be collected if the well recovers 80%. If the well does not recover 80%, then that well should be declared dry for this particular sample round.
- Water samples shall be obtained immediately after purging is complete. A new pair of disposable sampling gloves (latex) shall be worn for the collection of each sample.
- Record in the Field Log Book the total volume of purge water pumped from the well. Volume determination may be made using either an in-line flow meter with totalizer; or by measuring the height of the collected purge water in the collection tank, measuring the diameter of the tank, and calculating the volume.
- Carefully withdraw the purge pump from the well and decontaminate the pump and hose after purging is complete.

- Dispose of all waste items in accordance with SOP 1-10: Site Clean-Up Activities.

### 8.4 Sampling Handling and Preservation

Refer to SOP 2-8: Preservation and Handling of Aqueous Samples for specific information regarding sample preservation and handling.

**Appendix C**
EPA Method 1669

# Method 1669

# Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels

**July 1996**

**U.S. Environmental Protection Agency**
**Office of Water**
**Engineering and Analysis Division (4303)**
**401 M Street S.W.**
**Washington, D.C. 20460**

## Acknowledgements

This sampling method was prepared under the direction of William A. Telliard of the Engineering and Analysis Division (EAD) within the U.S. Environmental Agency's (EPA's) Office of Science and Technology (OST). This sampling method was prepared under EPA Contract 68-C3-0337 by the DynCorp Environmental Programs Division, with assistance from Interface, Inc.

The following researchers contributed to the philosophy behind this sampling method. Their contribution is gratefully acknowledged:

Shier Berman, National Research Council, Ottawa, Ontario, Canada;
Nicholas Bloom, Frontier Geosciences Inc, Seattle, Washington;
Eric Crecelius, Battelle Marine Sciences Laboratory, Sequim, Washington;
Russell Flegal, University of California/Santa Cruz, California;
Gary Gill, Texas A&M University at Galveston, Texas;
Carlton Hunt and Dion Lewis, Battelle Ocean Sciences, Duxbury, Massachusetts;
Carl Watras, Wisconsin Department of Natural Resources, Boulder Junction, Wisconsin

Additional support was provided by Ted Martin of the EPA Office of Research and Development's Environmental Monitoring Systems Laboratory in Cincinnati, Ohio and by Arthur Horowitz of the U.S. Geological Survey.

This version of the method was prepared after observations of sampling teams from the University of California at Santa Cruz, the Wisconsin Department of Natural Resources, the U.S. Geological Survey, and Battelle Ocean Sciences. The assistance of personnel demonstrating the sampling techniques used by these institutions is gratefully acknowledged.

## Disclaimer

This sampling method has been reviewed and approved for publication by the Analytical Methods Staff within the Engineering and Analysis Division of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

## Further Information

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## Introduction

This sampling method was designed to support water quality monitoring programs authorized under the Clean Water Act. Section 304(a) of the Clean Water Act requires EPA to publish water quality criteria that reflect the latest scientific knowledge concerning the physical fate (e.g., concentration and dispersal) of pollutants, the effects of pollutants on ecological and human health, and the effect of pollutants on biological community diversity, productivity, and stability.

Section 303 of the Clean Water Act requires states to set a water quality standard for each body of water within its boundaries. A state water quality standard consists of a designated use or uses of a waterbody or a segment of a waterbody, the water quality criteria that are necessary to protect the designated use or uses, and an antidegradation policy. These water quality standards serve two purposes: (1) they establish the water quality goals for a specific waterbody, and (2) they are the basis for establishing water quality-based treatment controls and strategies beyond the technology-based controls required by Sections 301(b) and 306 of the Clean Water Act.

In defining water quality standards, the state may use narrative criteria, numeric criteria, or both. However, the 1987 amendments to the Clean Water Act required states to adopt numeric criteria for toxic pollutants (designated in Section 307(a) of the Act) based on EPA Section 304(a) criteria or other scientific data, when the discharge or presence of those toxic pollutants could reasonably be expected to interfere with designated uses.

In some cases, these water quality criteria are as much as 280 times lower than those achievable using existing EPA methods and required to support technology-based permits. Therefore, this sampling method, and the analytical methods referenced in Table 1 of this document, were developed by EPA to specifically address state needs for measuring toxic metals at water quality criteria levels, when such measurements are necessary to protect designated uses in state water quality standards. The latest criteria published by EPA are those listed in the National Toxics Rule (57 *FR* 60848) and the Stay of Federal Water Quality Criteria for Metals (60 *FR* 22228). These rules include water quality criteria for 13 metals, and it is these criteria on which this sampling method and the referenced analytical methods are based.

In developing these methods, EPA found that one of the greatest difficulties in measuring pollutants at these levels was precluding sample contamination during collection, transport, and analysis. The degree of difficulty, however, is highly dependent on the metal and site-specific conditions. This method, therefore, is designed to provide the level of protection necessary to preclude contamination in nearly all situations. It is also designed to provide the procedures necessary to produce reliable results at the lowest possible water quality criteria published by EPA. In recognition of the variety of situations to which this method may be applied, and in recognition of continuing technological advances, the method is performance-based. Alternative procedures may be used, so long as those procedures are demonstrated to yield reliable results.

Requests for additional copies of this method should be directed to:

U.S. EPA NCEPI
11029 Kenwood Road
Cincinnati, OH 45242
513/489–8190

Note: This document is intended as guidance only. Use of the terms "must," "may," and "should" are included to mean that EPA believes that these procedures must, may, or should be followed in order to produce the desired results when using this guidance. In addition, the guidance is intended to be performance-based, in that the use of less stringent procedures may be used so long as neither samples nor blanks are contaminated when following those modified procedures. Because the only way to measure the performance of the modified procedures is through the collection and analysis of uncontaminated blank samples in accordance with this guidance and the referenced methods, it is highly recommended that any modifications be thoroughly evaluated and demonstrated to be effective before field samples are collected.

# Method 1669

# Sampling Ambient Water for Determination of Metals at EPA Water Quality Criteria Levels

## 1.0 Scope and Application

1.1 This method is for the collection and filtration of ambient water samples for subsequent determination of total and dissolved metals at the levels listed in Table 1. It is designed to support the implementation of water quality monitoring and permitting programs administered under the Clean Water Act.

1.2 This method is applicable to the metals listed below and other metals, metals species, and elements amenable to determination at trace levels.

| Analyte | Symbol | Chemical Abstract Services Registry Number (CASRN) |
|---|---|---|
| Antimony | (Sb) | 7440-36-0 |
| Arsenic | (As) | 7440-38-2 |
| Cadmium | (Cd) | 7440-43-9 |
| Chromium (III) | $Cr^{+3}$ | 16065-83-1 |
| Chromium (VI) | $Cr^{+6}$ | 18540-29-9 |
| Copper | (Cu) | 7440-50-8 |
| Lead | (Pb) | 7439-92-1 |
| Mercury | (Hg) | 7439-97-6 |
| Nickel | (Ni) | 7440-02-0 |
| Selenium | (Se) | 7782-49-2 |
| Silver | (Ag) | 7440-22-4 |
| Thallium | (Tl) | 7440-28-0 |
| Zinc | (Zn) | 7440-66-6 |

1.3 This method is accompanied by the 1600 series methods listed in Table 1. These methods include the sample handling, analysis, and quality control procedures necessary for reliable determination of trace metals in aqueous samples.

1.4 This method is not intended for determination of metals at concentrations normally found in treated and untreated discharges from industrial facilities. Existing regulations (40 *CFR* Parts 400-500) typically limit concentrations in industrial discharges to the mid to high part-per-billion (ppb) range, whereas ambient metals concentrations are normally in the low part-per-trillion (ppt) to low ppb range. This guidance is therefore directed at the collection of samples to be measured at or near the levels listed in Table 1. Actual concentration ranges to which this guidance is applicable will be dependent on the sample matrix, dilution levels, and other laboratory operating conditions.

1.5 The ease of contaminating ambient water samples with the metal(s) of interest and interfering substances cannot be overemphasized. This method includes sampling techniques that should maximize the ability of the sampling team to collect samples reliably and eliminate sample contamination. These techniques are given in Section 8.0 and are based on findings of researchers performing trace metals analyses (References 1-9).

1.6 Clean and Ultraclean—The terms "clean" and "ultraclean" have been used in other Agency guidance to describe the techniques needed to reduce or eliminate contamination in trace metals determinations. These terms are not used in this sampling method due to a lack of exact definitions. However, the information provided in this method is consistent with summary guidance on clean and ultraclean techniques (Reference 10).

1.7 This sampling method follows the EPA Environmental Methods Management Council's "Format for Method Documentation" (Reference 11).

1.8 Method 1669 is "performance-based"; i.e., an alternate sampling procedure or technique may be used, so long as neither samples nor blanks are contaminated when following the alternate procedures. Because the only way to measure the performance of the alternate procedures is through the collection and analysis of uncontaminated blank samples in accordance with this guidance and the methods referenced in Table 1, it is highly recommended that any modifications be thoroughly evaluated and demonstrated to be effective before field samples are collected. Section 9.2 provides additional details on the tests and documentation required to support equivalent performance.

1.9 For dissolved metal determinations, samples must be filtered through a 0.45 µm capsule filter at the field site. The filtering procedures are described in this method. The filtered samples may be preserved in the field or transported to the laboratory for preservation. Procedures for field preservation are detailed in this sampling method; procedures for laboratory preservation are provided in the methods referenced in Table 1. Preservation requirements are summarized in Table 2.

1.10 The procedures in this method are for use only by personnel thoroughly trained in the collection of samples for determination of metals at ambient water quality control levels.

## 2.0 Summary of Method

2.1 Before samples are collected, all sampling equipment and sample containers are cleaned in a laboratory or cleaning facility using detergent, mineral acids, and reagent water as described in the methods referenced in Table 1. The laboratory or cleaning facility is responsible for generating an acceptable equipment blank to demonstrate that the sampling equipment and containers are free from trace metals contamination before they are shipped to the field sampling team. An acceptable blank is one that is free from contamination below the minimum level (ML) specified in the referenced analytical method (Section 9.3).

2.2 After cleaning, sample containers are filled with weak acid solution, individually double-bagged, and shipped to the sampling site. All sampling equipment is also bagged for storage or shipment.

***NOTE:*** *EPA has found that, in some cases, it may be possible to empty the weak acid solution from the bottle immediately prior to transport to the field site. In this case, the bottle should be refilled with reagent water (Section 7.1).*

2.3 The laboratory or cleaning facility must prepare a large carboy or other appropriate clean container filled with reagent water (Section 7.1) for use with collection of field blanks during sampling activities. The reagent-water-filled container should be shipped to the field site and handled as all other sample containers and sampling equipment. At least

one field blank should be processed per site, or one per every ten samples, whichever is more frequent (Section 9.4). If samples are to be collected for determination of trivalent chromium, the sampling team processes additional QC aliquots are processed as described in Section 9.6.

2.4 Upon arrival at the sampling site, one member of the two-person sampling team is designated as "dirty hands"; the second member is designated as "clean hands." All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handled by the individual designated as "clean hands." "Dirty hands" is responsible for preparation of the sampler (except the sample container itself), operation of any machinery, and for all other activities that do not involve direct contact with the sample.

2.5 All sampling equipment and sample containers used for metals determinations at or near the levels listed in Table 1 must be nonmetallic and free from any material that may contain metals.

2.6 Sampling personnel are required to wear clean, nontalc gloves at all times when handling sampling equipment and sample containers.

2.7 In addition to processing field blanks at each site, a field duplicate must be collected at each sampling site, or one field duplicate per every 10 samples, whichever is more frequent (Section 9.5). Section 9.0 gives a complete description of quality control requirements.

2.8 Sampling

2.8.1 Whenever possible, samples are collected facing upstream and upwind to minimize introduction of contamination.

2.8.2 Samples may be collected while working from a boat or while on land.

2.8.3 Surface samples are collected using a grab sampling technique. The principle of the grab technique is to fill a sample bottle by rapid immersion in water and capping to minimize exposure to airborne particulate matter.

2.8.4 Subsurface samples are collected by suction of the sample into an immersed sample bottle or by pumping the sample to the surface.

2.9 Samples for dissolved metals are filtered through a 0.45 µm capsule filter at the field site. After filtering, the samples are double-bagged and iced immediately. Sample containers are shipped to the analytical laboratory. The sampling equipment is shipped to the laboratory or cleaning facility for recleaning.

2.10 Acid preservation of samples is performed in the field or in the laboratory. Field preservation is necessary for determinations of trivalent chromium. It has also been shown that field preservation can increase sample holding times for hexavalent chromium to 30 days; therefore it is recommended that preservation of samples for hexavalent chromium be performed in the field. For other metals, however, the sampling team may prefer to utilize laboratory preservation of samples to expedite field operations and to minimize the potential for sample contamination.

2.11 Sampling activities must be documented through paper or computerized sample tracking systems.

## 3.0 Definitions

3.1 Apparatus—Throughout this method, the sample containers, sampling devices, instrumentation, and all other materials and devices used in sample collection, sample processing, and sample analysis activities will be referred to collectively as the Apparatus.

3.2 Definitions of other terms are given in the Glossary (Section 15.0) at the end of this method.

## 4.0 Contamination and Interferences

4.1 Contamination Problems in Trace Metals Analysis

4.1.1 Preventing ambient water samples from becoming contaminated during the sampling and analytical process is the greatest challenge faced in trace metals determinations. In recent years, it has been shown that much of the historical trace metals data collected in ambient water are erroneously high because the concentrations reflect contamination from sampling and analysis rather than ambient levels (Reference 12). Therefore, it is imperative that extreme care be taken to avoid contamination when collecting and analyzing ambient water samples for trace metals.

4.1.2 There are numerous routes by which samples may become contaminated. Potential sources of trace metals contamination during sampling include metallic or metal-containing sampling equipment, containers, labware (e.g. talc gloves that contain high levels of zinc), reagents, and deionized water; improperly cleaned and stored equipment, labware, and reagents; and atmospheric inputs such as dirt and dust from automobile exhaust, cigarette smoke, nearby roads, bridges, wires, and poles. Even human contact can be a source of trace metals contamination. For example, it has been demonstrated that dental work (e.g., mercury amalgam fillings) in the mouths of laboratory personnel can contaminate samples that are directly exposed to exhalation (Reference 3).

4.2 Contamination Control

4.2.1 Philosophy—The philosophy behind contamination control is to ensure that any object or substance that contacts the sample is nonmetallic and free from any material that may contain metals of concern.

4.2.1.1 The integrity of the results produced cannot be compromised by contamination of samples. Requirements and suggestions for controlling sample contamination are given in this sampling method and in the analytical methods referenced in Table 1.

4.2.1.2 Substances in a sample or in the surrounding environment cannot be allowed to contaminate the Apparatus used to collect samples for trace metals measurements. Requirements and suggestions for protecting the

Apparatus are given in this sampling method and in the methods referenced in Table 1.

4.2.1.3 While contamination control is essential, personnel health and safety remain the highest priority. Requirements and suggestions for personnel safety are given in Section 5 of this sampling method and in the methods referenced in Table 1.

4.2.2 Avoiding contamination—The best way to control contamination is to completely avoid exposure of the sample and Apparatus to contamination in the first place. Avoiding exposure means performing operations in an area known to be free from contamination. Two of the most important factors in avoiding/reducing sample contamination are (1) an awareness of potential sources of contamination and (2) strict attention to work being performed. Therefore, it is imperative that the procedures described in this method be carried out by well trained, experienced personnel. Documentation of training should be kept on file and readily available for review.

4.2.2.1 Minimize exposure—The Apparatus that will contact samples or blanks should only be opened or exposed in a clean room, clean bench, glove box, or clean plastic bag, so that exposure to atmospheric inputs is minimized. When not being used, the Apparatus should be covered with clean plastic wrap, stored in the clean bench or in a plastic box or glove box, or bagged in clean, colorless zip-type bags. Minimizing the time between cleaning and use will also reduce contamination.

4.2.2.2 Wear gloves—Sampling personnel must wear clean, nontalc gloves (Section 6.7) during all operations involving handling of the Apparatus, samples, and blanks. Only clean gloves may touch the Apparatus. If another object or substance is touched, the glove(s) must be changed before again handling the Apparatus. If it is even suspected that gloves have become contaminated, work must be halted, the contaminated gloves removed, and a new pair of clean gloves put on. Wearing multiple layers of clean gloves will allow the old pair to be quickly stripped with minimal disruption to the work activity.

4.2.2.3 Use metal-free Apparatus—All Apparatus used for metals determinations at the levels listed in Table 1 must be nonmetallic and free of material that may contain metals. When it is not possible to obtain equipment that is completely free of the metal(s) of interest, the sample should not come into direct contact with the equipment.

4.2.2.3.1 Construction materials—Only the following materials should come in contact with samples: fluoropolymer (FEP, PTFE), conventional or linear polyethylene, polycarbonate, polysulfone, polypropylene, or ultrapure quartz. PTFE is less desirable than FEP because the sintered material in PTFE may contain contaminants and is susceptible to serious memory effects (Reference 6). Fluoropolymer or glass containers should be used for samples that will be analyzed for mercury because mercury vapors can diffuse

in or out of other materials, resulting either in contamination or low-biased results (Reference 3). Metal must not be used under any circumstance. Regardless of construction, all materials that will directly or indirectly contact the sample must be cleaned using the procedures described in the referenced analytical methods (see Table 1) and must be known to be clean and metal-free before proceeding.

4.2.2.3.2 The following materials have been found to contain trace metals and must not be used to hold liquids that come in contact with the sample or must not contact the sample, unless these materials have been shown to be free of the metals of interest at the desired level: Pyrex, Kimax, methacrylate, polyvinylchloride, nylon, and Vycor (Reference 6). In addition, highly colored plastics, paper cap liners, pigments used to mark increments on plastics, and rubber all contain trace levels of metals and must be avoided (Reference 13).

4.2.2.3.3 Serialization—Serial numbers should be indelibly marked or etched on each piece of Apparatus so that contamination can be traced, and logbooks should be maintained to track the sample from the container through the sampling process to shipment to the laboratory. Chain-of-custody procedures may also be used if warranted so that contamination can be traced to particular handling procedures or lab personnel.

4.2.2.3.4 The Apparatus should be clean when the sampling team receives it. If there are any indications that the Apparatus is not clean (e.g., a ripped storage bag), an assessment of the likelihood of contamination must be made. Sampling must not proceed if it is possible that the Apparatus is contaminated. If the Apparatus is contaminated, it must be returned to the laboratory or cleaning facility for proper cleaning before any sampling activity resumes.

4.2.2.3.5 Details for recleaning the Apparatus between collection of individual samples are provided in Section 10.0.

4.2.2.4 Avoid sources of contamination—Avoid contamination by being aware of potential sources and routes of contamination.

4.2.2.4.1 Contamination by carryover—Contamination may occur when a sample containing low concentrations of metals is processed immediately after a sample containing relatively high concentrations of these metals. At sites where more than one sample will be collected, the sample known or expected to contain the lowest concentration of metals should be collected first with the sample containing the

highest levels collected last (Section 8.1.4). This will help minimize carryover of metals from high- concentration samples to low- concentration samples. If the sampling team does not have prior knowledge of the waterbody, or when necessary, the sample collection system should be rinsed with dilute acid and reagent water between samples and followed by collection of a field blank (Section 10.3).

4.2.2.4.2 Contamination by samples—Significant contamination of the Apparatus may result when untreated effluents, in-process waters, landfill leachates, and other samples containing mid- to high-level concentrations of inorganic substances are processed. As stated in Section 1.0, this sampling method is not intended for application to these samples, and samples containing high concentrations of metals must not be collected, processed, or shipped at the same time as samples being collected for trace metals determinations.

4.2.2.4.3 Contamination by indirect contact—Apparatus that may not directly contact samples may still be a source of contamination. For example, clean tubing placed in a dirty plastic bag may pick up contamination from the bag and subsequently transfer the contamination to the sample. Therefore, it is imperative that every piece of the Apparatus that is directly or indirectly used in the collection of ambient water samples be cleaned as specified in the analytical method(s) referenced in Table 1.

4.2.2.4.4 Contamination by airborne particulate matter—Less obvious substances capable of contaminating samples include airborne particles. Samples may be contaminated by airborne dust, dirt, particulate matter, or vapors from automobile exhaust; cigarette smoke; nearby corroded or rusted bridges, pipes, poles, or wires; nearby roads; and even human breath (Section 4.1.2). Whenever possible, the sampling activity should occur as far as possible from sources of airborne contamination (Section 8.1.3). Areas where nearby soil is bare and subject to wind erosion should be avoided.

4.3 Interferences—Interferences resulting from samples will vary considerably from source to source, depending on the diversity of the site being sampled. If a sample is suspected of containing substances that may interfere in the determination of trace metals, sufficient sample should be collected to allow the laboratory to identify and overcome interference problems.

## 5.0 Safety

5.1 The toxicity or carcinogenicity of the chemicals used in this method has not been precisely determined; however, these chemicals should be treated as a potential health

hazard. Exposure should be reduced to the lowest possible level. Sampling teams are responsible for maintaining a current awareness file of OSHA regulations for the safe handling of the chemicals specified in this method. A reference file of Material Safety Data Sheets should also be made available to all personnel involved in sampling. It is also suggested that the organization responsible perform personal hygiene monitoring of each sampling team member who uses this method and that the results of this monitoring be made available to the member.

5.2 Operating in and around waterbodies carries the inherent risk of drowning. Life jackets must be worn when operating from a boat, when sampling in more than a few feet of water, or when sampling in swift currents.

5.3 Collecting samples in cold weather, especially around cold water bodies, carries the risk of hypothermia, and collecting samples in extremely hot and humid weather carries the risk of dehydration and heat stroke. Sampling team members should wear adequate clothing for protection in cold weather and should carry an adequate supply of water or other liquids for protection against dehydration in hot weather.

## 6.0 Apparatus and Materials

***NOTE:*** *Brand names, suppliers, and part numbers are for illustration only and no endorsement is implied. Equivalent performance may be achieved using apparatus and materials other than those specified here. Meeting the performance requirements of this method is the responsibility of the sampling team and laboratory.*

6.1 All sampling equipment and sample containers must be precleaned in a laboratory or cleaning facility, as described in the methods referenced in Table 1, before they are shipped to the field site. Performance criteria for equipment cleaning is described in the referenced methods. To minimize difficulties in sampling, the equipment should be packaged and arranged to minimize field preparation.

6.2 Materials such as gloves (Section 6.7), storage bags (Section 6.8), and plastic wrap (Section 6.9), may be used new without additional cleaning unless the results of the equipment blank pinpoint any of these materials as a source of contamination. In this case, either a different supplier must be obtained or the materials must be cleaned.

6.3 Sample Bottles—Fluoropolymer (FEP, PTFE), conventional or linear polyethylene, polycarbonate, or polypropylene; 500 mL or 1 L with lids. If mercury is a target analyte, fluoropolymer or glass bottles should be used. Refer to the methods referenced in Table 1 for bottle cleaning procedures.

6.3.1 Cleaned sample bottles should be filled with 0.1% HCl (v/v). In some cases, it may be possible to empty the weak acid solution from the sample bottle immediately prior to transport to the field site. In this case, the bottle should be refilled with reagent water (Section 7.1).

6.3.2 Whenever possible, sampling devices should be cleaned and prepared for field use in a class 100 clean room. Preparation of the devices in the field should be done within the glove bag (Section 6.6). Regardless of design, sampling devices must be constructed of nonmetallic material (Section 4.2.2.3.1) and free from material that contains metals. Fluoropolymer or other material shown not to

adsorb or contribute mercury must be used if mercury is a target analyte; otherwise, polyethylene, polycarbonate, or polypropylene are acceptable. Commercially available sampling devices may be used provided that any metallic or metal-containing parts are replaced with parts constructed of nonmetallic material.

6.4 Surface Sampling Devices—Surface samples are collected using a grab sampling technique. Samples may be collected manually by direct submersion of the bottle into the water or by using a grab sampling device. Examples of grab samplers are shown in Figures 1 and 2 and may be used at sites where depth profiling is neither practical nor necessary.

6.4.1 The grab sampler in Figure 1 consists of a heavy fluoropolymer collar fastened to the end of a 2-m-long polyethylene pole, which serves to remove the sampling personnel from the immediate vicinity of the sampling point. The collar holds the sample bottle. A fluoropolymer closing mechanism, threaded onto the bottle, enables the sampler to open and close the bottle under water, thereby avoiding surface microlayer contamination (Reference 14). Polyethylene, polycarbonate, and polypropylene are also acceptable construction materials unless mercury is a target analyte. Assembly of the cleaned sampling device is as follows (refer to Figure 1):

6.4.1.1 Thread the pull cord (with the closing mechanism attached) through the guides and secure the pull ring with a simple knot. Screw a sample bottle onto the closing device and insert the bottle into the collar. Cock the closing plate so that the plate is pushed away from the operator.

6.4.1.2 The cleaned and assembled sampling device should be stored in a double layer of large, clean zip-type polyethylene bags or wrapped in two layers of clean polyethylene wrap if it will not be used immediately.

6.4.2 An alternate grab sampler design is shown in Figure 2. This grab sampler is used for discrete water samples and is constructed so that a capped clean bottle can be submerged, the cap removed, sample collected, and bottle recapped at a selected depth. This device eliminates sample contact with conventional samplers (e.g., Niskin bottles), thereby reducing the risk of extraneous contamination. Because a fresh bottle is used for each sample, carryover from previous samples is eliminated (Reference 15).

6.5 Subsurface Sampling Devices—Subsurface sample collection may be appropriate in lakes and sluggish deep river environments or where depth profiling is determined to be necessary. Subsurface samples are collected by pumping the sample into a sample bottle. Examples of subsurface collection systems include the jar system device shown in Figure 3 and described in Section 6.5.1 or the continuous-flow apparatus shown in Figure 4 and described in Section 6.5.2.

6.5.1 Jar sampler (Reference 14)—The jar sampler (Figure 3) is comprised of a heavy fluoropolymer 1-L jar with a fluoropolymer lid equipped with two 1/4 in. fluoropolymer fittings. Sample enters the jar through a short length of fluoropolymer tubing inserted into one fitting. Sample is pulled into the jar by pumping on fluoropolymer tubing attached to the other fitting. A thick

fluoropolymer plate supports the jar and provides attachment points for a fluoropolymer safety line and fluoropolymer torpedo counterweight.

6.5.1.1 Advantages of the jar sampler for depth sampling are (1) all wetted surfaces are fluoropolymer and can be rigorously cleaned; (2) the sample is collected into a sample jar from which the sample is readily recovered, and the jar can be easily recleaned; (3) the suction device (a peristaltic or rotary vacuum pump, Section 6.15) is located in the boat, isolated from the sampling jar; (4) the sampling jar can be continuously flushed with sample, at sampling depth, to equilibrate the system; and (5) the sample does not travel through long lengths of tubing that are more difficult to clean and keep clean (Reference 14). In addition, the device is designed to eliminate atmospheric contact with the sample during collection.

6.5.1.2 To assemble the cleaned jar sampler, screw the torpedo weight onto the machined bolt attached to the support plate of the jar sampler. Attach a section of the 1/4 in. o.d. tubing to the jar by inserting the tubing into the fitting on the lid and pushing down into the jar until approximately 8 cm from the bottom. Tighten the fitting nut securely. Attach the solid safety line to the jar sampler using a bowline knot to the loop affixed to the support plate.

6.5.1.3 For the tubing connecting the pump to the sampler, tubing lengths of up to 12 m have been used successfully (Reference 14).

6.5.2 Continuous-flow sampler (References 16-17)—This sampling system, shown in Figure 4, consists of a peristaltic or submersible pump and one or more lengths of precleaned fluoropolymer or styrene/ethylene/butylene/ silicone (SEBS) tubing. A filter is added to the sampling train when sampling for dissolved metals.

6.5.2.1 Advantages of this sampling system include (1) all wetted surfaces are fluoropolymer or SEBS and can be readily cleaned; (2) the suction device is located in the boat, isolated from the sample bottle; (3) the sample does not travel through long lengths of tubing that are difficult to clean and keep clean; and (4) in-line filtration is possible, minimizing field handling requirements for dissolved metals samples.

6.5.2.2 The sampling team assembles the system in the field as described in Section 8.2.8. System components include an optional polyethylene pole to remove sampling personnel from the immediate vicinity of the sampling point and the pump, tubing, filter, and filter holder listed in Sections 6.14 and 6.15.

6.6 Field-Portable Glove Bag—I2R, Model R-37-37H (nontalc), or equivalent. Alternately, a portable glove box may be constructed with a nonmetallic (PVC pipe or other suitable material) frame and a frame cover made of an inexpensive, disposable, nonmetallic material (e.g., a thin-walled polyethylene bag) (Reference 7).

6.7 Gloves—Clean, nontalc polyethylene, latex, vinyl, or PVC; various lengths. Shoulder-length gloves are needed if samples are to be collected by direct submersion of the sample bottle into the water or when sampling for mercury.

6.7.1 Gloves, shoulder-length polyethylene—Associated Bag Co., Milwaukee, WI, 66-3-301, or equivalent.

6.7.2 Gloves, PVC—Fisher Scientific Part No. 11-394-100B, or equivalent.

6.8 Storage Bags—Clean, zip-type, nonvented, colorless polyethylene (various sizes).

6.9 Plastic Wrap—Clean, colorless polyethylene.

6.10 Cooler—Clean, nonmetallic, with white interior for shipping samples.

6.11 Ice or Chemical Refrigerant Packs—To keep samples chilled in the cooler during shipment.

6.12 Wind Suit—Pamida, or equivalent.

***NOTE:*** *This equipment is necessary only for collection of metals, such as mercury, that are known to have elevated atmospheric concentrations.*

6.12.1 An unlined, long-sleeved wind suit consisting of pants and jacket and constructed of nylon or other synthetic fiber is worn when sampling for mercury to prevent mercury adsorbed onto cotton or other clothing materials from contaminating samples.

6.12.2 Washing and drying—The wind suit is washed by itself or with other wind suits only in a home or commercial washing machine and dried in a clothes dryer. The clothes dryer must be thoroughly vacuumed, including the lint filter, to remove all traces of lint before drying. After drying, the wind suit is folded and stored in a clean polyethylene bag for shipment to the sample site.

6.13 Boat

6.13.1 For most situations (e.g., most metals under most conditions), the use of an existing, available boat is acceptable. A flat-bottom, Boston Whaler-type boat is preferred because sampling materials can be stored with reduced chance of tipping.

6.13.1.1 Immediately before use, the boat should be washed with water from the sampling site away from any sampling points to remove any dust or dirt accumulation.

6.13.1.2 Samples should be collected upstream of boat movement.

6.13.2 For mercury, and for situations in which the presence of contaminants cannot otherwise be controlled below detectable levels, the following equipment and precautions may be necessary:

6.13.2.1 A metal-free (e.g., fiberglass) boat, along with wooden or fiberglass oars. Gasoline- or diesel-fueled boat motors should be avoided when possible because the exhaust can be a source of contamination. If the body of water is large enough to require use of a boat motor, the engine should be shut off at a distance far enough from the sampling point to avoid contamination, and the sampling team should manually propel the boat to the sampling point. Samples should be collected upstream of boat movement.

6.13.2.2 Before first use, the boat should be cleaned and stored in an area that minimizes exposure to dust and atmospheric particles. For example, cleaned boats should not be stored in an area that would allow exposure to automobile exhaust or industrial pollution.

6.13.2.3 The boat should be frequently visually inspected for possible contamination.

6.13.2.4 After sampling, the boat should be returned to the laboratory or cleaning facility, cleaned as necessary, and stored away from any sources of contamination until next use.

6.14 Filtration Apparatus—Required when collecting samples for dissolved metals determinations.

6.14.1 Filter—0.45 µm, 15 mm diameter or larger, tortuous-path capsule filters (Reference 18), Gelman Supor 12175, or equivalent.

6.14.2 Filter holder—For mounting filter to the gunwale of the boat. Rod or pipe made from plastic material and mounted with plastic clamps.

***NOTE:*** *A filter holder may not be required if one or a few samples are to be collected. For these cases, it may only be necessary to attach the filter to the outlet of the tubing connected to the pump.*

6.15 Pump and Pump Apparatus—Required for use with the jar sampling system (Section 6.5.1) or the continuous-flow system (Section 6.5.2). Peristaltic pump; 115 V a.c., 12 V d.c., internal battery, variable-speed, single-head, Cole-Parmer, portable, "Masterflex L/S," Catalog No. H-07570-10 drive with Quick Load pump head, Catalog No. H-07021-24, or equivalent.

***NOTE:*** *Equivalent pumps may include rotary vacuum, submersible, or other pumps free from metals and suitable to meet the site-specific depth sampling needs.*

6.15.1 Cleaning—Peristaltic pump modules do not require cleaning. However, nearly all peristaltic pumps contain a metal head and metal controls. Touching the head or controls necessitates changing of gloves before touching the Apparatus. If a submersible pump is used, a large volume of sample should be pumped to clean the stainless steel shaft (hidden behind the impeller) that comes in contact with the sample. Pumps with metal impellers should not be used.

6.15.2 Tubing—For use with peristaltic pump. SEBS resin, approximately 3/8 in. i.d. by approximately 3 ft, Cole-Parmer size 18, Cat. No. G-06464-18, or approximately 1/4 in. i.d., Cole-Parmer size 17, Catalog No. G-06464-17, or equivalent. Tubing is cleaned by soaking in 5-10% HCl solution for 8-24 hours, rinsing with reagent water in a clean bench in a clean room, and drying in the clean bench by purging with mercury-free air or nitrogen. After drying, the tubing is double-bagged in clear polyethylene bags, serialized with a unique number, and stored until use.

6.15.3 Tubing—For connection to peristaltic pump tubing. Fluoropolymer, 3/8 or 1/4 in. o.d., in lengths as required to reach the point of sampling. If sampling will be at some depth from the end of a boom extended from a boat, sufficient tubing to extend to the end of the boom and to the depth will be required. Cleaning of the fluoropolymer can be the same as cleaning the tubing for the rotary vacuum pump (Section 6.15.1.2). If necessary, more aggressive cleaning (e.g., concentrated nitric acid) may be used.

6.15.4 Batteries to operate submersible pump—12 V, 2.6 amp, gel cell, YUASA NP2.6-12, or equivalent. A 2 amp fuse connected at the positive battery terminal is strongly recommended to prevent short circuits from overheating the battery. A 12 V, lead-acid automobile or marine battery may be more suitable for extensive pumping.

6.15.5 Tubing connectors—Appropriately sized PVC, clear polyethylene, or fluoropolymer "barbed" straight connectors cleaned as the tubing above. Used to connect multiple lengths of tubing.

6.16 Carboy—For collection and storage of dilute waste acids used to store bottles.

6.17 Apparatus—For field preservation of aliquots for trivalent chromium determinations.

6.17.1 Fluoropolymer forceps—1 L fluoropolymer jar, and 30 mL fluoropolymer vials with screw-caps (one vial per sample and blank). It is recommended that 1 mL of ultrapure nitric acid (Section 7.3) be added to each vial prior to transport to the field to simplify field handling activities (See Section 8.4.4.6).

6.17.2 Filters—0.4 µm, 47 mm polycarbonate Nuclepore (or equivalent). Filters are cleaned as follows. Fill a 1 L fluoropolymer jar approximately two-thirds full with 1 N nitric acid. Using fluoropolymer forceps, place individual filters in the fluoropolymer jar. Allow the filters to soak for 48 hours. Discard the acid, and rinse five times with reagent water. Fill the jar with reagent water, and soak the filters for 24 hours. Remove the filters when ready for use, and using fluoropolymer forceps, place them on the filter apparatus (Section 6.17.3).

6.17.3 Vacuum filtration apparatus—Millipore 47 mm size, or equivalent, vacuum pump and power source (and extension cords, if necessary) to operate the pump.

6.17.4 Eppendorf auto pipet and colorless pipet tips (100-1000 µL)

6.17.5 Wrist-action shaker—Burrel or equivalent.

6.17.6 Fluoropolymer wash bottles—One filled with reagent water (Section 7.1) and one filled with high- purity 10% HCl (Section 7.4.4), for use in rinsing forceps and pipet tips.

## 7.0 Reagents and Standards

7.1 Reagent Water—Water in which the analytes of interest and potentially interfering substances are not detected at the Method Detection Limit (MDL) of the analytical method used for analysis of samples. Prepared by distillation, deionization, reverse osmosis, anodic/cathodic stripping voltammetry, or other techniques that remove the metal(s) and potential interferent(s). A large carboy or other appropriate container filled with reagent water must be available for the collection of field blanks.

7.2 Nitric Acid—Dilute, trace-metal grade, shipped with sampling kit for cleaning equipment between samples.

7.3 Sodium Hydroxide—Concentrated, 50% solution for use when field-preserving samples for hexavalent chromium determinations (Section 8.4.5).

7.4 Reagents—For field-processing aliquots for trivalent chromium determinations

7.4.1 Nitric Acid, Ultrapure—For use when field-preserving samples for trivalent chromium determinations (Sections 6.17 and 8.4.4).

7.4.2 Ammonium Iron (II) Sulfate Solution (0.01M)—Used to prepare the chromium (III) extraction solution (Section 7.4.3) necessary for field preservation of samples for trivalent chromium (Section 8.4.4). Prepare the ammonium iron (II) sulfate solution by adding 3.92 g ammonium iron (II) sulfate (ultrapure grade) to a 1 L volumetric flask. Bring to volume with reagent water. Store in a clean polyethylene bottle.

7.4.3 Chromium (III) extraction solution—For use when field-preserving samples for trivalent chromium determinations (Section 8.4.4). Prepare this solution by adding 100 mL of ammonium iron (II) sulfate solution (Section 7.4.2) to a 125 mL polyethylene bottle. Adjust pH to 8 with approximately 2 mL of ammonium hydroxide solution. Cap and shake on a wrist-action shaker for 24 hours. This iron (III) hydroxide solution is stable for 30 days.

7.4.4 Hydrochloric acid—High-purity, 10% solution, shipped with sampling kit in fluoropolymer wash bottles for cleaning trivalent chromium sample preservation equipment between samples.

7.4.5 Chromium stock standard solution (1000 µg/mL)—Prepared by adding 3.1 g anhydrous chromium chloride to a 1 L flask and diluting to volume with 1% hydrochloric acid. Store in polyethylene bottle. A commercially available standard solution may be substituted.

7.4.6 Standard chromium spike solution (1000 µg/L)—Used to spike sample aliquots for matrix spike/matrix spike duplicate (MS/MSD) analysis and to prepare ongoing precision and recovery standards. Prepared by spiking 1 mL of the

chromium stock standard solution (Section 7.4.5) into a 1 L flask. Dilute to volume with 1% HCl. Store in a polyethylene bottle.

7.4.7 Ongoing precision and recovery (OPR) standard (25 µg/L)—Prepared by spiking 2.5 mL of the standard chromium spike solution (Section 7.4.6) into a 100 mL flask. Dilute to volume with 1% HCl. One OPR is required for every 10 samples.

## 8.0 Sample Collection, Filtration, and Handling

8.1 Site Selection

8.1.1 Selection of a representative site for surface water sampling is based on many factors including: study objectives, water use, point source discharges, non-point source discharges, tributaries, changes in stream characteristics, types of stream bed, stream depth, turbulence, and the presence of structures (bridges, dams, etc.). When collecting samples to determine ambient levels of trace metals, the presence of potential sources of metal contamination are of extreme importance in site selection.

8.1.2 Ideally, the selected sampling site will exhibit a high degree of cross-sectional homogeneity. It may be possible to use previously collected data to identify locations for samples that are well mixed or are vertically or horizontally stratified. Since mixing is principally governed by turbulence and water velocity, the selection of a site immediately downstream of a riffle area will ensure good vertical mixing. Horizontal mixing occurs in constrictions in the channel. In the absence of turbulent areas, the selection of a site that is clear of immediate point sources, such as industrial effluents, is preferred for the collection of ambient water samples (Reference 19).

8.1.3 To minimize contamination from trace metals in the atmosphere, ambient water samples should be collected from sites that are as far as possible (e.g., at least several hundred feet) from any metal supports, bridges, wires or poles. Similarly, samples should be collected as far as possible from regularly or heavily traveled roads. If it is not possible to avoid collection near roadways, it is advisable to study traffic patterns and plan sampling events during lowest traffic flow (Reference 7).

8.1.4 The sampling activity should be planned to collect samples known or suspected to contain the lowest concentrations of trace metals first, finishing with the samples known or suspected to contain the highest concentrations. For example, if samples are collected from a flowing river or stream near an industrial or municipal discharge, the upstream sample should be collected first, the downstream sample collected second, and the sample nearest the discharge collected last. If the concentrations of pollutants is not known and cannot be estimated, it is necessary to use precleaned sampling equipment at each sampling location.

8.2 Sample Collection Procedure—Before collecting ambient water samples, consideration should be given to the type of sample to be collected, the amount of sample needed, and the devices to be used (grab, surface, or subsurface samplers). Sufficient sample volume

should be collected to allow for necessary quality control analyses, such as matrix spike/matrix spike duplicate analyses.

8.2.1 Four sampling procedures are described:

8.2.1.1 Section 8.2.5 describes a procedure for collecting samples directly into the sample container. This procedure is the simplest and provides the least potential for contamination because it requires the least amount of equipment and handling.

8.2.1.2 Section 8.2.6 describes a procedure for using a grab sampling device to collect samples.

8.2.1.3 Section 8.2.7 describes a procedure for depth sampling with a jar sampler. The size of sample container used is dependent on the amount of sample needed by the analytical laboratory.

8.2.1.4 Section 8.2.8 describes a procedure for continuous-flow sampling using a submersible or peristaltic pump.

8.2.2 The sampling team should ideally approach the site from down current and downwind to prevent contamination of the sample by particles sloughing off the boat or equipment. If it is not possible to approach from both, the site should be approached from down current if sampling from a boat or approached from downwind if sampling on foot. When sampling from a boat, the bow of the boat should be oriented into the current (the boat will be pointed upstream). All sampling activity should occur from the bow.

If the samples are being collected from a boat, it is recommended that the sampling team create a stable workstation by arranging the cooler or shipping container as a work table on the upwind side of the boat, covering this worktable and the upwind gunnel with plastic wrap or a plastic tablecloth, and draping the wrap or cloth over the gunnel. If necessary, duct tape is used to hold the wrap or cloth in place.

8.2.3 All operations involving contact with the sample bottle and with transfer of the sample from the sample collection device to the sample bottle (if the sample is not directly collected in the bottle) are handled by the individual designated as "clean hands." "Dirty hands" is responsible for all activities that do not involve direct contact with the sample.

Although the duties of "clean hands" and "dirty hands" would appear to be a logical separation of responsibilities, in fact, the completion of the entire protocol may require a good deal of coordination and practice. For example, "dirty hands" must open the box or cooler containing the sample bottle and unzip the outer bag; clean hands must reach into the outer bag, open the inner bag, remove the bottle, collect the sample, replace the bottle lid, put the bottle back into the inner bag, and zip the inner bag. "Dirty hands" must close the outer bag and place it in a cooler.

To minimize unnecessary confusion, it is recommended that a third team member be available to complete the necessary sample documentation (e.g., to document sampling location, time, sample number, etc). Otherwise, "dirty hands" must perform the sample documentation activity (Reference 7).

8.2.4 Extreme care must be taken during all sampling operations to minimize exposure of the sample to human, atmospheric, and other sources of contamination. Care must be taken to avoid breathing directly on the sample, and whenever possible, the sample bottle should be opened, filled, and closed while submerged.

8.2.5 Manual collection of surface samples directly into the sample bottle.

8.2.5.1 At the site, all sampling personnel must put on clean gloves (Section 6.7) before commencing sample collection activity, with "clean hands" donning shoulder-length gloves. If samples are to be analyzed for mercury, the sampling team must also put their precleaned wind suits on at this time. Note that "clean hands" should put on the shoulder-length polyethylene gloves (Section 6.7.1) and both "clean hands" and "dirty hands" should put on the PVC gloves (Section 6.7.2).

8.2.5.2 "Dirty hands" must open the cooler or storage container, remove the double-bagged sample bottle from storage, and unzip the outer bag.

8.2.5.3 Next, "clean hands" opens the inside bag containing the sample bottle, removes the bottle, and reseals the inside bag. "Dirty hands" then reseals the outer bag.

8.2.5.4 "Clean hands" unscrews the cap and, while holding the cap upside down, discards the dilute acid solution from the bottle into a carboy for wastes (Section 6.16) or discards the reagent water directly into the water body.

8.2.5.5 "Clean hands" then submerges the sample bottle, and allows the bottle to partially fill with sample. "Clean hands" screws the cap on the bottle, shakes the bottle several times, and empties the rinsate away from the site. After two more rinsings, "clean hands" holds the bottle under water and allows bottle to fill with sample. After the bottle has filled (i.e., when no more bubbles appear), and while the bottle is still inverted so that the mouth of the bottle is underwater, "clean hands" replaces the cap of the bottle. In this way, the sample has never contacted the air.

8.2.5.6 Once the bottle lid has been replaced, "dirty hands" reopens the outer plastic bag, and "clean hands" opens the inside bag, places the bottle inside it, and zips the inner bag.

8.2.5.7 "Dirty hands" zips the outer bag.

8.2.5.8 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.5.9 If the sample is to be analyzed for dissolved metals, it is filtered in accordance with the procedure described in Section 8.3.

8.2.6 Sample collection with grab sampling device—The following steps detail sample collection using the grab sampling device shown in Figure 1 and described in Section 6.4.1. The procedure is indicative of the "clean hands/dirty hands" technique that must be used with alternative grab sampling devices such as that shown in Figure 2 and described in Section 6.4.2.

8.2.6.1 The sampling team puts on gloves (and wind suits, if applicable). Ideally, a sample bottle will have been preattached to the sampling device in the class 100 clean room at the laboratory. If it is necessary to attach a bottle to the device in the field, "clean hands" performs this operation, described in Section 6.4.2, inside the field-portable glove bag (Section 6.6).

8.2.6.2 "Dirty hands" removes the sampling device from its storage container and opens the outer polyethylene bag.

8.2.6.3 "Clean hands" opens the inside polyethylene bag and removes the sampling device.

8.2.6.4 "Clean hands" changes gloves.

8.2.6.5 "Dirty hands" submerges the sampling device to the desired depth and pulls the fluoropolymer pull cord to bring the seal plate into the middle position so that water can enter the bottle.

8.2.6.6 When the bottle is full (i.e., when no more bubbles appear), "dirty hands" pulls the fluoropolymer cord to the final stop position to seal off the sample and removes the sampling device from the water.

8.2.6.7 "Dirty hands" returns the sampling device to its large inner plastic bag, "clean hands" pulls the bottle out of the collar, unscrews the bottle from the sealing device, and caps the bottle. "Clean hands" and "dirty hands" then return the bottle to its double-bagged storage as described in Sections 8.2.5.6 through 8.2.5.7.

8.2.6.8 Closing mechanism—"Clean hands" removes the closing mechanism from the body of the grab sampler, rinses the device with reagent water (Section 7.1), places it inside a new clean plastic bag, zips the bag, and places the bag inside an outer bag held by "dirty hands." "Dirty hands" zips the outer bag and places the double-bagged closing mechanism in the equipment storage box.

8.2.6.9 Sampling device—"Clean hands" seals the large inside bag containing the collar, pole, and cord and places the bag into a large outer bag held by "dirty hands." "Dirty hands" seals the outside bag and places the double-bagged sampling device into the equipment storage box.

8.2.6.10 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.6.11 If the sample is to be analyzed for dissolved metals, it is filtered in accordance with the procedures described in Section 8.3.

8.2.7 Depth sampling using a jar sampling device (Figure 3 and Section 6.5.1)

8.2.7.1 The sampling team puts on gloves (and wind suits, if applicable) and handles bottles as with manual collection (Sections 8.2.5.1 through 8.2.5.4 and 8.2.5.6 through 8.2.5.7).

8.2.7.2 "Dirty hands" removes the jar sampling device from its storage container and opens the outer polyethylene bag.

8.2.7.3 "Clean hands" opens the inside polyethylene bag and removes the jar sampling apparatus. Ideally, the sampling device will have been preassembled in a class 100 clean room at the laboratory. If, however, it is necessary to assemble the device in the field, "clean hands" must perform this operation, described in Section 6.5.2, inside a field-portable glove bag (Section 6.6).

8.2.7.4 While "dirty hands" is holding the jar sampling apparatus, "clean hands" connects the pump to the to the 1/4 in. o.d. flush line.

8.2.7.5 "Dirty hands" lowers the weighted sampler to the desired depth.

8.2.7.6 "Dirty hands" turns on the pump allowing a large volume (>2 L) of water to pass through the system.

8.2.7.7 After stopping the pump, "dirty hands" pulls up the line, tubing, and device and places them into either a field-portable glove bag or a large, clean plastic bag as they emerge.

8.2.7.8 Both "clean hands" and "dirty hands" change gloves.

8.2.7.9 Using the technique described in Sections 8.2.5.2 through 8.2.5.4, the sampling team removes a sample bottle from storage, and "clean hands" places the bottle into the glove bag.

8.2.7.10 "Clean hands" tips the sampling jar and dispenses the sample through the short length of fluoropolymer tubing into the sample bottle.

8.2.7.11 Once the bottle is filled, "clean hands" replaces the cap of the bottle, returns the bottle to the inside polyethylene bag, and zips the bag. "Clean hands" returns the zipped bag to the outside polyethylene bag held by "dirty hands."

8.2.7.12 "Dirty hands" zips the outside bag. If the sample is to be analyzed for dissolved metals, it is filtered as described in Section 8.3.

8.2.7.13 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.2.8 Continuous-flow sampling (Figure 4 and Section 6.5.2)—The continuous-flow sampling system uses peristaltic pump (Section 6.15) to pump sample to the boat or to shore through the SEBS-resin or PTFE tubing.

8.2.8.1 Before putting on wind suits or gloves, the sampling team removes the bags containing the pump (Section 6.15), SEBS-resin tubing (Section 6.15.2), batteries (Section 6.15.4), gloves (Section 6.7), plastic wrap (Section 6.9), wind suits (Section 6.12), and, if samples are to be filtered, the filtration apparatus (Section 6.14) from the coolers or storage containers in which they are packed.

8.2.8.2 "Clean hands" and "dirty hands" put on the wind suits and PVC gloves (Section 6.7.2).

8.2.8.3 "Dirty hands" removes the pump from its storage bag, and opens the bag containing the SEBS-resin tubing.

8.2.8.4 "Clean hands" installs the tubing while "dirty hands" holds the pump. "Clean hands" immerses the inlet end of the tubing in the sample stream.

8.2.8.5 Both "clean hands" and "dirty hands" change gloves. "Clean hands" also puts on shoulder length polyethylene gloves (Section 6.7.1).

8.2.8.6 "Dirty hands" turns the pump on and allows the pump to run for 5-10 minutes or longer to purge the pump and tubing.

8.2.8.7 If the sample is to be filtered, "clean hands" installs the filter at the end of the tubing, and "dirty hands" sets up the filter holder on the gunwale as shown in Figure 4.

***NOTE:*** *The filtration apparatus is not attached until immediately before sampling to prevent buildup of particulates from clogging the filter.*

8.2.8.8 The sample is collected by rinsing the sample bottle and cap three times and collecting the sample from the flowing stream.

8.2.8.9 Documentation—After each sample is collected, the sample number is documented in the sampling log, and any unusual observations concerning the sample and the sampling are documented.

8.3 Sample Filtration—The filtration procedure described below is used for samples collected using the manual (Section 8.2.5), grab (Section 8.2.6), or jar (Section 8.2.7) collection systems (Reference 7). In-line filtration using the continuous-flow approach is described in Section 8.2.8.7. Because of the risk of contamination, it is recommended that samples for mercury be shipped unfiltered by overnight courier and filtered when received at the laboratory.

8.3.1 Set up the filtration system inside the glove bag, using the shortest piece of pump tubing as is practicable. Place the peristaltic pump immediately outside of the glove bag and poke a small hole in the glove bag for passage of the tubing. Also, attach a short length of tubing to the outlet of the capsule filter.

8.3.2 "Clean hands" removes the water sample from the inner storage bag using the technique described in Sections 8.2.5.2 through 8.2.5.4 and places the sample inside the glove bag. "Clean hands" also places two clean empty sample bottles, a bottle containing reagent water, and a bottle for waste in the glove bag.

8.3.3 "Clean hands" removes the lid of the reagent water bottle and places the end of the pump tubing in the bottle.

8.3.4 "Dirty hands" starts the pump and passes approximately 200 mL of reagent water through the tubing and filter into the waste bottle. "Clean hands" then moves the outlet tubing to a clean bottle and collects the remaining reagent water as a blank. "Dirty hands" stops the pump.

8.3.5 "Clean hands" removes the lid of the sample bottle and places the intake end of the tubing in the bottle.

8.3.6 "Dirty hands" starts the pump and passes approximately 50 mL through the tubing and filter into the remaining clean sample bottle and then stops the pump. "Clean hands" uses the filtrate to rinse the bottle, discards the waste sample, and returns the outlet tube to the sample bottle.

8.3.7 "Dirty hands" starts the pump and the remaining sample is processed through the filter and collected in the sample bottle. If preservation is required, the sample is acidified at this point (Section 8.4).

8.3.8 "Clean hands" replaces the lid on the bottle, returns the bottle to the inside bag, and zips the bag. "Clean hands" then places the zipped bag into the outer bag held by "dirty hands."

8.3.9 "Dirty hands" zips the outer bag, and places the double-bagged sample bottle into a clean, ice-filled cooler for immediate shipment to the laboratory.

***NOTE:*** *It is not advisable to reclean and reuse filters. The difficulty and risk associated with failing to properly clean these devices far outweighs the cost of purchasing a new filter.*

8.4 Preservation

8.4.1 Field preservation is not necessary for dissolved metals, except for trivalent and hexavalent chromium, provided that the sample is preserved in the laboratory and allowed to stand for at least two days to allow the metals adsorbed to the container walls to redissolve. Field preservation is advised for hexavalent chromium in order to provide sample stability for up to 30 days. Mercury samples should be shipped by overnight courier and preserved when received at the laboratory.

8.4.2 If field preservation is required, preservation must be performed in the glove bag or in a designated clean area, with gloved hands, as rapidly as possible to preclude particulates from contaminating the sample. For preservation of trivalent chromium, the glove bag or designated clean area must be large enough to accommodate the vacuum filtration apparatus (Section 6.17.3), and an area should be available for setting up the wrist-action shaker (Section 6.17.5). It is also advisable to set up a work area that contains a "clean" cooler for storage of clean equipment, a "dirty" cooler for storage of "dirty" equipment, and a third cooler to store samples for shipment to the laboratory.

8.4.3 Preservation of aliquots for metals other than trivalent and hexavalent chromium—Using a disposable, precleaned, plastic pipet, add 5 mL of a 10% solution of ultrapure nitric acid in reagent water per liter of sample. This will be sufficient to preserve a neutral sample to pH <2.

8.4.4 Preservation of aliquots for trivalent chromium (References 8-9).

8.4.4.1 Decant 100 mL of the sample into a clean polyethylene bottle.

8.4.4.2 Clean an Eppendorf pipet by pipeting 1 mL of 10% HCl (Section (7.4.4) followed by 1 mL of reagent water into an acid waste container. Use the rinsed pipet to add 1 mL of chromium (III) extraction solution (Section 7.4.3) to each sample and blank.

8.4.4.3 Cap each bottle tightly, place in a clean polyethylene bag, and shake on a wrist action shaker (Section 6.17.5) for one hour.

8.4.4.4 Vacuum-filter the precipitate through a 0.4 µm pretreated filter membrane (Section 6.17.2), using fluoropolymer forceps (Section 6.17.1) to handle the membrane, and a 47 mm vacuum filtration apparatus with a precleaned filter holder (Section 6.17.3). After all sample has filtered, rinse the inside of the filter holder with approximately 15 mL of reagent water.

8.4.4.5 Using the fluoropolymer forceps, fold the membrane in half and then in quarters, taking care to avoid touching the side containing the filtrate to any surface. (Folding is done while the membrane is sitting on the filter holder and allows easy placement of the membrane into the sample vial). Transfer the filter to a 30 mL fluoropolymer vial. If the fluoropolymer vial was not pre-equipped with the ultrapure nitric acid (Section 7.4.1), rinse the pipet by drawing and discharging 1 mL of 10% HCl followed by 1 mL of reagent water into a waste container, and add 1 mL of ultrapure nitric acid to the sample vial.

8.4.4.6 Cap the vial and double-bag it for shipment to the laboratory.

8.4.4.7 Repeat Steps 8.4.4.4-8.4.4.6 for each sample, rinsing the fluoropolymer forceps and the pipet with 10% high-purity HCl followed by reagent water between samples.

8.4.5 Preservation of aliquots for hexavalent chromium (Reference 20).

8.4.5.1 Decant 125 mL of sample into a clean polyethylene bottle.

8.4.5.2 Prepare an Eppendorf pipet by pipeting 1 mL of 10% HCl (Section 7.4.4) followed by 1 mL of reagent water into an acid waste container. Use the rinsed pipet to add 1 mL NaOH to each 125 mL sample and blank aliquot.

8.4.5.3 Cap the vial(s) and double-bag for shipment to the laboratory.

## 9.0 Quality Assurance/Quality Control

9.1 The sampling team shall employ a strict quality assurance/ quality control (QA/QC) program. The minimum requirements of this program include the collection of equipment blanks, field blanks, and field replicates. It is also desirable to include blind QC samples as part of the program. If samples will be processed for trivalent chromium determinations, the sampling team shall also prepare method blank, OPR, and MS/MSD samples as described in Section 9.6.

9.2 The sampling team is permitted to modify the sampling techniques described in this method to improve performance or reduce sampling costs, provided that reliable analyses of samples are obtained and that samples and blanks are not contaminated. Each time a modification is made to the procedures, the sampling team is required to demonstrate that the modification does not result in contamination of field and equipment blanks. The requirements for modification are given in Sections 9.3 and 9.4. Because the acceptability of a modification is based on the results obtained with the modification, the sampling team must work with an analytical laboratory capable of making trace metals determinations to demonstrate equivalence.

9.3 Equipment Blanks

9.3.1 Before using any sampling equipment at a given site, the laboratory or equipment cleaning contractor is required to generate equipment blanks to demonstrate that the equipment is free from contamination. Two types of equipment blanks are required: bottle blanks and sampling equipment blanks.

9.3.2 Equipment blanks must be run on all equipment that will be used in the field. If, for example, samples are to be collected using both a grab sampling device and the jar sampling device, then an equipment blank must be run on both pieces of equipment.

9.3.3 Equipment blanks are generated in the laboratory or at the equipment cleaning contractor's facility by processing reagent water through the equipment using the same procedures that are used in the field (Section 8.0). Therefore, the "clean hands/dirty hands" technique used during field sampling should be followed when preparing equipment blanks at the laboratory or cleaning facility. In addition, training programs must require must require sampling personnel to collect a clean equipment blank before performing on-site field activities.

9.3.4 Detailed procedures for collecting equipment blanks are given in the analytical methods referenced in Table 1.

9.3.5 The equipment blank must be analyzed using the procedures detailed in the

referenced analytical method (see Table 1). If any metal(s) of interest or any potentially interfering substance is detected in the equipment blank at the minimum level specified in the referenced method, the source of contamination/interference must be identified and removed. The equipment must be demonstrated to be free from the metal(s) of interest before the equipment may be used in the field.

9.4 Field Blank

9.4.1 To demonstrate that sample contamination has not occurred during field sampling and sample processing, at least one field blank must be generated for every 10 samples that are collected at a given site. Field blanks are collected before sample collection.

9.4.2 Field blanks are generated by filling a large carboy or other appropriate container with reagent water (Section 7.1) in the laboratory, transporting the filled container to the sampling site, processing the water through each of the sample processing steps and equipment (e.g., tubing, sampling devices, filters, etc.) that will be used in the field, collecting the field blank in one of the sample bottles, and shipping the bottle to the laboratory for analysis in accordance with the method(s) referenced in Table 1. For example, manual grab sampler field blanks are collected by directly submerging a sample bottle into the water, filling the bottle, and capping. Subsurface sampler field blanks are collected by immersing the tubing into the water and pumping water into a sample container.

9.4.3 Filter the field blanks using the procedures described in Section 8.3.

9.4.4 If it is necessary to acid clean the sampling equipment between samples (Section 10.0), a field blank should be collected after the cleaning procedures but before the next sample is collected.

9.4.5 If trivalent chromium aliquots are processed, a separate field blank must be collected and processed through the sample preparation steps given in Sections 8.4.4.1 through 8.4.4.6.

9.5 Field Duplicate

9.5.1 To assess the precision of the field sampling and analytical processes, at least one field duplicate sample must be collected for every 10 samples that are collected at a given site.

9.5.2 The field duplicate is collected either by splitting a larger volume into two aliquots in the glove box, by using a sampler with dual inlets that allows simultaneous collection of two samples, or by collecting two samples in rapid succession.

9.5.3 Field duplicates for dissolved metals determinations must be processed using the procedures in Section 8.3. Field duplicates for trivalent chromium must be processed through the sample preparation steps given in Sections 8.4.4.1 through 8.4.4.6.

9.6 Additional QC for Collection of Trivalent Chromium Aliquots

9.6.1 Method blank—The sampling team must prepare one method blank for every ten or fewer field samples. Each method blank is prepared using the steps in Sections 8.4.4.1 through 8.4.4.6 on a 100 mL aliquot of reagent water (Section 7.1). Do not use the procedures in Section 8.3 to process the method blank through the 0.45 µm filter (Section 6.14.1), even if samples are being collected for dissolved metals determinations.

9.6.2 Ongoing precision and recovery (OPR)—The sampling team must prepare one OPR for every ten or fewer field samples. The OPR is prepared using the steps in Sections 8.4.4.1 through 8.4.4.6 on the OPR standard (Section 7.4.7). Do not use the procedures in Section 8.3 to process the OPR through the 0.45 µm filter (Section 6.14.1), even if samples are being collected for dissolved metals determinations.

9.6.3 MS/MSD—The sampling team must prepare one MS and one MSD for every ten or fewer field samples.

9.6.3.1 If, through historical data, the background concentration of the sample can be estimated, the MS and MSD samples should be spiked at a level of one to five times the background concentration.

9.6.3.2 For samples in which the background concentration is unknown, the MS and MSD samples should be spiked at a concentration of 25 µg/L.

9.6.3.3 Prepare the matrix spike sample by spiking a 100-mL aliquot of sample with 2.5 mL of the standard chromium spike solution (Section 7.4.6), and processing the MS through the steps in Sections 8.4.4.1 through 8.4.4.6.

9.6.3.4 Prepare the matrix spike duplicate sample by spiking a second 100-mL aliquot of the same sample with 2.5 mL of the standard chromium spike solution, and processing the MSD through the steps in Sections 8.4.4.1 through 8.4.4.6.

9.6.3.5 If field samples are collected for dissolved metals determinations, it is necessary to process an MS and an MSD through the 0.45 µm filter as described in Section 8.3.

## 10.0 Recleaning the Apparatus Between Samples

10.1 Sampling activity should be planned so that samples known or suspected to contain the lowest concentrations of trace metals are collected first with the samples known or suspected to contain the highest concentrations of trace metals collected last. In this manner, cleaning of the sampling equipment between samples in unnecessary. If it is not possible to plan sampling activity in this manner, dedicated sampling equipment should be provided for each sampling event.

10.2 If samples are collected from adjacent sites (e.g., immediately upstream or downstream), rinsing of the sampling Apparatus with water that is to be sampled should be sufficient.

10.3 If it is necessary to cross a gradient (i.e., going from a high-concentration sample to a low-concentration sample), such as might occur when collecting at a second site, the following procedure may be used to clean the sampling equipment between samples:

10.3.1 In the glove bag, and using the "clean hands/dirty hands" procedure in Section 8.2.5, process the dilute nitric acid solution (Section 7.2) through the Apparatus.

10.3.2 Dump the spent dilute acid in the waste carboy or in the waterbody away from the sampling point.

10.3.3 Process 1 L of reagent water through the Apparatus to rinse the equipment and discard the spent water.

10.3.4 Collect a field blank as described in Section 9.4.

10.3.5 Rinse the Apparatus with copious amounts of the ambient water sample and proceed with sample collection.

10.4 Procedures for recleaning trivalent chromium preservation equipment between samples are described in Section 8.4.4.

## 11.0 Method Performance

Samples were collected in the Great Lakes during September–October 1994 using the procedures in this sampling method.

## 12.0 Pollution Prevention

12.1 The only materials used in this method that could be considered pollutants are the acids used in the cleaning of the Apparatus, the boat, and related materials. These acids are used in dilute solutions in small amounts and pose little threat to the environment when managed properly.

12.2 Cleaning solutions containing acids should be prepared in volumes consistent with use to minimize the disposal of excessive volumes of acid.

12.3 To the extent possible, the Apparatus used to collect samples should be cleaned and reused to minimize the generation of solid waste.

## 13.0 Waste Management

13.1 It is the sampling team's responsibility to comply with all federal, state, and local regulations governing waste management, particularly the discharge regulations, hazardous waste identification rules, and land disposal restrictions; and to protect the air, water, and land by minimizing and controlling all releases from field operations.

13.2 For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* and *Less is Better—Laboratory Chemical Management for Waste Reduction*, available from the American Chemical Society's Department of Government Relations and Science Policy, 1155 16th Street NW, Washington, DC 20036.

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## 15.0 Glossary of Definitions and Purposes

These definitions and purposes are specific to this sampling method but have been conformed to common usage as much as possible.

15.1 Ambient Water—Waters in the natural environment (e.g., rivers, lakes, streams, and other receiving waters), as opposed to effluent discharges.

15.2 Apparatus—The sample container and other containers, filters, filter holders, labware, tubing, pipets, and other materials and devices used for sample collection or sample preparation, and that will contact samples, blanks, or analytical standards.

15.3 Equipment Blank—An aliquot of reagent water that is subjected in the laboratory to all aspects of sample collection and analysis, including contact with all sampling devices and apparatus. The purpose of the equipment blank is to determine if the sampling devices and apparatus for sample collection have been adequately cleaned before they are shipped to the field site. An acceptable equipment blank must be achieved before the sampling devices and Apparatus are used for sample collection.

15.4 Field Blank—An aliquot of reagent water that is placed in a sample container in the laboratory, shipped to the field, and treated as a sample in all respects, including contact with the sampling devices and exposure to sampling site conditions, filtration, storage, preservation, and all analytical procedures. The purpose of the field blank is to determine whether the field or sample transporting procedures and environments have contaminated the sample.

15.5 Field Duplicates (FD1 and FD2)—Two identical aliquots of a sample collected in separate sample bottles at the same time and place under identical circumstances using a duel

inlet sampler or by splitting a larger aliquot and treated exactly the same throughout field and laboratory procedures. Analyses of FD1 and FD2 give a measure of the precision associated with sample collection, preservation, and storage, as well as with laboratory procedures.

15.6 Matrix Spike (MS) and Matrix Spike Duplicate (MSD)—Aliquots of an environmental sample to which known quantities of the analytes are added in the laboratory. The MS and MSD are analyzed exactly like a sample. Their purpose is to quantify the bias and precision caused by the sample matrix. The background concentrations of the analytes in the sample matrix must be determined in a separate aliquot and the measured values in the MS and MSD corrected for background concentrations.

15.7 May—This action, activity, or procedural step is optional.

15.8 May Not—This action, activity, or procedural step is prohibited.

15.9 Minimum Level (ML)—The lowest level at which the entire analytical system gives a recognizable signal and acceptable calibration point (Reference 21).

15.10 Must—This action, activity, or procedural step is required.

15.11 Reagent Water—Water demonstrated to be free from the metal(s) of interest and potentially interfering substances at the MDL for that metal in the referenced method or additional method.

15.12 Should—This action, activity, or procedural step is suggested but not required.

15.13 Trace-Metal Grade—Reagents that have been demonstrated to be free from the metal(s) of interest at the method detection limit (MDL) of the analytical method to be used for determination of this metal(s).

The term "trace-metal grade" has been used in place of "reagent grade" or "reagent" because acids and other materials labeled "reagent grade" have been shown to contain concentrations of metals that will interfere in the determination of trace metals at levels listed in Table 1.

**TABLE 1. ANALYTICAL METHODS, METALS, AND CONCENTRATION LEVELS APPLICABLE TO METHOD 1669**

| Method | Technique | Metal | MDL (µg/L) [1] | ML (µg/L) [2] |
|---|---|---|---|---|
| 1631 | Oxidation/Purge & Trap/CVAFS | Mercury | 0.0002 | 0.0005 |
| 1632 | Hydride AA | Arsenic | 0.003 | 0.01 |
| 1636 | Ion Chromatography | Hexavalent Chromium | 0.23 | 0.5 |
| 1637 | CC/STGFAA | Cadmium | 0.0075 | 0.02 |
| | | Lead | 0.036 | 0.1 |
| 1638 | ICP/MS | Antimony | 0.0097 | 0.02 |
| | | Cadmium | 0.013 | 0.1 |
| | | Copper | 0.087 | 0.2 |
| | | Lead | 0.015 | 0.05 |
| | | Nickel | 0.33 | 1 |
| | | Selenium | 0.45 | 1 |
| | | Silver | 0.029 | 0.1 |
| | | Thallium | 0.0079 | 0.02 |
| | | Zinc | 0.14 | 0.5 |
| 1639 | STGFAA | Antimony | 1.9 | 5 |
| | | Cadmium | 0.023 | 0.05 |
| | | Trivalent Chromium | 0.10 | 0.2 |
| | | Nickel | 0.65 | 2 |
| | | Selenium | 0.83 | 2 |
| | | Zinc | 0.14 | 0.5 |
| 1640 | CC/ICP/MS | Cadmium | 0.0024 | 0.01 |
| | | Copper | 0.024 | 0.1 |
| | | Lead | 0.0081 | 0.02 |
| | | Nickel | 0.029 | 0.1 |

[1] Method Detection Limit as determined by 40 *CFR* Part 136, Appendix B.
[2] Minimum Level (ML) calculated by multiplying laboratory-determined MDL by 3.18 and rounding result to nearest multiple of 1, 2, 5, 10, 20, 50, etc., in accordance with procedures used by EAD and described in the EPA *Draft National Guidance for the Permitting, Monitoring, and Enforcement of Water Quality-Based Effluent Limitations Set Below Analytical Detection/Quantitation Levels*, March 22, 1994.

**TABLE 2. ANALYTES, PRESERVATION REQUIREMENTS, AND CONTAINERS**

| Metal | Preservation Requirements | Acceptable Containers |
|---|---|---|
| Antimony<br>Arsenic<br>Cadmium<br>Copper<br>Lead<br>Nickel<br>Selenium<br>Silver<br>Thallium<br>Zinc | Add 5 mL of 10% $HN0_3$ to 1-L sample; preserve on-site or immediately upon laboratory receipt. | 500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid |
| Chromium (III) | Add 1 mL chromium (III) extraction solution to 100 mL aliquot, vacuum filter through 0.4 µm membrane, add 1 mL 10% $HN0_3$; preserve on-site immediately after collection. | 500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid |
| Chromium (IV) | Add 50% NaOH; preserve immediately after sample collection. | 500 mL or 1 L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid |
| Mercury | Total: Add 0.5% high-purity HCl or 0.5% BrCl to pH < 2; Total & Methyl: Add 0.5% high-purity HCL; preserve on-site or immediately upon laboratory receipt | Fluoropolymer or borosilicate glass bottles with fluoropolymer or fluoropolymer-lined caps |

**Figure 1 - Grab Sampling Device**

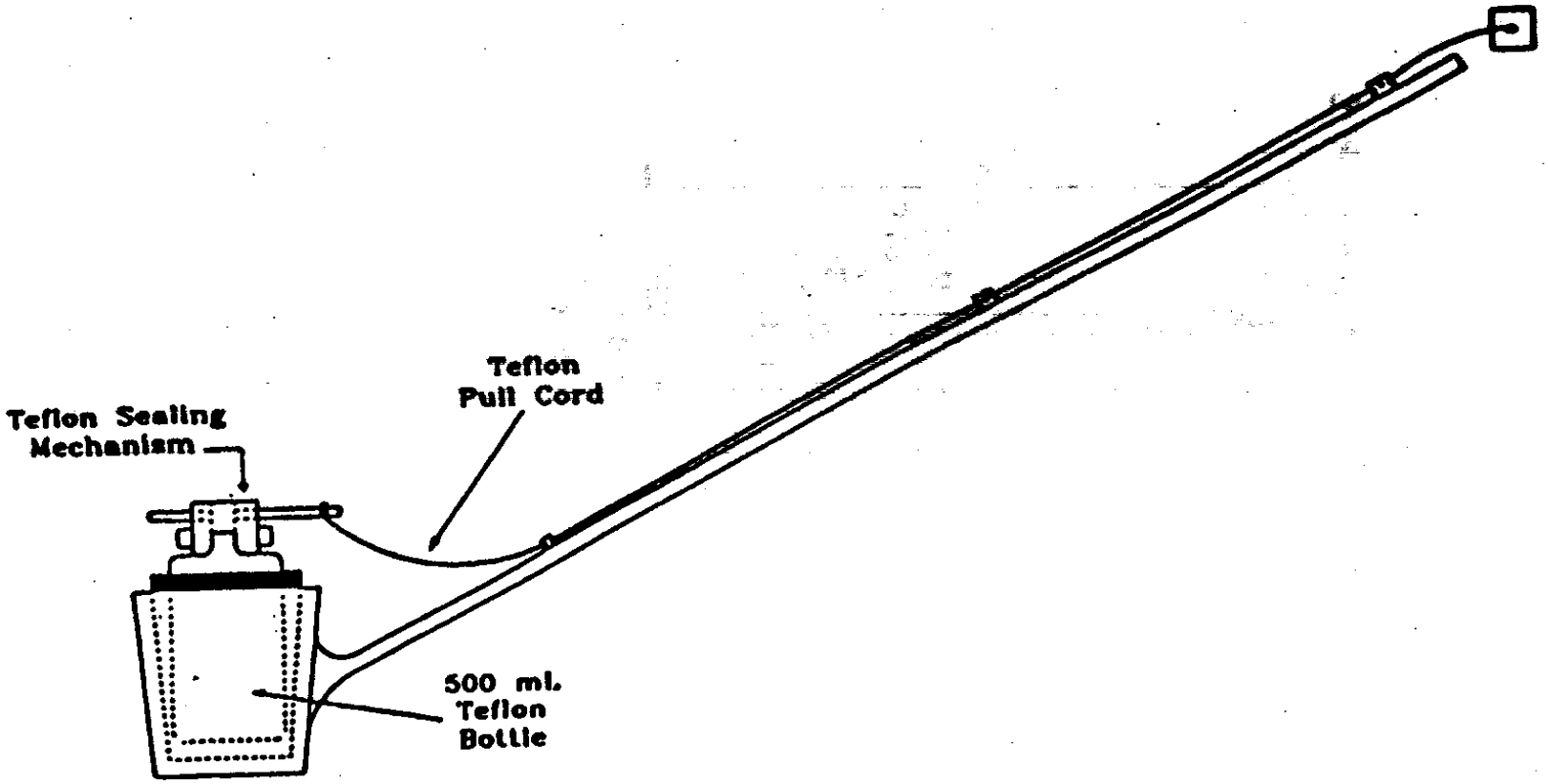


**Figure 2 - Grab Sampling Device**

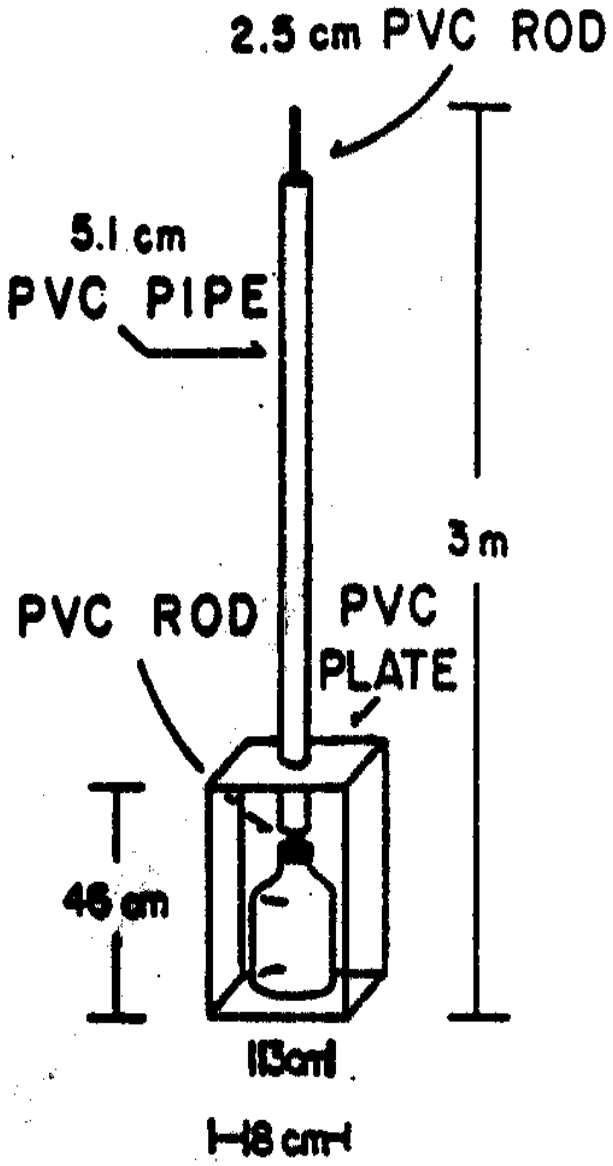


**Figure 3 - Jar Sampling Device**

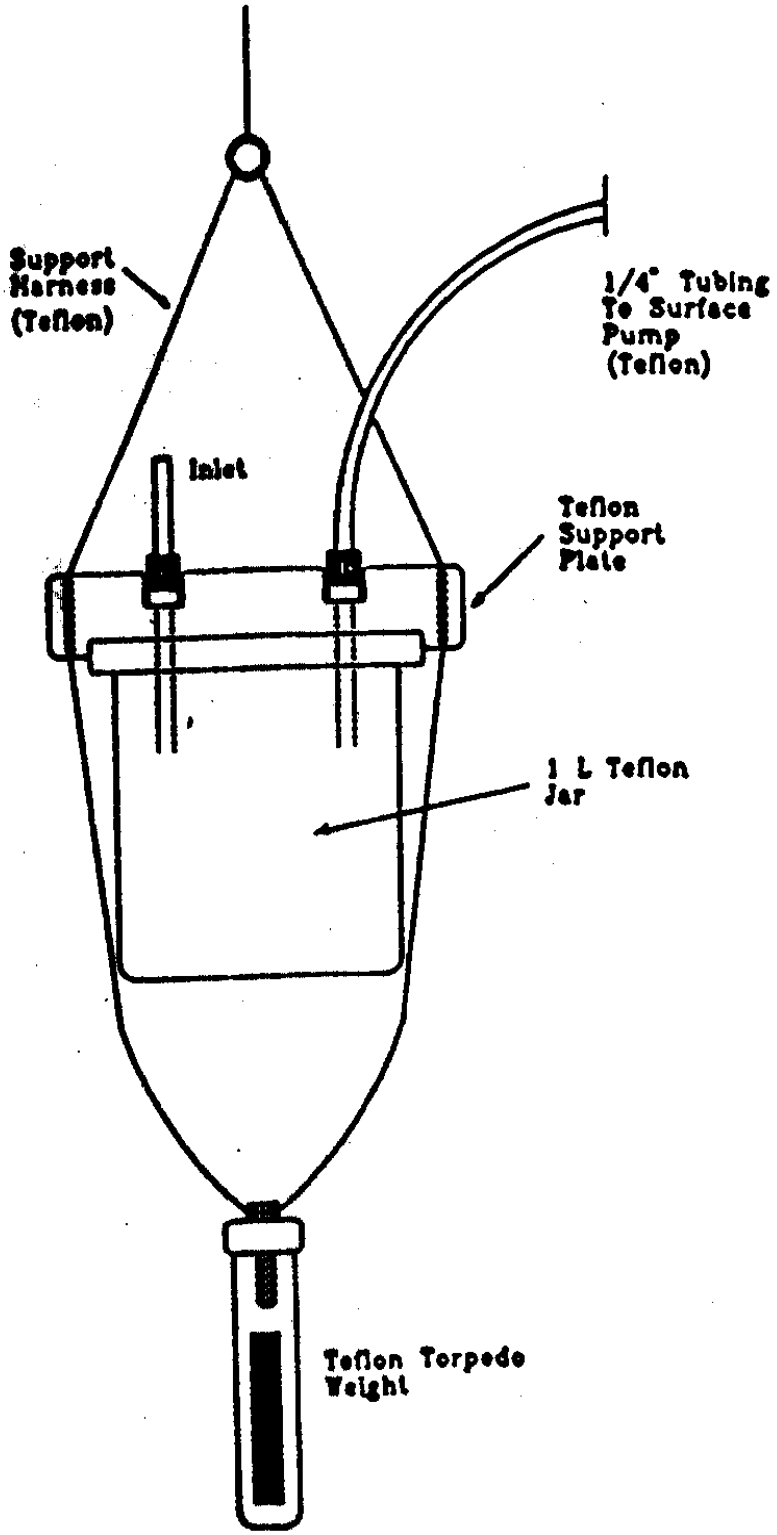
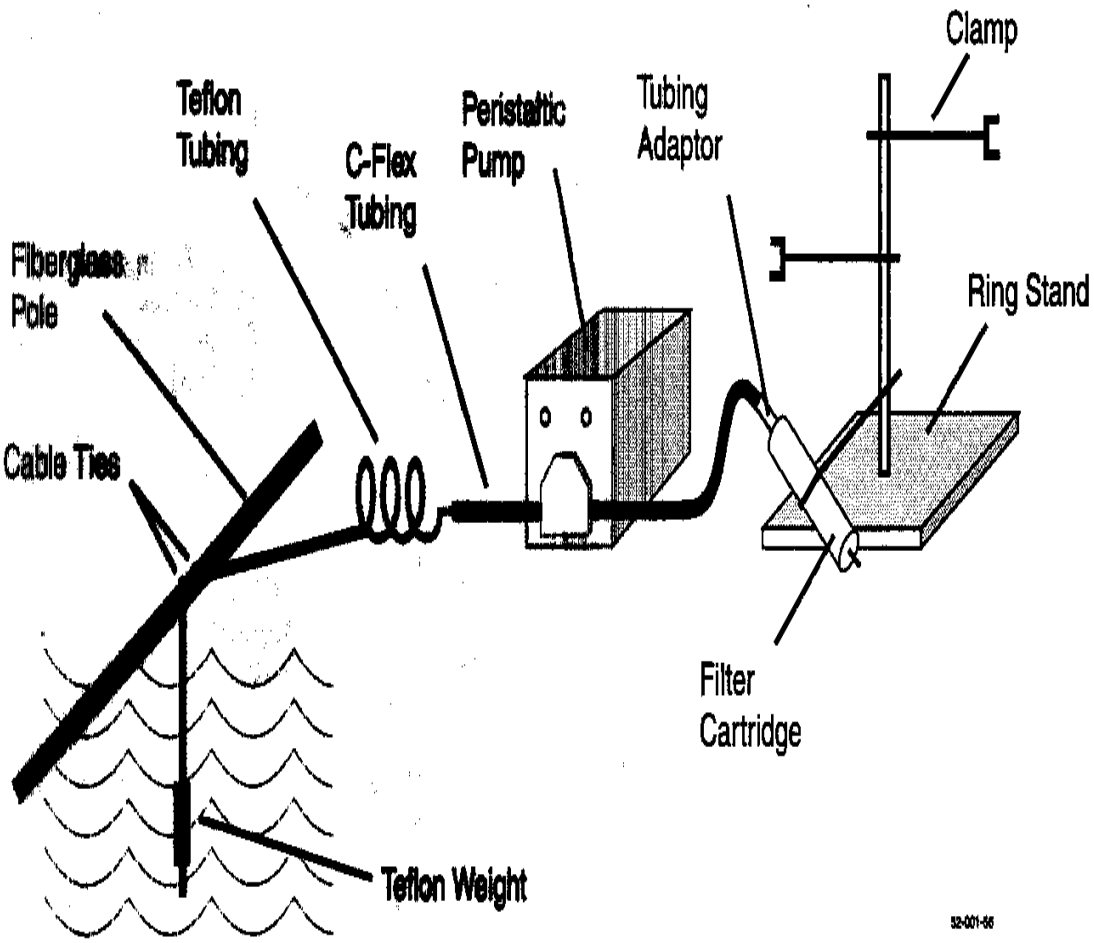


**Figure 4 - Sample Pumping System**



**Appendix D**

EPA Guidelines for Measuring Stream Flows

Water Resources
Research Laboratory

U. S. Department of the Interior
Bureau of Reclamation

# WATER MEASUREMENT MANUAL

## A WATER RESOURCES TECHNICAL PUBLICATION

Water Measurement web page

A guide to effective water measurement practices for better water management

U.S. Department of the Interior

Bureau of Reclamation

In cooperation with

United States Department of Agriculture

Agricultural Research Service

FIRST EDITION 1953
SECOND EDITION 1967
REPRINTED 1967, 1971
REVISED REPRINT 1974
REPRINTED 1975, 1977, 1981
REVISED REPRINT 1984
REPRINTED 1993
THIRD EDITION 1997
REVISED REPRINTED 2001
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

# PREFACE

The mission of many public and private water resources organizations is to manage and conserve existing water supplies. These management efforts involve making sound technical and economic decisions concerning new and existing water needs, while respecting the environment by sustaining or restoring the aquatic ecosystems which may be affected. One key to better management practices, including water conservation, is reliable and accurate water measurement. The term "water measurement" as used in this manual refers to the measurement of flow (unit volume per unit time). Major advances in measurement technology along with a continued demand for the *Water Measurement Manual* are responsible for initiating this revision.

The first edition of the *Water Measurement Manual* (1953) had a distribution of 11,000 copies and was compiled from the Bureau of Reclamation (Reclamation) publication *Manual for Measurement of Irrigation Water* (1946). This previous manual had five earlier editions beginning in 1913 and extending to 1940. The continual demand for the *Water Measurement Manual* and the need for updating resulted in the second edition (1967). From 1967 to 1984, two revised reprints plus five reprints of the second edition were published. The demand and need for the second edition has continued because of conservation pressure and increased user competition for water; therefore, this third edition was prepared to supplement and update information contained in the second edition.

Modern trends of technical practice, along with the developments in personal computers, have resulted in increased emphasis on using custom-fitted, long-throated measurement structures that can be designed to measure flow and are simpler to fabricate. Consequently, fewer short-form flumes are being considered for new installations. Thus, information on Parshall flumes has been reduced and incorporated in the more general "Flumes" chapter, which recommends long-throated flumes for new installation in preference to Parshall flumes.

The main Parshall flume information retained in this edition relates to maintenance and operation needs of existing flumes, including flume dimensions, free flow measurement, submerged flow measurement, and head losses. The sections on size selection and setting crest elevation for Parshall flumes have been deleted or reduced in this edition. Where Parshall flumes may be desired or required by State law, examples in the previous editions of the manual can be referred to for size selection and setting the crest elevation.

New chapters and sections were added to make the third edition more current technologically and more useful to other government organizations. The new chapters added are:

- Basic Concepts Related to Flowing Water and Measurement
- Selection of Water Measuring Devices
- Measurement Accuracy
- Inspection of Water Measurement Systems
- Acoustic Flow Measurement
- Discharge Measurement Using Tracers

Russ Dodge was the primary author/editor for the revisions in this third edition. Reclamation especially appreciates the efforts of John Replogle and Albert Clemmens (from the U.S. Water Conservation Laboratory) of the Agricultural Research Service for writing major portions of chapters or separate sections relating to selection of devices, long-throated flumes, overshot weirs, and other devices, as well as for reviewing revisions of the entire manual.

Reclamation is also indebted to the U.S. Natural Resources Conservation Service, formerly the Soil Conservation Service, for contribution of material and reviews by Leland Hardy and Thomas Spofford. In addition to personnel from outside organizations, several Reclamation personnel contributed to revisions of new sections and chapters. Warren Frizell revised the chapter on measuring and recording water stage or head and conducted a peer review of the manual. Tracy Vermeyen wrote the chapter on acoustic flow measurements. Brent Mefford wrote much of the chapter on selection of water measurement devices. Dave Rogers wrote the section on radial gate flow measurements and the use of the RADGAT computer program. Tony Wahl compiled the tables in appendix A. Cliff Pugh coordinated the assembly, reviews, and publication. Jerry Fitzwater assembled and modified many of the drawings and figures. Tom Hovland was the primary technical editor in charge of publication editing and organization, and Teri Manross did the desktop publishing and copy editing. Jim Higgs created the online version of the manual, which is available at www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/

Certain trade names appear in the manual. Mention of such names should not be construed as an endorsement or recommendation of a product by the Bureau of Reclamation, Agricultural Research Service, or Natural Resource Conservation Service.

# CHAPTER 1 - INTRODUCTION

## 1. Need

Public concepts of how to share and manage the finite supplies of water are changing. Increasing competition exists between power, irrigation, municipal, industrial, recreation, aesthetic, and fish and wildlife uses. Within the United States, critical examinations of water use will be based on consumption, perceived waste, population density, and impact on ecological systems and endangered species. Water districts will need to seek ways to extend the use of their shares of water by the best available technologies. Best management measures and practices without exception depend upon conservation of water. The key to conservation is good water measurement practices.

As district needs for water increase, plans will be formulated to extend the use of water. Rather than finding and developing new sources, water often can be less expensively provided by conservation and equitable distribution of existing water supplies. Every cubic foot of water recovered as a result of improving water measurement produces more revenue than the same amount obtained from a new source. Better measurement procedures extend the use of water because poor operation and deterioration usually result in the delivery of excess water to users or lose it through waste. Beyond the district or supply delivery point, attention to measurement, management, and maintenance will also extend the farmer's water use and help prevent reduced yields and other crop damage caused by over-watering.

## 2. Benefits of Better Water Measurement

Besides proper billing for water usage, many benefits are derived by upgrading water measurement programs and systems. Although some of the benefits are intangible, they should be considered during system design or when planning a water measurement upgrade. Good water management requires accurate water measurement. Some benefits of water measurement are:

- Accurate accounting and good records help allocate equitable shares of water between competitive uses both on and off the farm.
- Good water measurement practices facilitate accurate and equitable distribution of water within district or farm, resulting in fewer problems and easier operation.
- Accurate water measurement provides the on-farm irrigation decision-maker with the information needed to achieve the best use of the irrigation water applied while typically minimizing negative environmental impacts.
- Installing canal flow measuring structures reduces the need for time-consuming current metering. Without these structures, current metering is frequently needed after making changes of delivery and to make seasonal corrections for changes of boundary resistance caused by weed growths or changes of sectional shape by bank slumping and sediment deposits.
- Instituting accurate and convenient water measurement methods improves the evaluation of seepage losses in unlined channels. Thus, better determinations of the cost benefits of proposed canal and ditch improvements are possible.
- Permanent water measurement devices can also form the basis for future improvements, such as remote flow monitoring and canal operation automation.

- Good water measurement and management practice prevents excess runoff and deep percolation, which can damage crops, pollute ground water with chemicals and pesticides, and result in project farm drainage flows containing contaminants.
- Accounting for individual water use combined with pricing policies that penalize excessive use.

## 3. Scope

This revised manual has three principal purposes. The first is to provide water users and districts guidance in selecting, managing, inspecting, and maintaining their water measurement devices. The second is to describe the standard methods and devices commonly used to measure irrigation water. The third is to acquaint irrigation system operators with a variety of other established but less common methods and with new or special techniques.

## 4. Use of the Manual

The order of chapters, or even sections within chapters, will not match all reader preferences or needs. Readers are not expected to read this manual from beginning to end. Individual readers have their own needs and can find required subjects and sections in the index and table of contents. Also, this manual does not attempt to fully cover advanced water measurement technology or theory. Nor is the manual meant to be a substitute for codes or standards such as International Organization for Standards (ISO) (1975) (1983) (1991) or American Society of Mechanical Engineers (ASME) (1992). These or other standards may be deemed necessary by regulation or management decision. When advance application approaches are needed, the reader should go to references at the end of each chapter. Good office references to have on hand are Bos (1989), which thoroughly covers water measurement devices; Bos et al. (1991) on flumes; and Clemmens et al. (1993), which provides software and excellent discussions of long-throated flumes and broad-crested weir computer design and calibration. The U.S. Government (1980) compiled a handbook containing information and references concerning most kinds of devices and techniques for open and closed channel flow. This publication also contains information concerning developing gaging stations with both permanent and shifting controls, both manmade and natural. The American Society of Mechanical Engineers (1971) and International Organization for Standards (ISO) (1991) provide considerable information on venturi meters and orifices in pipelines and give approach length requirements for various valve and bend combinations upstream from these meters. The Agricultural Research Service (ARS) *Field Manual* (Brakensiek et al., 1979) has information on H-flumes, triangular short-crested weirs, current metering, and other devices and methods used in agricultural hydrology.

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# CHAPTER 2 - BASIC CONCEPTS RELATED TO FLOWING WATER AND MEASUREMENT

## 1. Introduction

Experiences with the Bureau of Reclamation's Water Management Workshops, held each year in Denver, Colorado, have indicated a need to explain fundamental concepts of flowing water and its measurement. The workshops have also demonstrated the need to present concepts in simple terms using step-by-step development (Schuster, 1970). Because of more recent water measurement developments and the new chapters and sections added to this edition, this chapter has expanded the previous edition's appendix material into a more complete form. Thus, many more equations are included to maintain step-by-step development of the new material. Readers who have difficulties with algebra or the technical writing level should skim the text to provide exposure to concepts and terminology related to water measurement. More experienced water providers and users can use this chapter as a quick review of hydraulic principles related to water measurement.

Eventually, operators may wish to further investigate and seek more advanced references in hydraulics and fluid mechanics. Streeter (1951) has a chapter on flow measurement that covers tube-type flow meters. Bean (1971) has full information on fluid meter theory and provides detailed material for determining coefficients for tube-type meters. King and Brater (1963) have a thorough discussion of general critical depth relations and detailed relationships for most common hydraulic flow section shapes. Bos (1989) covers the entire field of open channel water measurement devices.

## 2. Kinds of Flow

Flow is classified into open channel flow and closed conduit flow. Open channel flow conditions occur whenever the flowing stream has a free or unconstrained surface that is open to the atmosphere. Flows in canals or in vented pipelines which are not flowing full are typical examples. The presence of the free water surface prevents transmission of pressure from one end of the conveyance channel to another as in fully flowing pipelines. Thus, in open channels, the only force that can cause flow is the force of gravity on the fluid. As a result, with steady uniform flow under free discharge conditions, a progressive fall or decrease in the water surface elevation always occurs as the flow moves downstream.

In hydraulics, a pipe is any closed conduit that carries water under pressure. The filled conduit may be square, rectangular, or any other shape, but is usually round. If flow is occurring in a conduit but does not completely fill it, the flow is not considered pipe or closed conduit flow, but is classified as open channel flow.

Flow occurs in a pipeline when a pressure or head difference exists between ends. The rate or discharge that occurs depends mainly upon (1) the amount of pressure or head difference that exists from the inlet to the outlet; (2) the friction or resistance to flow caused by pipe length, pipe roughness, bends, restrictions, changes in conduit shape and size, and the nature of the fluid flowing; and (3) the cross-sectional area of the pipe.

## 3. Basic Principles of Water Measurement

Most devices measure flow indirectly. Flow measuring devices are commonly classified into those that sense or measure velocity and those that measure pressure or head. The head or velocity is measured, and then charts, tables, or equations are used to obtain the discharge. Some water measuring devices that use measurement of head, *h*, or pressure, *p*, to determine discharge, *Q*, are:

(1) Weirs
(2) Flumes
(3) Orifices
(4) Venturi meters
(5) Runup measurement on a flat "weir stick"

Head, *h*, or depth commonly is used for the open channel devices such as flumes and weirs. Either pressure, *p*, or head, *h*, is used with tube-type flowmeters such as a venturi.

Pressure, *p*, is the force per unit area as shown on figure 2-1 that acts in every direction normal to containing or submerged object boundaries. If an open vertical tube is inserted through and flush with the wall of a pipe under pressure, water will rise to a height, *h*, until the weight, *W*, of water in the tube balances the pressure force, $F_p$, on the wall opening area, *a*, at the wall connection. These tubes are called piezometers. The volume of water in the piezometer tube is designated *ha*. The volume times the unit weight of water, $\gamma ha$, is the weight, *W*.

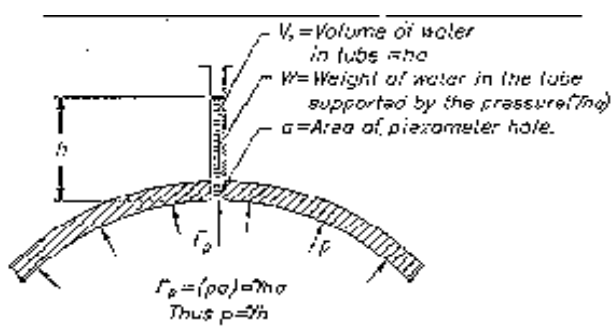


Figure 2-1. – Pressure definition

The pressure force, $F_p$, on the tap connection area is designated *pa*. The weight and pressure force are equal, and dividing both by the area, *a*, gives the unit pressure on the wall of the pipe in terms of head, *h*, written as:

$$p = \gamma h \quad (2\text{-}1)$$

or:

$$h = \frac{p}{\gamma} \quad (2\text{-}2)$$

Thus, head is pressure, *p*, divided by unit weight of water, γ, or 62.4 pounds per cubic foot ($lb/ft^3$). Pressure is often expressed in **psi** or pounds per square inch ($lb/in^2$), which may be converted to feet of water by multiplying the ($lb/in^2$) value by 2.31. For example, 30 $lb/in^2$ is produced by 69.3 feet of water. When the head principle is used, the discharge, *Q*, is computed from an equation such as the one used for a sharp-crested rectangular weir of length, *L*:

$$Q = CLh^{3/2} \quad (2\text{-}3)$$

A coefficient, *C*, is included that accounts for simplifying assumptions and other deficiencies in deriving the equation. The coefficient can vary widely in nonstandard installations, but is well defined for standard installations or is constant over a specified range of discharge.

The flow cross-sectional area, *A*, does not appear directly in the equation, but an area can be extracted by rewriting this equation:

$$Q = CLhh^{1/2} \quad (2\text{-}4)$$

in which:

$$A = Lh \quad (2\text{-}5)$$

In this form, *C* also contains a hidden square root of 2*g*, which, when multiplied by $(h)^{1/2}$, is the theoretical velocity. This velocity does not need to be directly measured or sensed. Because the weir equation computes velocity from a measuring head, a weir is classified as a head measuring device.

Some devices that actually sample or sense velocities, *v*, are:

(1) Float and stopwatch
(2) Current and propeller meters
(3) Vane deflection meters

These devices generally do not measure the average velocity, *V*, for an entire flow cross section. Thus, the relationship between sampled velocities, *v*, and the mean velocity, *V*, must be known as well as the flow section area, *A*, to which the mean velocity applies. Then, the discharge, *Q*, sometimes called the flow rate, is the product, *AV*.

Discharge or rate of flow has units of volume divided by unit time. Thus, discharge can be accurately determined by measuring the time, $t$, to fill a known volume, $V_o$:

$$Q = \frac{V_o}{t} \quad (2\text{-}6)$$

Water measurement devices can be calibrated using very accurate volumetric tanks and clocks. More commonly, weight of water in the tanks is used by converting the weight of water per unit volume. The weight of water per cubic foot, called unit weight or specific weight, $\gamma$, is 62.4 lb/ft$^3$ at standard atmospheric conditions.

## 4. Discharge-Area-Velocity Relationships

Flow rate or discharge, $Q$, is the volume of water in cubic feet passing a flow section per unit time, usually measured in cubic feet per second (ft$^3$/s). The distance, $d_v$, in feet that water will travel at a given velocity in a pipe of constant diameter is velocity, $V$, in feet per second (ft/s) multiplied by time, $t$, in seconds, or:

$$d_v = Vt \quad (2\text{-}7)$$

The volume, $V_o$, in cubic feet passing from the upstream to the downstream ends of this distance is the distance, $d_v$, in feet times area, $A$, in square feet of the flow section. Thus:

$$V_o = d_v A = AVt \quad (2\text{-}8)$$

To get the time rate of flow or discharge, $Q$, in cubic feet per second, divide the right and left sides of equation 2-8 by time, $t$, in seconds, resulting in:

$$Q = AV \quad (2\text{-}9)$$

Flow in open channels of rectangular cross section is often expressed in terms of unit discharge, $q$, in cubic feet per second per foot of width which is discharge, $Q$, in cubic feet per second divided by cross-sectional width, $L_b$, in feet or:

$$q = \frac{Q}{L_b} = \frac{VA}{L_b} = VD \quad (2\text{-}10)$$

The area, $A$, is $L_bD$, where $D$ is the depth of flow. The continuity concept is an important extension of equation 2-9. On the basis that water is incompressible and none is lost from a flowing system, then as the cross-sectional area changes, the velocity must adjust itself such that the values of $Q$ or $VA$ are constant:

$$Q = A_1V_1 = A_2V_2 = \ldots\ldots = A_nV_n \quad (2\text{-}11)$$

where the subscript denotes any number of arbitrarily selected positions along the flowing system. This principle, known as continuity, is especially useful in the analysis of tube flow measurement devices such as the venturi meter.

## 5. Flow Totalization

Water is sold and measured in terms of total volume consumed, say cubic feet, over some convenient time period, perhaps for billing each month. Many flowmeters have built in capability to sum or totalize volume continually. Thus, the volume consumed is obtained by taking the difference of two sequential monthly readings. To aid irrigation operation and management, most meters provide instantaneous rate of flow or discharge displayed in units such as cubic feet per second. These flow rates are used to set flow and predict the volume of water that will be consumed for intervals of time after flow setting.

## 6. Other Examples of Velocity Flow Measurement Devices

Measuring devices not previously mentioned are dilution in the concentration of tracers, such as salts and dyes; acoustic or magnetic meters; pitot tubes; rotameters, which are tapered tubes with suspended flow indicators; and many others that are not commonly used. In the dilution method, discharge is calculated by determining the quantity of water necessary to dilute a known quantity of concentrated chemical or dye solution. Chemical analysis or color comparison is used to determine the degree of dilution of the injected or mixed samples. In transit time acoustic meters, the velocity of sound pulses in the direction of flow is compared to the velocity of sound pulses opposite to the direction of flow to determine the mean velocity and, thus, discharge. With Doppler acoustic meters, sound pulses are reflected from moving particles within the water mass, similar to radar. In the magnetic meter, the flowing water acts like a moving electrical conductor passing through a magnetic field to produce a voltage that is proportional to discharge. Pitot tubes relate velocity head, $V^2/2g$, to discharge.

## 7. Velocity Head Concept

A dropped rock or other object will gain speed rapidly as it falls. Measurements show that an object dropping 1 foot (ft) will reach a velocity of 8.02 feet per second (ft/s). An object dropping 4 ft will reach a velocity of 16.04 ft/s. After an 8ft drop, the velocity attained is 22.70 ft/s. This gain in speed or acceleration is caused by the force of gravity, which is equal to 32.2 feet per second per second (ft/s$^2$). This acceleration caused by gravity is referred to as $g$.

If water is stored in a tank and a small opening is made in the tank wall 1 ft below the water surface, the water will spout from the opening with a velocity of 8.02 ft/s. This velocity has the same magnitude that a freely falling rock attains after falling 1 ft. Similarly, at openings 4 ft and 8 ft below the water surface, the velocity of the spouting water will be 16.04 and 22.68 ft/s, respectively. Thus, the velocity of water leaving an opening under a given head, $h$, is the same as the velocity that would be attained by a body falling that same distance.

The equation that shows how velocity changes with $h$ and defines velocity head is:

$$V = \sqrt{2gh} \quad (2\text{-}12)$$

which may also be written in velocity head form as:

$$h = \frac{V^2}{2g} \quad (2\text{-}13)$$

## 8. Orifice Relationships

Equations 2-9 and 2-13 can be used to develop an equation for flow through an orifice, which is a sharp-edged hole in the side or bottom of a container of water (figure 2-2a). To find the velocity of flow in the orifice, use equation 2-13, then multiply by area to get *AV*, or discharge, *Q*, resulting in:

$$Q_1 = A\sqrt{2gh} \quad (2\text{-}14)$$

The subscript *t* denotes theoretical discharge through an orifice. This equation assumes that the water is frictionless and is an ideal fluid. A correction must be made because water is not an ideal fluid. Most of the approaching flow has to curve toward the orifice opening. The water, after passing through the orifice, continues to contract or curve from the sharp orifice edge. If the orifice edges are sharp, the jet will appear as shown on figure 2-2. The maximum jet contraction occurs at a distance of one-half the orifice diameter ($d/2$) downstream from the sharp edge. The cross-sectional area of the jet is about six-tenths of the area of the orifice. Thus, equation 2-14 must be corrected using a contraction coefficient, $C_c$, to produce the actual discharge of water being delivered. Thus, the actual discharge equation is written as:

$$Q_a = C_c A\sqrt{2gh} \quad (2\text{-}15)$$

For a sharp-edged rectangular slot orifice where full contraction occurs, the contraction coefficient is about 0.61, and the equation becomes:

$$Q_a = 0.61A\sqrt{2gh} \quad (2\text{-}16)$$

A nonstandard installation will require further calibration tests to establish the proper contraction coefficient because the coefficient actually varies with the proximity to the orifice edge with respect to the approach and exit boundaries and approach velocity.

## 9. Thin Plate Weir Relationships

Most investigators derive the equation for sharp-crested rectangular weirs by mathematical integration of elemental orifice strips over the nappe (Bos, 1989). Each strip is considered an orifice with a different head on it.

The resulting rectangular weir equation for theoretical discharge is:

$$Q_t = \frac{2}{3}(2g)^{1/2} L_b h^{3/2} \quad (2\text{-}17)$$

A correction factor is needed to account for simplifications and assumptions. Thus, a discharge coefficient, $C_d$, is added to obtain actual discharge, expressed as:

$$Q_a = C_d \frac{2}{3} \sqrt{2g}\, L_b h^{3/2} \quad (2\text{-}18)$$

This relationship is the basic weir equation and can be modified to account for weir blade shape and approach velocity. However, $C_d$ must be determined by analysis and calibration tests. For standard weirs, $C_d$ is well defined or constant for measuring within specified head ranges.

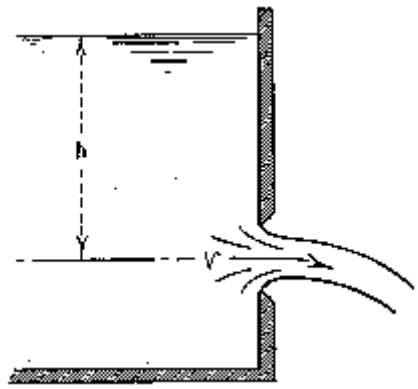


Figure 2-2a -- Orifice flow.

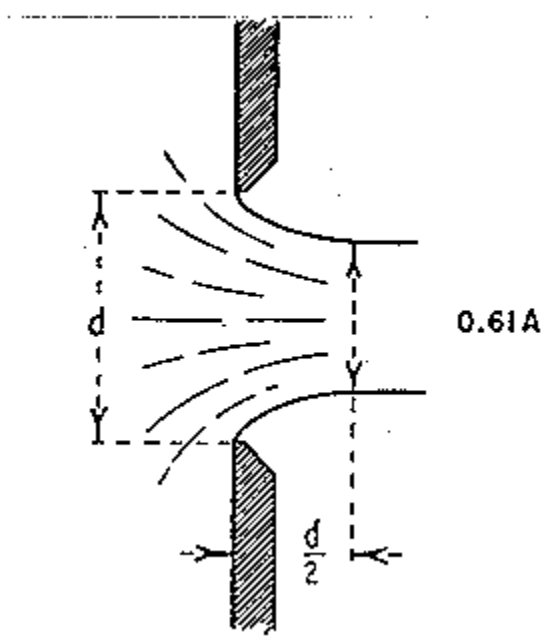


Figure 2-2b -- Contraction at an orifice.

## 10. Energy Balance Flow Relationships

Hydraulic problems concerning fluid flow are generally handled by accounting in terms of energy per pound of flowing water. Energy measured in this form has units of feet of water. The total amount of energy is that caused by motion, or velocity head, $V^2/2g$, which has units of feet, plus the potential energy head, $Z$, in feet, caused by elevation referenced to an arbitrary datum selected as reference zero elevation, plus the pressure energy head, $h$, in feet. The head, $h$, is depth of flow for the open channel flow case and $p/\gamma$ defined by equation 2-2 for the closed conduit case. This summation of energy is shown for three cases on figure 2-3.

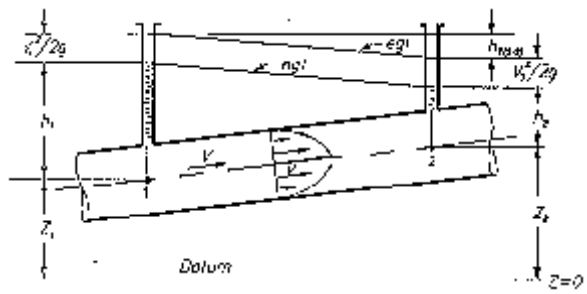


Figure 2-3a -- Energy balance in pipe flow.

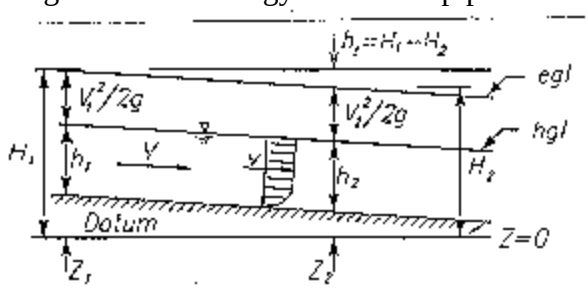


Figure 2-3b -- Energy balance in open channel flow.

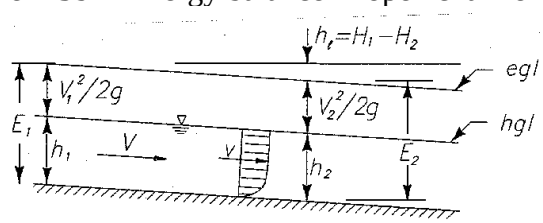


Figure 2-3c -- Specific energy balance.

Figures 2-3a and 2-3b show the total energy head, $H_1$; for example, at point 1, in a pipe and an open channel, which can be written as:

$$H_1 = h_1 + \frac{V_1^2}{2g} + Z_1 \quad (2\text{-}19)$$



At another downstream location, point 2:

$$H_2 = h_2 + \frac{V_2^{\,2}}{2g} + Z_2 \quad (2\text{-}20)$$

Energy has been lost because of friction between points 1 and 2, so the downstream point 2 has less energy than point 1. The energy balance is retained by adding a head loss, $h_{f\,(1\text{-}2)}$. The total energy balance is written as:

$$h_1 = \frac{V_1^{\,2}}{2g} + Z_1 = h_2 + \frac{V_2^{\,2}}{2g} + Z_2 + h_{f\,(1\text{-}2)} \quad (2\text{-}21)$$

The upper sloping line drawn between the total head elevations is the energy gradeline, *egl*. The next lower sloping solid line for both the pipe and open channel cases shown on figure 2-3 is the hydraulic grade line, *hgl*, which is also the water surface for open channel flow, or the height to which water would rise in piezometer taps for pipe flow.

A special energy form is commonly used in hydraulics in which the channel invert is selected as the reference *Z* elevation (figure 2-3c). Thus, *Z* drops out, and energy is the sum of depth, *h*, and velocity head only. Energy above the invert expressed this way is called specific energy, *E*. This simplified form of energy equation is written as:

$$\textit{Specific energy} = E = \frac{V^2}{2g} + h \quad (2\text{-}22)$$

Equations 2-21 and 2-11 lead to several interesting conclusions. In a fairly short pipe that has little or insignificant friction loss, total energy at one point is essentially equal to the total energy at another point. If the size of the pipeline decreases from the first point to the second, the velocity of flow must increase from the first point to the second. This increase occurs because with steady flow, the quantity of flow passing any point in the completely filled pipeline remains the same. From the continuity equation (equation 2-11), when the flow area decreases, the flow velocity must increase.

The second interesting point is that when the velocity increases in the smaller section of the pipeline, the pressure head, *h*, decreases. At first, this decrease may seem strange, but equation 2-21 shows that when $V^2/2g$ increases, *h* must decrease proportionately because the total energy from one point to another in the system remains constant, neglecting friction loss. The fact that the pressure does decrease when the velocity in a given system increases is the basis for tube-type flow measuring devices.

In open channel flow where the flow accelerates, more of its supply of energy becomes velocity head, and depth must decrease. On the other hand, when the flow slows down, the depth must increase.



An example of accelerating flow with corresponding decreasing depth is found at the approach to weirs. The drop in the water surface is called drawdown. Another example occurs at the entrance to inverted siphons or conduits where the flow accelerates as it passes from the canal, through a

contracting transition, and into the siphon barrel. An example of decelerating flow with a rising water surface is found at the outlet of an inverted siphon, where the water loses velocity as it expands in a transition back into canal flow.

Flumes are excellent examples of measuring devices that take advantage of the fact that changes in depth occur with changes in velocity. When water enters a flume, it accelerates in a converging section. The acceleration of the flow causes the water surface to drop a significant amount. This change in depth is directly related to the rate of flow.

**11. Hydraulic Mean Depth and Hydraulic Radius**

Figure 2-4 shows an irregular flow cross section with different methods for defining depth of flow. In terms of frictional head losses, the perimeter is important. Hydraulic radius, $R_h$, is defined as the area of the flow section divided by the wetted perimeter, $P_w$, which is shown on figure 2-4 and is written as:

$$R_h = \frac{A}{P_w} \quad (2\text{-}23)$$

Thus, wetted perimeter times the hydraulic radius is equal to the area of irregular section flow as shown on figures 2-4a and 2-4c.

For use in Froude number and energy relationships in open channel flow hydraulics, mean depth, $h_m$, is defined as the depth which, when multiplied by the top water surface width, $T$, is equal to the irregular section area, $A$, shown on figures 2-4a and 2-4b, of the flow section and is commonly used for critical flow relationships. The equation for hydraulic mean depth, $h_m$, is:

$$h_m = \frac{A}{T} \quad (2\text{-}24)$$

In rectangular channels, hydraulic radius, $R_h$, does not equal depth, but approaches depth as the channel becomes very wide. However, the hydraulic mean depth, $h_m$, is the same as the depth of the rectangular flow section.

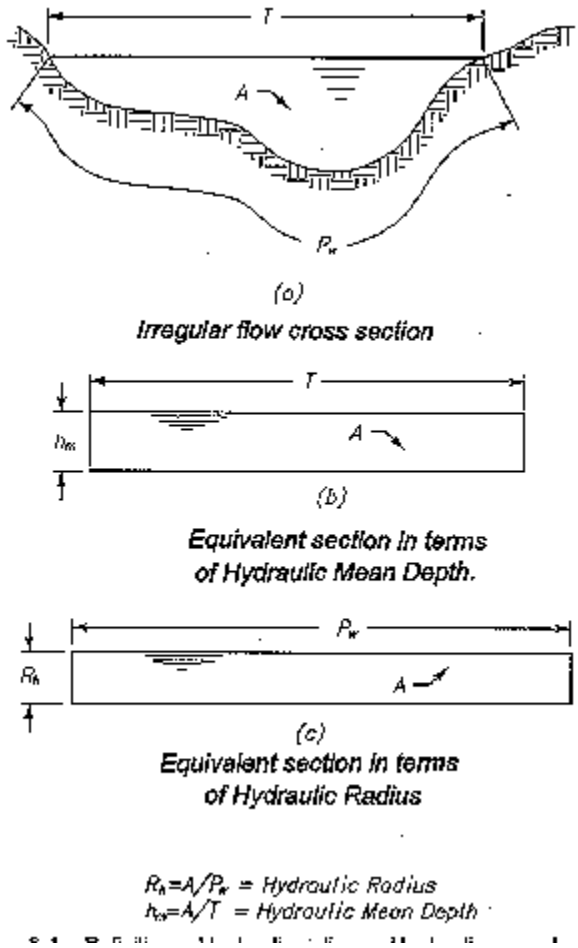


Figure 2-4 -- Definitions of hydraulic radius and hydraulic mean depth (area is the same for all three cases).

## 12. Froude Number, Critical Flow Relationships

In open channel hydraulics, the Froude number is a very important non-dimensional parameter. The Froude number, *F*, is the ratio of inertia force to gravity force, which simplifies to:

$$F = \frac{V}{\sqrt{gh_m}} \quad (2\text{-}25)$$

where the subscript *m* denotes hydraulic mean depth as defined previously in section 11 of this chapter.

For open channel modeling, the Froude number of a model is made equal to the Froude number of the actual full size device. The length ratio is set and the scale ratios for velocity and discharge are determined from the equality. However, the modeler must make sure that differences in friction loss between the model and the actual device are insignificant or accounted for in some way.

Open channel flow water measurement generally requires that the Froude number, $F$, of the approach flow be less than 0.5 to prevent wave action that would hinder or possibly prevent an accurate head reading.

When the Froude number is 1, the velocity is equal to the velocity of wave propagation, or celerity. When this condition is attained, downstream wave or pressure disturbances cannot travel upstream. A Froude number of 1 also defines a very special hydraulic condition. This flow condition is called critical and defines the critical mean depth and critical velocity relationship as:

$$F_c = \frac{V_c}{\sqrt{gh_{cm}}} \quad (2\text{-}26)$$

The subscript $c$ denotes critical flow condition. The critical hydraulic mean depth, $h_{cm}$, is the depth at which total specific energy is minimum for a given discharge. Conversely, $h_{cm}$ is the depth at which the discharge is maximum for a given total specific energy. When depth is greater than critical, the resulting velocity is considered streaming or tranquil and is called subcritical velocity. Conversely, when the depth is less than critical, the flow is rapid or shooting and is called super-critical velocity.

Water measurement flumes function best by forcing flow to pass through critical depth; then discharge can be measured using one head measurement station upstream. Also, for weirs and flumes, one unique head value exists for each discharge, simplifying calibration. This flow condition is called free flow. However, if the downstream depth submerges critical depth, then separate calibrations at many levels of submergence are required, and two head measurements are needed to measure flow.

Designing flumes for submerged flow will always decrease accuracy of flow measurement. Flumes and weirs can be submerged unintentionally by poor design, construction errors, structural settling, attempts to supply increased delivery needs by increasing downstream heads, accumulated sediment deposits, or weed growths.

Important critical flow relationships can be derived using equation 2-26 and rewriting in the form:

$$V_c = \sqrt{gh_{cm}} \quad (2\text{-}27)$$

Solving for head in equation 2-27 results in:

$$h_{cm} = \frac{V_c^{\,2}}{g} \quad (2\text{-}28)$$

Dividing both sides of this equation by 2 gives critical velocity head in terms of critical mean depth written as:

$$\frac{V_c^{\,2}}{2g} = \frac{h_{cm}}{2} \quad (2\text{-}29)$$

The total energy head with $Z$ equal to zero for critical flow using equation 2-19 is:

$$H_c = h_c + \frac{V_c^{\,2}}{2g} \quad (2\text{-}30)$$

Squaring both sides of equation 2-27 and replacing velocity with $Q/A$ and $h_{cm}$ with $A/T$ according to equation 2-24 and rearranging results in:

$$\frac{Q_c^{\,2}}{g} = \frac{A_c^{\,3}}{T_c} \quad (2\text{-}31)$$

This equation and the specific energy equation 2-22 are the basic critical flow relationships for any channel shape.

## 13. Discharge Equation for Broad-Crested Rectangular Weirs

The discharge equation for the rectangular broad-crested weir will now be derived similar to Bos (1989). The width, $L_b$, of a rectangular flow section is the same as $T$, the top water surface width. Also, $h_c$ is the same as $h_{cm}$, and using equation 2-29 for velocity head, equation 2-30 can be rewritten as:

$$H_c = h_c + \frac{h_c}{2} \quad (2\text{-}32)$$

or:

$$H_c = \frac{3}{2} h_c \quad (2\text{-}33)$$

Conversely:

$$h_c = \frac{2}{3} H_c \quad (2\text{-}34)$$

Multiplying both sides of equation 2-27 by the area, $A_c$, of the flow section, which is $L_b h_c$, results in discharge expressed as:

$$Q = L_b h_c \sqrt{g h_c} = L_b \sqrt{g h_c}^{\,3/2} \quad (2\text{-}35)$$

To get unit discharge, $q$, this equation is divided by the width of flow, $L_b$, resulting in:

$$q = \frac{Q}{L_b} = \sqrt{gh_c}^{\,3/2} \quad (2\text{-}36)$$

Solving for $h_c$:

$$h_c = \sqrt[3]{\frac{q^2}{g}} \quad (2\text{-}37)$$

Using equation 2-34 to replace $h_c$ with $H_c$ in equation 2-35 results in theoretical discharge, $Q_t$:

$$Q_1 = L_b \sqrt{g}\,(\frac{2}{3} H_c)^{3/2} \quad (2\text{-}38)$$

Discharges in equations 2-35 through 2-38 are usually considered actual, assuming uniform velocity throughout the critical depth cross section and assuming that no correction of velocity distribution is needed.

Because specific energy is constant in a fairly short measuring structure with insignificant friction losses, specific energy, $H_c$, at the critical location can be replaced with specific energy, $H_1$, at a head measuring station a short distance upstream. However, some friction loss, possible flow curvature, and non-uniform velocity distribution occur. Thus, a coefficient of $C_d$ must be added to correct for these effects, resulting in an expression for actual discharge:

$$Q_a = C_d L_b \frac{2}{3} \sqrt{\frac{2}{3}}\, g H_1^{3/2} \quad (2\text{-}39)$$

For measurement convenience, the total head, $H_1$, is replaced with the depth, $h_1$. To correct for neglecting the velocity head at the measuring station, a velocity coefficient, $C_v$, must be added, resulting in:

$$Q_a = C_d C_v L_b \frac{2}{3} \sqrt{\frac{2}{3}}\, g h_1^{3/2} \quad (2\text{-}40)$$

This equation applies to both long-throated flumes or broad-crested weirs and can be modified for any shape by analyses using the energy balance with equation 2-31.

These equations differ only in numerical constants that are derived from assumptions and selection of basic relationships used in their derivation. However, experimental determination of the coefficient values for $C$ and $C_v$ would compensate, making each equation produce the same discharge for the same measuring head. Either equation could be used.

The examples given above show that traditional discharge equations are often a mixture of rational analysis and experimental coefficient evaluation.

However, recent development of computer modeling of long-throated flumes (Clemmens et al. [1991]) precludes the need for experimental determination of coefficients. These long-throated flumes are covered in chapter 8.

## 14. Application of Energy Principle to Tube-Type Flowmeters

The energy equation can be used to derive the venturi meter (figure 2-5) equation by assuming that the centerline of the meter is horizontal ($Z_1 = Z_2$); and due to its short length, there is no head loss, $h_f = 0$. Although these assumptions were made to simplify the derivation, the final results will be identical for any orientation of the venturi meter.

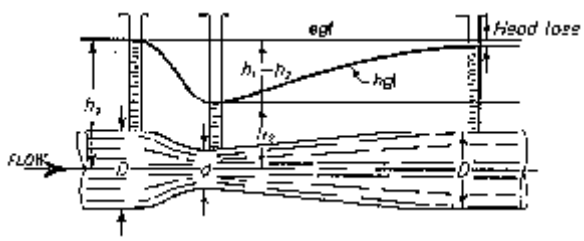


Figure 2-5 -- Venturi meter.

Thus:

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} \quad (2\text{-}41)$$

By the continuity equation for the approach and throat sections:

$$V_1A_1 = V_2A_2 \quad (2\text{-}42)$$

Either $V_1$ *or* $V_2$ can be solved for in terms of the other; for example:

$$V_2 = V_1 \left(\frac{A_1}{A_2}\right) \quad (2\text{-}43)$$

Substituting this result into the energy equation results in:

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_1^2}{2g}\left(\frac{A_1}{A_2}\right)^2 \quad (2\text{-}44)$$

Solving for the head difference gives:

$$h_1 - h_2 = \frac{V_1^2}{2g}\left(\frac{A_1}{A_2}\right)^2 - \frac{V_1^2}{2g} = \frac{V_1^2}{2g}\left[\left(\frac{A_1}{A_2}\right)^2 - 1\right] \quad (2\text{-}45)$$

Solving for $V_1^2$:

$$V_1^2 = \frac{(h_1 - h_2)2g}{(\frac{A_1}{A_2})^2 - 1} \quad (2\text{-}46)$$

Taking the square root of both sides and multiplying both sides by $A_1$ results in the theoretical discharge equation:

$$Q_t = V_1 A_1 = A_1 \sqrt{\frac{2g(h_1 - h_2)}{(\frac{A_1}{A_2})^2 - 1}} \quad (2\text{-}47)$$

To obtain actual discharge, a coefficient, $C_d$, added to compensate for velocity distribution and for minor losses not accounted for in the energy equation yields:

$$Q_a = C_d A_1 \sqrt{\frac{2g(h_1 - h_2)}{(\frac{A_1}{A_2})^2 - 1}} \quad (2\text{-}48a)$$

Some investigators solve for discharge using throat area and velocity, resulting in:

$$Q_a = C_d A_2 \sqrt{\frac{2g(h_1 - h_2)}{1 - (\frac{A_2}{A_1})^2}} \quad (2\text{-}48b)$$

However, equations 2-48a and 2-48b are identical and can be converted to:

$$Q_a = C_d A_1 A_2 \sqrt{\frac{2g(h_1 - h_2)}{A_1^2 - A_2^2}} \quad (2\text{-}49)$$

Equations 2-48b and 2-49 also apply to nozzles and orifices in pipes. On figure 2-5, the hydraulic grade line, *hgl*, represents the pressure that acts on the walls of the venturi meter. An appreciable drop will be noticed at the narrow throat, and a gradual pressure rise is seen as the flow leaves the throat and smoothly spreads and slows in the expanding portion of the meter.

Figure 2-6 shows the conditions that occur in a pipe orifice meter. As the flow approaches the orifice plate, the water near the pipe walls is slowed and stopped in the corners formed by the plate and the pipe walls. As a result, the pressure just ahead of the orifice at point B is a little greater than in the pipeline farther upstream at A. As the flow accelerates and passes through the orifice, the pressure drops and is lowest just downstream from the plate where the jet is smallest, and the velocity is highest at point C.

Farther down-stream, the flow begins to spread out and slow down, and a rise in pressure occurs at points D and E.

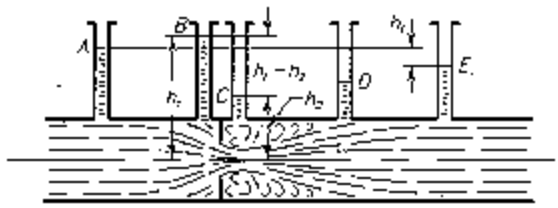


Figure 2-6 -- Pipe orifice meter.

In both venturi meters and orifice meters, the pressure difference between the inlet tap and the throat or minimum pressure tap is related to discharge tables or curves using the suitable coefficients with the proper equation. An example discharge curve is shown for an 8-inch (in) venturi meter on figure 2-7. Thus, the meters may serve as reliable flow measuring devices.

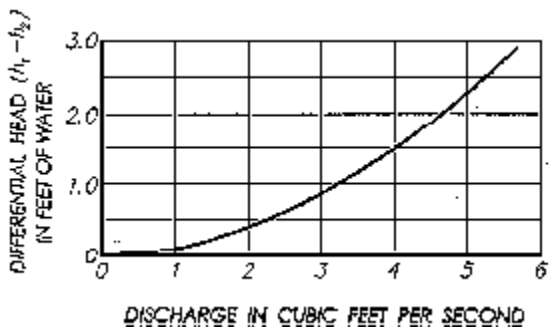


Figure 2-7 -- Typical calibration curve for an 8-in venturi meter.

## 15. Equation Coefficients

The previous examples show that coefficients are used in water measurement to correct for factors which are not fully accounted for using simplifying assumptions during derivations of equations. For the convenience of using a measured water head, $h_1$, instead of the more complex total head, $H_1$, $C_v$ is used because velocity head is often ignored in equations.

Orifices require an area correction to account for jet contraction in an orifice, the flow is forced to curve around and spring from the sharp edge, forming a contracted jet or vena contracta. Thus, the contracted area of flow, $A_c$, should be used in hydraulic relationships. Thus, the area, $A_o$, of the orifice must be corrected by a coefficient of contraction defined as:

$$C_c = \frac{A_c}{A_o} \quad (2\text{-}50)$$

Properly designed venturi meters and nozzles have no contraction, which makes $C_c$ unity because of the smooth transitions that allow the water to flow parallel to the meter boundary surfaces. Ultimately, the actual discharge must be measured experimentally by calibration tests, and the theoretical discharge must be corrected.

A common misconception is that coefficients are constant. They may indeed be constant for a range of discharge, which is the case for many standard measuring devices. Complying with structural and operational limits for standard devices will prevent measurement error caused by using coefficients outside of the proper ranges. Some water measuring devices cover wider ranges using variable coefficients of discharge by means of plots and tables of values with respect to head and geometry parameters.

Coefficients also vary with measuring station head or pressure tap location. Therefore, users should make sure that the coefficients used match pressure or head measurement locations. Water measurement equations generally require use of some to all of these coefficients to produce accurate results.

Often, composite numerical coefficients are given that are product combinations of area or a dimension factored from the area, acceleration of gravity, integration constants, and the correction coefficients. However, geometry dimensions and physical constants, such as acceleration of gravity, are better kept separate from the nondimensional coefficients that account for the difference between theoretical and actual conditions. Otherwise, converting equations from English to metric units is more difficult.

Equation 2-49 also applies to orifices and nozzles. The coefficient of discharge for venturi meters ranges from 0.9 to about unity in the turbulent flow range and varies with the diameter ratio of throat to pipe. The coefficient of discharge for orifices in pipes varies from 0.60 to 0.80 and varies with the diameter ratio. For flow nozzles in pipelines, the coefficient varies from 0.96 to 1.2 for turbulent flow and varies with the diameter ratio. ASME (1983) and ISO (1991) have a detailed treatment of pipeline meter theory, coefficients, and instruction in their use.

**16. Normal Flow Equations and Friction Head Loss**

Many measuring devices, such as flumes, weirs, and submerged orifices, are sensitive to exit flow conditions. Flumes and weirs can be drowned out by too much downstream submergence depth, and submerged orifices can have too little downstream water above the top orifice edge. Therefore, reliable knowledge of exit depth conditions is needed to properly set the elevation of crests and orifices so as to not compromise accuracy. Inaccurate assessment of downstream depth has even made some measuring device installations useless. Good operation and flow depth forecasts are needed to ensure the design effectiveness of new irrigation measurement systems. Designing for the insertion of a new device into an existing system provides a good opportunity to obtain actual field measurements for investigating possible submergence problems.

The use of actual discharge water surface measurements is recommended. In the absence of actual measurements, normal flow equations are often used to predict flow depths.

Normal flow occurs when the water surface slope, $S_{ws}$, is the same as the invert or bottom slope, $S_o$. When normal flow is approached, the velocity equations of Chezy, Manning, and Darcy-Weisbach are used to compute depth of flow. However, these equations are in terms of hydraulic radius, $R_h$, and depth must be determined on the basis of the definition of $R_h$, which is the cross-sectional area, $A$, divided by its wetted perimeter, $P_w$.

Chezy developed the earliest velocity equation, expressed as:

$$V = C\sqrt{R_h S} \quad (2\text{-}51)$$

Manning's equation is more frequently used and is expressed as:

$$V = \frac{1.49}{n} R_h^{2/3} S^{1/2} \quad (2\text{-}52)$$

The Darcy-Weisbach equation is a more rigorous relationship, written as:

$$V = \sqrt{\frac{8gR_h S}{f}} \quad (2\text{-}53)$$

The coefficients $C$, $n$, and $f$ are friction factors. The Darcy-Weisbach friction factor, $f$, is nondimensional and is a function of Reynolds number, $4R_hV/L$, and relative roughness, $k/4R_h$, in which $L$ is kinematic viscosity, and $k$ is a linear measure of boundary roughness size. The Reynolds number accounts for variation of viscosity. This function is given in the form of plots in any fluid mechanics textbook; for example, Streeter (1951), Rouse (1950), and Chow (1959). These plots are generally in terms of pipe diameter, $D$, which should be replaced with $4R_h$ for open channel flow. Values of $k$ have been determined empirically and are constant for a given flow boundary material as long as the roughness can be considered a homogenous texture rather than large roughness elements relative to the depth.

Solving equations 2-51, 2-52, and 2-53 for $V/(R_hS)^{1/2}$ results in a combined flow equation and relationship between the three friction factors, $C$, $n$, and $f$, written as:

$$\frac{1.49R_h^{1/6}}{n} = \sqrt{\frac{8g}{f}} = C = \frac{V}{\sqrt{R_h S}} \quad (2\text{-}54)$$

Solving for velocity using equation 2-54 and multiplying by area produces a discharge equation and can be used in the slope area method of determining discharge as discussed in chapter 13.

All three of these friction factors have been determined empirically, computed from measurement of equation variables. The Chezy factor, $C$, varies with hydraulic radius, slope, and physical boundary roughness. The Chezy factor varies from 22 to 220.

Manning's friction factor, $n$, varies from 0.02 for fine earth lined channels to 0.035 for gravel. If the channel beds are strewn with rocks or are 1/3 full of vegetation, the $n$ value can be as much as 0.06. The $n$ values for concrete vary from 0.011 to 0.016 as finish gets rougher. Values of $k$ can be found in hydraulic and fluid mechanics textbooks such as Streeter (1951), Rouse (1950), and Chow (1959). The value of $k$ for concrete varies from 0.01 to 0.0001 ft depending on condition and quality of finishing.

Because Chezy and Manning equations and their friction factors have been determined for ordinary channel flows, they do not accurately apply to shallow flow, nor can these two equations be corrected for temperature viscosity effects. Values of $k$ are constant for given material surfaces for $k/4R_h$ equal or less than 1/10 and when $4R_hV/\nu$ is greater than 200,000.

Flow depths downstream are more likely the result of intentional structural restriction or water delivery head requirements downstream. Therefore, in designing and setting the elevation of flumes and weirs, the flow conditions just downstream need to be carefully assessed or specified in terms of required downstream operations and limits of measuring devices. More advanced hydraulic analyses are needed where normal flow is not established. For gradually varied flow, the friction equations can be used as trial and error computations applied to average end section hydraulic variables for relatively short reach lengths. The design and setting of crest elevations in an existing system permit the establishment of operation needs and downstream depths by actual field measurement.

## 17. Approach Flow Conditions

Water measurement devices are generally calibrated with certain approach flow conditions. The same approach conditions must be attained in field applications of measuring devices.

Poor flow conditions in the area just upstream from the measuring device can cause large discharge indication errors. In general, the approaching flow should be subcritical. The flow should be fully developed, mild in slope, and free of curves, projections, and waves. Pipeline meters commonly require 10 diameters of straight pipe approach. Fittings and combinations of fittings, such as valves and bends, located upstream from a flowmeter can increase the number of required approach diameters. *Fluid Meters* (American Society of Mechanical Engineers, 1983) and International Organization for Standardization (1991) give requirements for many pipeline configurations. By analogy and using a minimum of 10 pipe diameters of straight approach, open channel flow would require 40 hydraulic radii of straight, unobstructed, unaltered approach.

A typical example approach criteria as specified by Bos (1989) follows:

- If the control width is greater than 50 percent of the approach channel width, then 10 average approach flow widths of straight, unobstructed approach are required.
- If the control width is less than 50 percent of the approach width, then 20 control widths of straight, unobstructed approach are required.
- If upstream flow is below critical depth, a jump should be forced to occur. In this case, 30 measuring heads of straight, unobstructed approach after the jump should be provided.
- If baffles are used to correct and smooth out approach flow, then 10 measuring heads ($10h_1$) should be placed between the baffles and the measuring station.

Approach flow conditions should be continually checked for deviation from these conditions as described in chapter 8 of this manual.

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# CHAPTER 3 - MEASUREMENT ACCURACY

## 1. Introduction

Accurate application of water measuring devices generally depends upon standard designs or careful selection of devices, care of fabrication and installation, good calibration data and analyses, and proper user operation with sufficiently frequent inspection and maintenance procedures. In operations, accuracy requires continual verification that the measuring system, including the operators, is functioning properly. Thus, good training and supervision is required to attain measurements within prescribed accuracy bounds. **Accuracy** is the degree of conformance of a measurement to a standard or true value. The standards are set by users, providers, governments, or compacts between these entities. Accuracy is usually stated in terms of deviation of discharge discussed subsequently. All parts of a measuring system, including the user, need to be considered in accessing the system's total accuracy.

A measurement system usually consists of a **primary element**, which is that part of the system that creates what is sensed, and is measured by a **secondary element**. For example, weirs and flumes are primary elements. A staff gage is the secondary element.

Purchasers and users of water measurement devices generally depend upon standard designs and manufacturers to provide calibrations and assurances of accuracy. A few irrigation water users or providers have the facilities to check the condition and accuracy of flow measuring devices. These facilities have comparison flowmeters and/or volumetric tanks for checking their flowmeters. These test systems are used to check devices for compliance with specification and to determine maintenance needs. However, maintaining facilities such as these is not generally practical.

One purpose of this chapter is to define terms used by manufacturers and sales representatives related to measuring device specifications, calibration, and error analyses. Various disciplines and organizations do not fully agree on some of these definitions. Therefore, one should ask for clarification of these definitions when others use these terms. Another purpose is to provide example analyses which can help in managing the accuracy of irrigation water delivery.

## 2. Definitions of Terms Related to Accuracy

**Precision** is the ability to produce the same value within given accuracy bounds when successive readings of a specific quantity are measured. Precision represents the maximum departure of all readings from the mean value of the readings. Thus, a measurement cannot be more accurate than the inherent precision of the combined primary and secondary precision. **Error** is the deviation of a measurement, observation, or calculation from the truth. The deviation can be small and inherent in the structure and functioning of the system and be within the bounds or limits specified. Lack of care and mistakes during fabrication, installation, and use can often cause large errors well outside expected performance bounds.

Since the true value is seldom known, some investigators prefer to use the term **Uncertainty**. Uncertainty describes the possible error or range of error which may exist. Investigators often classify errors and uncertainties into spurious, systematic, and random types.

**Spurious errors** are commonly caused by accident, resulting in false data. Misreading and intermittent mechanical malfunction can cause discharge readings well outside of expected random statistical distribution about the mean. A hurried operator might incorrectly estimate discharge. Spurious errors can be minimized by good supervision, maintenance, inspection, and training. Experienced, well-trained operators are more likely to recognize readings that are significantly out of the expected range of deviation. Unexpected spiral flow and blockages of flow in the approach or in the device itself can cause spurious errors. Repeating measurements does not provide any information on spurious error unless repetitions occur before and after the introduction of the error. On a statistical basis, spurious errors confound evaluation of accuracy performance.

**Systematic errors** are errors that persist and cannot be considered entirely random. Systematic errors are caused by deviations from standard device dimensions. Systematic errors cannot be detected by repeated measurements. They usually cause persistent error on one side of the true value. For example, error in determining the crest elevation for setting staff or recorder chart gage zeros relative to actual elevation of a weir crest causes systematic error. The error for this case can be corrected when discovered by adjusting to accurate dimensional measurements. Worn, broken, and defective flowmeter parts, such as a permanently deformed, over-stretched spring, can cause systematic errors. This kind of systematic error is corrected by maintenance or replacement of parts or the entire meter. Fabrication error comes from dimensional deviation of fabrication or construction allowed because of limited ability to exactly reproduce important standard dimensions that govern pressure or heads in measuring devices. Allowable tolerances produce small systematic errors which should be specified.

Calibration equations can have systematic errors, depending on the quality of their derivation and selection of form. Equation errors are introduced by selection of equation forms that usually only approximate calibration data. These errors can be reduced by finding better equations or by using more than one equation to cover specific ranges of measurement. In some cases, tables and plotted curves are the only way to present calibration data.

**Random errors** are caused by such things as the estimating required between the smallest division on a head measurement device and water surface waves at a head measuring device. Loose linkages between parts of flowmeters provide room for random movement of parts relative to each other, causing subsequent random output errors. Repeating readings decreases average random error by a factor of the square root of the number of readings.

**Total error** of a measurement is the result of systematic and random errors caused by component parts and factors related to the entire system. Sometimes, error limits of all component factors are well known. In this case, total limits of simpler systems can be determined by computation (Bos et al., 1991).

In more complicated cases, different investigators may not agree on how to combine the limits. In this case, only a thorough calibration of the entire system as a unit will resolve the difference. In any case, it is better to do error analysis with data where entire system parts are operating simultaneously and compare discharge measurement against an adequate discharge comparison standard.

**Calibration** is the process used to check or adjust the output of a measuring device in convenient units of gradations. During calibration, manufacturers also determine robustness of equation forms and coefficients and collect sufficient data to statistically define accuracy performance limits. In the case of long-throated flumes and weirs, calibration can be done by computers using hydraulic theory. Users often do less rigorous calibration of devices in the field to check and help correct for problems of incorrect use and installation of devices or structural settlement. A calibration is no better than the comparison standards used during calibration.

**Comparison standards** for water measurement are systems or devices capable of measuring discharge to within limits at least equal to the desired limits for the device being calibrated. Outside of the functioning capability of the primary and secondary elements, the quality of the comparison standard governs the quality of calibration.

**Discrepancy** is simply the difference of two measurements of the same quantity. Even if measured in two different ways, discrepancy does not indicate error with any confidence unless the accuracy capability of one of the measurement techniques is fully known and can be considered a working standard or better. Statistical **deviation** is the difference or departure of a set of measured values from the arithmetic mean.

**Standard Deviation Estimate** is the measure of dispersion of a set of data in its distribution about the mean of the set. Arithmetically, it is the square root of the mean of the square of deviations, but sometimes it is called the root mean square deviation. In equation form, the estimate of standard deviation is:

$$S = \sqrt{\frac{\Sigma(X_{avg} - X_{Ind})^2}{(N-1)}} \quad (3\text{-}1)$$

where:

$S$ = the estimate of standard deviation

$X_{Avg}$ = the mean of a set of values

$X_{Ind}$ = each individual value from the set

$N$ = the number of values in a set

$\Sigma$ = summation

The variable $X$ can be replaced with data related to water measurement such as discharge coefficients, measuring heads, and forms of differences of discharge.

The sample number, $N$, is used to calculate the mean of all the individual deviations, and ($N$ - 1) is used to calculate the estimate of standard deviation. This is done because when you know the mean of the set of $N$ values and any subset of ($N$ - 1) values, the one excluded value can be calculated. Using ($N$-1) in the calculation is important for a small number of readings.

For the sample size that is large enough, and if the mean of the individual deviations is close to zero and the maximum deviation is less than $\pm 3S$, the sample distribution can be considered normally distributed. With normal distribution, it is expected that any additional measured value would be within $\pm 3S$ with a 99.7 percent chance, $\pm 2S$ with a 95.4 percent chance, and $\pm S$ with a 68.3 percent chance.

Measurement device specifications often state accuracy capability as plus or minus some percentage of discharge, meaning without actually stating, $\pm 2S$, two times the standard deviation of discharge comparisons from a calibration. However, the user should expect an infrequent deviation of $\pm 3S$.

Error in water measurement is commonly expressed in percent of comparison standard discharge as follows:

$$E_{\%Q_{Cs}} = \frac{100(Q_{Ind} - Q_{Cs})}{Q_{Cs}} \quad (3\text{-}2)$$

where:

$Q_{Ind}$ = indicated discharge from device output

$Q_{Cs}$ = comparison standard discharge concurrently measured in a much more precise way

$E_{\%Q_{Cs}}$ = error in percent comparison standard discharge

Comparison standard discharge is sometimes called actual discharge, but it is an ideal value that can only be approached by using a much more precise and accurate method than the device being checked.

Water providers might encounter other terms used by instrument and electronic manufacturers. Some of these terms will be described. However, no universal agreement exists for the definition of these terms. Therefore, water providers and users should not hesitate to ask manufacturers' salespeople exactly what they mean or how they define terms used in their performance and accuracy claims. Cooper (1978) is one of the many good references on electronic instrumentation.

Error in **percent full scale**, commonly used in electronics and instrumentation specifications, is defined as:

$$E_{\%Q_{FS}} = \frac{100(Q_{Ind} - Q_{Cs})}{Q_{FS}} \quad (3\text{-}3)$$

where:

$Q_{Ind}$ = indicated discharge

$Q_{Cs}$ = comparison standard discharge concurrently measured

$Q_{FS}$ = full scale or maximum discharge

$E_{\%Q_{FS}}$ = error in percent full-scale discharge

To simply state that a meter is "3 percent accurate" is incomplete. Inspection of equations 3-2 and 3-3 shows that a percentage error statement requires an accompanying definition of terms used in both the numerator and denominator of the equations.

For example, a flowmeter having a full scale of 10 cubic feet per second ($ft^3/s$) and a full scale accuracy of 1 percent would be accurate to $\pm 0.1$ $ft^3/s$ for all discharges in the flowmeter measurement range. Some manufacturers state accuracy as 1 percent of measured value. In this case, the same example flowmeter would be accurate to within $\pm 0.1$ $ft^3/s$ at full scale; and correspondingly, a reading of 5 $ft^3/s$ would be accurate to within $\pm 0.05$ $ft^3/s$ for the same flowmeter at that measurement.

## 3. Capability Terms

The term **linearity** usually means the maximum deviation in tracking a linearly varying quantity, such as measuring head, and is generally expressed as percent of full scale. **Discrimination** is the number of decimals to which the measuring system can be read. **Repeatability** is the ability to reproduce the same reading for the same quantities. **Sensitivity** is the ratio of the change of measuring head to the corresponding change of discharge. **Range** is fully defined by the lowest and highest value that the device can measure without damage and comply with a specified accuracy. The upper and lower range bounds may be the result of mechanical limitations, such as friction at the lower end of the range and possible overdriving damage at the higher end of the range. Range can be designated in other ways: (1) as a simple difference between maximum discharge ($Q_{max}$) and minimum discharge ($Q_{min}$), (2) as the ratio ($Q_{max}/Q_{min}$), called **rangeability**, and (3) as a ratio expressed as 1:($Q_{min}/Q_{max}$). Neither the difference nor the ratios fully define range without knowledge of either the minimum or maximum discharge.

Additional terms are related more to dynamic variability and might be important when continuous records are needed or if the measurements are being sensed for automatic control of canals and irrigation.

**Hysteresis** is the maximum difference between measurement readings of a quantity established by the same mechanical set point when set from a value above and reset from a value below. Hysteresis can continually get worse as wear of parts increases friction or as linkage freedom increases. **Response** has several definitions in the instrumentation and measurement fields. For water measurement, one definition for response is the smallest change that can be sensed and displayed as a significant measurement. **Lag** is the time difference of an output reading when tracking a continuously changing quantity.

**Rise time** is often expressed in the form of the **time constant**, defined as the time for an output of the secondary element to achieve 63 percent of a step change of the input quantity of the primary element.

## 4. Comparison Standards

Water providers may want or be required to have well developed measurement programs that are highly managed and standardized. If so, irrigation managers may wish to consult International Organization for Standardization (1983), American Society for Testing Materials standards (1988), American Society of Mechanical Engineers Test Codes (1992), and the *National Handbook of Recommended Methods for Water Data Acquisition* (1980).

Research laboratories, organizations, and manufacturers that certify measurement devices may need to trace accuracy of measurement through the entire hierarchy of increasingly rigid standards.

The lowest standards in the entire hierarchy of physical comparison standards are called **working standards**, which are shop or field standards used to control quality of production and measurement. These standards might be gage blocks or rules used to assure proper dimensions of flumes during manufacture or devices carried by water providers and users to check the condition of water measurement devices and the quality of their output. Other possible working standards are weights, volume containers, and stop watches. More complicated devices are used, such as surveyor's levels, to check weir staff gage zeros. Dead weight testers and electronic standards are needed to check and maintain more sophisticated and complicated measuring devices, such as acoustic flowmeters and devices that use pressure cells to measure head.

For further measurement assurance and periodic checking, water users and organizations may keep secondary standards. **Secondary standards** are used to maintain integrity and performance of working standards. These secondary standards can be sent to government laboratories, one of which is the National Bureau of Standards in Washington, DC, to be periodically certified after calibration or comparison with very accurate replicas of primary standards. **Primary standards** are defined by international agreement and maintained at the International Bureau of Weights and Measurements, Paris, France.

Depending upon accuracy needs, each organization should trace their measurement performance up to and through the appropriate level of standards. For example, turbine acceptance testing combined with severe contractual performance penalties might require tracing to the primary standards level.

## 5. Examples of Calibration Approaches and Accuracy Calculations

The following examples show different approaches to calibration and demonstrate other simple calculations and analyses that can be done concerning accuracy. These calculations can be used to investigate how well a water provider or user is measuring flow. Also, some of the example analyses will help select secondary head measuring equipment and will help determine when maintenance or replacement is needed.

**(a) Number of Significant Figures in Computations**

Although accuracy is necessary in computing discharges from data gathered in the field, the computations should not be carried out to a greater number of significant figures than the quality of the data justifies. Doing so would imply an accuracy which does not exist and may give misleading results. For example, suppose it is desired to compute the discharge over a standard contracted rectangular weir using the formula:

$$Q = C(L\text{-}0.2h_1)h_1^{3/2} \quad (3\text{-}4)$$

where:

$Q$ = the discharge in $ft^3/s$

$C$ = 3.33, a constant for the weir

$L$ = the length of the weir in feet (ft)

$h_1$ = the observed head on the weir (ft)

If the length of the weir is 1.50 ft and the observed head is 0.41 ft, the significant equation output is 1.24 $ft^3/s$.

As a rule, in any computation involving multiplication or division in which one or more of the numbers is the result of observation, the answer should contain the same number of significant figures as is contained in the observed quantity having the fewest significant figures. In applying this rule, it should be understood that the last significant figure in the answer is not necessarily correct, but represents merely the most probable value.

**(b) Calibration of an Orifice**

The calibration of a submerged rectangular orifice requires measuring head for a series of discharges, covering the full range of operation, with another more precise and accurate system sometimes called a standard control. Based on hydraulic principles, discharge varies as the square root of the head differential, and the equation for discharge through a submerged orifice can be written as:

$$Q = C_d A \sqrt{2g(\Delta h)} \quad (3\text{-}5)$$

where:

$Q$ = discharge

$g$ = acceleration caused by gravity

$\Delta h$ = upstream head minus the head on the downstream side of the orifice

$A$ = the area of the orifice

$C_d$ = coefficient of discharge

Also, the coefficient of discharge, $C_d$, must be determined experimentally for any combination of orifice shape, measuring head locations, and the location of orifice relative to the flow boundaries. The coefficient has been found to be constant if the orifice perimeter is located away from the approach channel boundary at least a distance equal to twice the minimum orifice opening dimensions. Values of the discharge coefficient calculated by putting the measured calibration data into equation 3-5 may be constant within experimental error if the orifice geometry complies with all the requirements for standard orifices throughout the calibration range.

An example set of discharge data is shown in table 3-1. The theoretical hydraulic equation 3-5 was used to compute values of the coefficient of discharge, $C_d$. The mean of the values (0.61) is the most probable equation coefficient based on 15 readings. The deviation or spread of individual coefficient values from the mean value would be the measure of the uncertainty of the measuring system as used during the calibration. The deviation of coefficient values is an indication of how well the calibration was done. Therefore, accuracy statements should also include statements concerning the head reading technique capability and the accuracy of the standard device used to measure discharge. If several orifices of the same size were calibrated together, then the accuracy statements can be made concerning limits of fabrication and installation of the orifices.

The histogram of the same data as shown on figure 3-1 was developed by splitting the range of discharge values into five 0.005-$ft^3$/s intervals. Then the data were tallied as they occurred in each interval. The plotted values of occurrence approach a symmetrical bell shape curve centered around the mean of 0.61, indicating that the data are random or normally distributed and that enough data were obtained to determine a meaningful average value for the discharge coefficient.

| Table 3-1. An example of discharge data | | |
|---|---|---|
| Discharge ($ft^3/s$) | Head difference (ft) | Discharge coefficient |
| 3.702 | 0.253 | 0.611 |
| 3.613 | 0.245 | 0.606 |
| 3.545 | 0.232 | 0.608 |
| 3.361 | 0.209 | 0.611 |
| 3.267 | 0.197 | 0.616 |
| 3.172 | 0.189 | 0.606 |
| 3.005 | 0.163 | 0.618 |
| 2.924 | 0.161 | 0.605 |
| 2.842 | 0.154 | 0.602 |
| 2.565 | 0.127 | 0.598 |
| 2.450 | 0.109 | 0.616 |
| 2.323 | 0.100 | 0.610 |
| 1.986 | 0.073 | 0.611 |
| 1.813 | 0.060 | 0.615 |
| 1.640 | 0.050 | 0.609 |
| Standard deviation = | | $\Sigma C_d = 9.142$<br>$C_{d\,Avg} = 0.610$<br>$S = 0.006$ |

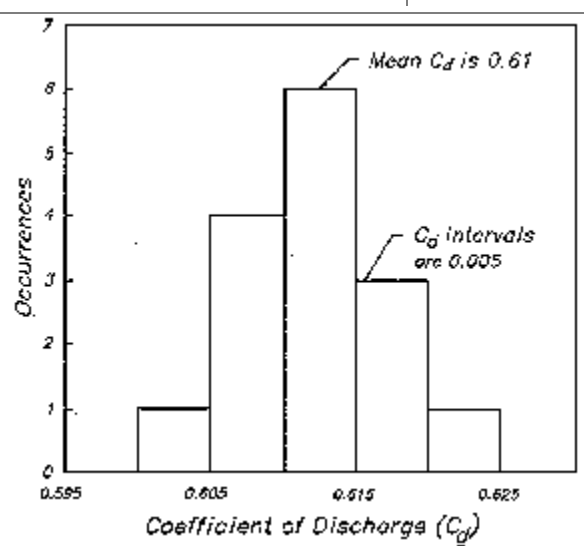


Figure 3-1 -- Histogram of discharge coefficients.

The measure of the spread of repeated measurements such as the discharge coefficient is the estimated standard deviation, which when using the form of equation 3-1 is written as:

$$S = \sqrt{\frac{\Sigma(C_d - C_{d\,Avg})^2}{(N-1)}} \quad (3\text{-}6)$$

where $\Sigma$ denotes summation, and $N$ is the number of $C_d$ values. The value of $S$ is the estimate of standard deviation, $\sigma$, which is approached more closely as the number of samples, $N$, becomes larger. Formal, small sample statistical methods can be used to evaluate confidence bounds around $S$ based on sample size. After $N$ has become large enough and normal distribution is verified, all previous and subsequent data are expected to fall within the bounds of $\pm S$, $\pm 2S$, and $\pm 3S$ for about 68.3, 95.4, and 99.7 percent confidence levels, respectively.

**(c) Error Analysis of Calibration Equation**

Often, structural compromise, in Parshall flumes for example, is such that hydraulic theory and analysis cannot determine the exponents or the coefficients. These devices must be calibrated by measuring head for a series of discharges well distributed over the flow range and measured with another, more accurate device. The data can be plotted as a best fit curve on graph paper. However, determination of equations for table generation would be preferable.

Parshall flumes and many other water measuring devices have close approximating equations of the form:

$$Q = Ch_1^{\,n} \quad (3\text{-}7)$$

If the data plot as a straight line on log-log graph paper, then equation 3-7 can be used as the calibration form, and a more rigorous statistical approach to calibration is possible. This equation can be linearized for regression analysis by taking the log of both sides, resulting in:

$$\log Q = n\log h_1 + \log C \quad (3\text{-}8)$$

Although a regression analysis can produce correlation coefficients greater than 0.99, with 1.0 being perfect, large deviations in discharge can exist. These deviations include error of estimating head between scale divisions for both the test and comparison standard devices, known errors of the comparison standard, and possible offset from linearity of the measuring device. For example, a laboratory calibration check of a 9-inch Parshall flume in a poor approach situation, using a venturi meter as the comparison standard, resulted in a correlation coefficient of 0.99924, an equation coefficient, $C$, of 3.041, and an exponent of 1.561 using 15 values of discharge versus measuring head pairs. For the properly set flume in tranquil flow, $C$ is 3.07 and $n$ is 1.56.

To overcome the defect of using correlation coefficients that are based on log units, the flume measuring capability should be investigated in terms of percent discharge deviations, $\Delta Q$, or expressed as:

$$\Delta Q\% = \frac{100(Q_{Eq} - Q_{Cs})}{Q_{Cs}} \quad (3\text{-}9)$$

where:

$\Delta Q\%$ = percent deviation of discharge

$Q_{Cs}$ = measured comparison standard discharge

$Q_{Eq}$ = discharge computed using measured heads and the regression equation

Then, calculate the estimate of standard deviation, $S$, and substitute $\Delta Q\%$ for $C_d$ in equation 3-6F from the previous example. For the Parshall flume example, $S$ was about 3.0 percent. The maximum deviation for the example flume was about -10 percent, and the average deviation was about 0.08 percent discharge, which is a small bias from the expected zero. Because of this small bias combined with a maximum absolute deviation of about 3$S$, the error was considered normally distributed, and the sample size, $N$, was considered adequate. Examples will be used to describe the next four sections.

**(d) Error Analysis of Head Measurement**

A water project was able to maintain a constant discharge long enough to obtain ten readings of head, $h_1$. These readings are listed in the first column of table 3-2.

This example process provides information on repetitions of hook gage readings but does not tell the whole story about system accuracy. Good repeatability combined with poor accuracy can be likened to shooting a tight, low scoring group on the outer margin of a target. Repetition is a necessary aspect of accuracy but is not sufficient by itself.

| Table 3-2. Determining sample standard deviation | | |
|---|---|---|
| Head ($h_1$) (ft) | Deviation ($h_1$ - $h_{1AVg}$) (ft) | $(Dev)^2$ $(h_1 - h_{1AVG})^2$ (square feet [$ft^2$]) |
| 1.012 | -0.0011 | 0.00000121 |
| 1.017 | 0.0039 | 0.00001521 |
| 1.014 | 0.0009 | 0.00000081 |
| 1.010 | -0.0031 | 0.00000961 |
| 1.015 | 0.0019 | 0.00000361 |
| 1.013 | -0.0001 | 0.00000001 |
| 1.012 | -0.0011 | 0.00000121 |
| 1.014 | 0.0009 | 0.00000081 |
| 1.013 | -0.0001 | 0.00000001 |
| 1.011 | -0.0021 | 0.00000441 |
| $\Sigma h_1$ = 10.131 | $\Sigma (h_1-h_{1AVg})$ = +0.0000 | $\Sigma (h_1-h_{1AVg})^2$ = 0.00003690 |
| $h_{1Avg}$ = 1.013 | | $S = (0.00003690)^{0.5}$ = 0.0061 |

**(e) Determining the Effect of Head Measurement on Accuracy**

Say a water provider or user measures a discharge of 8.96 $ft^3/s$ using a 3-ft suppressed weir with a staff gage estimating readings to ±0.01 ft. The head reading was 0.93 ft, and the water provider or user wants to investigate how much this estimate of head affects the accuracy of the discharge measurement. Assume that the reading and discharge are actual values and then add and subtract 0.01 ft to and from the 0.93-ft head reading, which gives heads of 0.94 ft and 0.92 ft. Discharges by table or equation for these new heads are 9.10 $ft^3/s$ and 8.82 $ft^3/s$. The difference of these discharges from 8.96 $ft^3/s$ in both cases is 0.14 $ft^3/s$, but of a different sign in each case. Thus, an uncertainty in discharge of ±0.14 $ft^3/s$ was caused by an uncertainty of ±0.01 ft in head reading. The uncertainty of the discharge measurement caused by estimating between divisions on the staff gage expressed in percent of actual discharge is calculated as follows:

$$\Delta Q\% = \frac{100(9.10 - 8.96)}{8.96} = 1.56\%$$

and:

$$\Delta Q\% = \frac{100(8.96 - 9.10)}{8.96} = 1.56\%$$

This calculation shows that estimating the staff gage ±0.01 ft contributes up to ±1.6 percent error in discharge at flows of about 9 $ft^3/s$.

Both calculations are required because both could have been different depending on the discharge equation form and the value of discharge relative to measuring range limits.

**(f) Computation to Help Select Head Measuring Device**

An organization uses several 3-ft weirs and wants to decide between depending on staff gage readings or vernier hook gage readings in a stilling well. From experience, they think that the staff gage measures head to within ±0.01 ft, and the hook gage measures to within ±0.002 ft. The equation for the 3-ft weir in the previous example calculation is:

$$Q = 9.99h_1^{3/2} \quad (3\text{-}10)$$

Using this equation and making calculations similar to the previous example, they produce table 3-3.

It is assumed that the water provider does not want to introduce more than 2 percent error caused by precision of head measurement. This amount of error is demarcated by the stepped line through the body of table 3-3. If the water providers needed to measure flow below 7 $ft^3/s$, they would have to use stilling wells and vernier point gages. This line shows that heads could be measured with a staff gage at locations where all deliveries exceed about 7 $ft^3/s$. They could select a higher cut-off percentage based on expected frequency of measurements at different discharges. The results of this type of analysis should be compared to the potential accuracy of the primary part of the measuring system.

Table 3-3. Discharge deviation

| Discharge ($ft^3/s$) | Equation Head (ft) | Percent deviation of discharge at calibration head at a plus $\Delta h_1$ of: | |
|---|---|---|---|
| | | $\Delta h_1$ ±0.002 ft | $\Delta h_1$ ±0.01 ft |
| | | Deviation (%) | Deviation (%) |
| 18 | 1.481 | 0.25 | 1.0 |
| 9 | 0.933 | 0.37 | 1.6 |
| 5 | 0.630 | 0.53 | 2.7 |
| 3 | 0.448 | 0.72 | 3.6 |
| 2 | 0.342 | 0.92 | 4.4 |
| 1 | 0.216 | 1.40 | 7.0 |

**(g) Relationship Between Full Scale and Actual**

Before buying several small acoustic flowmeters, a water provider requested that one be tested to see if the manufacturer's claim of accuracy was really true. Because the acoustic flowmeter is an electronic device, the manufacturer prefers to express calibration performance in terms of full-scale accuracy. The manufacturer claimed ±2 percent full-scale accuracy. Full-scale percentage accuracy is defined as the difference between comparison standard measured discharge and output flowmeter discharge relative to full-scale discharge. Full-scale discharge is equivalent to the discharge upper range limit of the flowmeter. The error in percent full-scale discharge is calculated using equation 3-3.

Figure 3-2 shows the test data for the acoustic flowmeter that was checked. Full-scale discharge is 0.768 $ft^3/s$ as shown by the vertical line on the right. The standard comparison discharge was measured using a volumetric calibration tank and electronic timer which can measure discharge within 0.5 percent. This plot indicates the

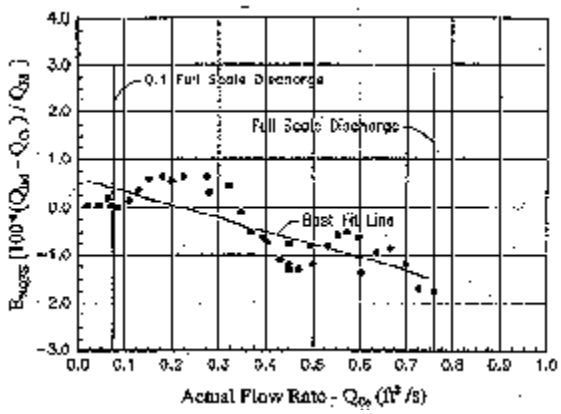


Figure 3-2 -- Percent full-scale deviation of flow rate versus actual (comparison standard) flow rate.

fit line slopes down to the right and passes through the zero error company claim of ±2.0-percent full-scale accuracy is true. The best axis to the left of midrange. This meter could be made to have a better full-scale accuracy by shifting the meter output vertically and/or tilting its output by electronics or computer programming.

The same data were converted and plotted in terms of percent comparison standard error of discharge using equation 3-11 on figure 3-3. To compare error in percent of actual discharge, $E_{\%Qact}$, with error in percent full-scale discharge, $E_{\%QFS}$, calculated contours of equal percent full scale were also plotted on figure 3-3.

$$E_{\%Qact} = \frac{100(Q_{Ind} - Q_{Cs})}{Q_{Cs}} \quad (3\text{-}11)$$

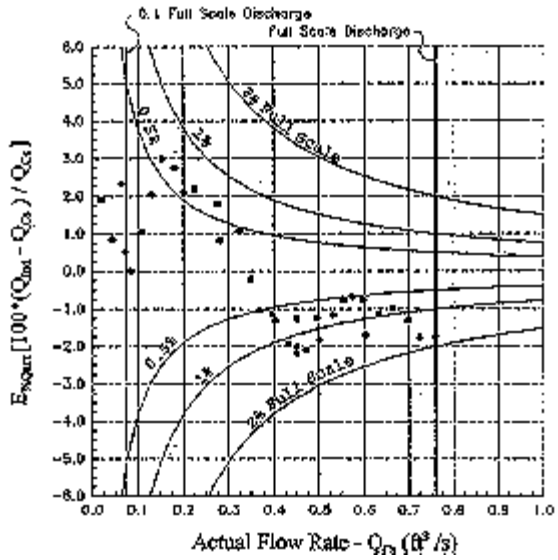


Figure 3-3 -- Comparison of actual (comparison standard) and full-scale accuracy.

**(h) Percent Registration Calibration**

Another way accuracy and calibration are expressed is in terms of percent registration. Calibration checks for open flow propeller meters are often presented this way. Percent registration is defined as:

$$\%R - 100\ \frac{Q_{Ind}}{Q_{Cs}} \quad (3\text{-}12)$$

A typical calibration check of a propeller meter mounted at the end of a pipe is plotted on figure 3-4. For this flowmeter, percent registration drops steeply below a discharge of 1 $ft^3/s$. This result clearly indicates some of the problems of measuring near the lower range limits of this flowmeter. A slight increase of bearing friction will shift the dropping part of the curve to the right because the discharge at which the propeller will not turn will increase. Thus, in effect, the range is shortened on its low discharge end. The percent registration on the flat part of the curve near maximum registration will also decrease with age and wear of the flowmeter. In fact, the manufacturer may set meters, when they are new, to register high in anticipation of future wear. For example, they may set meters to read 3 to 5 percent high, expecting wear to lower the curve to about 100 percent registration at about mid-life of the flowmeter.

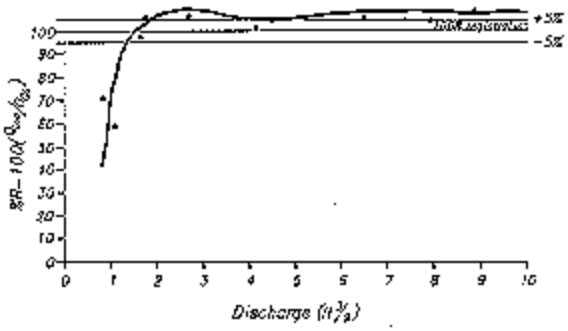

Figure 3-4 -- Percent registration form of calibration.

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# Chapter 4 - SELECTION OF WATER MEASURING DEVICES

## 1. General Requirements

Selecting the proper water measurement device for a particular site or situation is not an easy task. Many site-specific factors and variables must be considered and weighed. In addition, each system has unique operational requirements and concerns. Reliable estimates on future demands of the proposed system and knowledge of the immediate measurement needs are beneficial. Government laws and compact agreements should be checked for possible selection constraints before selecting a measurement device. Contractual agreements for the purchase of pumps, turbines, and water measuring devices for districts often dictate the measurement system required for compliance prior to payment. These constraints may be in terms of accuracy, specific comparison devices, and procedures. Bos (1989) provides a more detailed discussion on the selection of open channel water measurement devices than the information included here. He also provides a selection flow chart and a table of water measurement device properties to guide the selection process. In this chapter, we discuss selection issues for the most common devices used in the United States.

## 2. Types of Measuring Devices

Irrigation system operators commonly use many types of standard water measurement devices. In this manual, the following devices are discussed in subsequent chapters:

- Weirs
- Flumes
- Submerged orifices
- Current meters
- Acoustic flowmeters
- Other open-channel devices
- Other closed conduit devices

The first four methods given above are discussed in considerable detail in this manual because they are the most common methods used. A variety of other devices for open channels and closed conduits is available-particularly for smaller rates of flow.

These devices are discussed only briefly in chapters 11 and 12. This brief discussion does not mean that they are not useful devices. Such devices are appropriate for many applications.

## 3. Selection Considerations

The main factors which influence the selection of a measuring device include:

- Accuracy requirements
- Cost
- Legal constraints
- Range of flow rates
- Head loss
- Adaptability to site conditions

- Adaptability to variable operating conditions
- Type of measurements and records needed
- Operating requirements
- Ability to pass sediment and debris
- Longevity of device for given environment
- Maintenance requirements
- Construction and installation requirements
- Device standardization and calibration
- Field verification, troubleshooting, and repair
- User acceptance of new methods
- Vandalism potential
- Impact on environment

**(a) Accuracy**

The target or desired accuracy of the measurement system is an important consideration in measurement method selection. Most water measurement devices can produce accuracies of ±5 percent. Some devices are capable of ±1 percent under laboratory settings. However, in the field, maintaining such accuracies usually requires considerable expense or effort (e.g., special construction, recalibration, maintenance, etc.). Selecting a device that is not appropriate for the site conditions can result in a nonstandard installation of reduced accuracy, sometimes greater than ±10 percent.

Accuracies are usually reported for the primary measurement method or device. However, many methods rely on a secondary measurement, which typically adds error to the overall measurement. For example, the primary calibration for a weir is the relationship between head and discharge; this relationship typically contains a small error. However, the head must be measured, which potentially introduces additional error. Chapters 3 and 8 contain discussion and examples concerning the influence of secondary devices on accuracy.

**(b) Cost**

The cost of the measurement method includes the cost of the device itself, the installation, secondary devices, and operation and maintenance. Measurement methods vary widely in their cost and in their serviceable life span. Measurement methods are often selected based on the initial cost of the primary device with insufficient regard for the additional costs associated with providing the desired records of flows over an extended period of time.

**(c) Legal Constraints**

Governmental or administrative water board requirements may dictate types of accepted water measurement devices or methods. Water measurement devices which become a standard in one geographic area are often not accepted as a standard in another area. In this sense, the term "standard" does not necessarily signify accuracy or broad legal acceptance. Many water districts require certain water measurement devices used within the district to conform to their standard for the purpose of simplifying operation and maintenance.

**(d) Flow Range**

Many measurement methods have a limited range of flow conditions for which they are applicable. This range is usually related to the need for certain prescribed flow conditions which are assumed in the development of calibrations. Large errors in measurement can occur when the flow is outside this range. For example, using a bucket and stopwatch for large flows that engulf the bucket is not very accurate. Similarly, sharp-edged devices typically do not give good results with large flows, which are better measured with large flumes or broad-crested weirs.

In some cases, secondary devices can limit the practical range of flow rates. For example, with devices requiring a head measurement, the accuracy of the head measurement can limit the measurement of low flow rates. For some devices, accuracy is based on percent of the full-scale value. Then, at low values, the resulting accuracy is much lower, limiting the usefulness of such measurements. Generally, the device should be selected to cover the range desired. Choosing a device that can handle a larger than necessary flow rate could result in elimination of measurement capability at lower flow rates, and vice versa. For practical reasons, it may be reasonable to establish different accuracy requirements for high and low flows. Examples in chapter 3 discuss some of these problems in more detail.

**(e) Head Loss**

Most water measurement devices require a drop in head. On existing irrigation projects, such additional head may not be available, especially in areas with relatively flat topography. On new projects, incorporating additional head loss into the design can usually be accomplished at reasonable cost. However, a tradeoff usually exists between the cost of the device and the amount of head loss. For example, acoustic flowmeters are expensive and require little head loss; sharp-crested weirs are inexpensive but require a relatively large head loss. The head loss required for a particular measurement device usually varies over the range of discharges. In some cases, head used in measuring flow can reduce the capacity of the channel at that point.

**(f) Adaptability to Site Conditions**

The selection of a measurement device must consider the site of the proposed measurement. Several potential sites may be available for a given measurement; the selection of a device depends upon the exact site chosen. For example, discharge in a canal system can be measured within a reach of the channel or at a structure such as a culvert or check structure. A different device would typically be selected for each site. The device selected should not alter site hydraulic conditions so as to interfere with normal operation and maintenance. Also, the shape of the flow cross section will likely favor some devices over others. For example, the Parshall flume size selection process described in chapter 5 might result in a flume wider than the existing channel, adding substantial cost to the installation, whereas a long-throated flume might fit within the existing channel prism.

**(g) Adaptability to Variable Operating Conditions**

Most water delivery systems have a varying range of flows and conditions. The selected device must also be able to measure over the range of operating conditions encountered (e.g., variations in upstream and downstream head).

Devices like weirs or flumes should be avoided if downstream water levels can, under some conditions, submerge the device. In addition, the information provided by the measuring device needs to be useful for the operators performing their duties. Devices that are difficult and time consuming to operate are less apt to be used and are more likely to be used incorrectly.

In some cases, water measurement and water level or flow control need to be accomplished at the same site. A few devices are available for accomplishing both (e.g., constant-head orifice, vertically movable weirs, and Neyrpic flow module) (Bos, 1989). However, separate measurement and control devices are typically linked for this purpose. Special care is needed to assure that devices are compatible and, when used as a system, achieve both functions.

**(h) Type of Measurements and Records Needed**

An accurate measure of instantaneous flow rate is useful for system operators in setting and verifying flow rate. However, because flow rates change over time, a single, instantaneous reading may not accurately reflect the total volume of water delivered. Where accounting for water volume is desired, a method of accumulated individual flow measurements is needed. Where flows are steady, daily measurements may be sufficient to infer total volume. Most deliveries, however, require more frequent measurements. Totalization is essential where water users take water on demand. Totalizers and automatic recording devices are available for many measurement devices. For large structures, the cost for water-level sensing and recording hardware is small relative to the structure cost; but for small structures, these hardware costs do not change and thus become a major part of the measurement cost (often more costly than the structure itself).

Many water measurement methods are suitable for making temporary measurements (flow surveys) or performing occasional verification checks of other devices.

The method chosen for such a measurement might be quite different from that chosen for continuous monitoring. Although many of these flow survey methods are discussed in this manual, this chapter focuses on methods for permanent installations.

**(i) Operating Requirements**

Some measurement methods require manual labor to obtain a measurement. Current metering requires a trained staff with specialized equipment. Pen-and-ink style water-stage recorders need operators to change paper, add ink, and verify proper functioning. Manual recording of flows may require forms to be filled out and data to be accumulated for accounting purposes. Devices with manometers require special care and attention to assure correct differential head readings. Automated devices such as ultrasonic flowmeters and other systems that use transducers and electronics require operator training to set up, adjust, and troubleshoot problems. Setting gate controlled flow rates by simple canal level references or by current metering commonly requires several hours of waiting between gate changes for the downstream canal to fill and stabilize. However, flumes and weirs serve to quickly reach measured flow rate without waiting for the downstream canals to fill to stable conditions. The requirements of the operating personnel in using the devices and techniques for their desired purposes can be easily overlooked and must be considered in meter selection.

**(j) Ability to Pass Sediment and Debris**

Canal systems often carry a significant amount of sediment in the water. Removal of all suspended solids from the water is usually prohibitively expensive. Thus, some sediment will likely be deposited anywhere the velocities are reduced, which typically occurs near flow measuring structures. Whether this sediment causes a problem depends on the specific structure and the volume of sediment in the water. In some cases, this problem simply requires routine maintenance to remove accumulated sediment; in others, the accumulation can make the flow measurement inaccurate or the device inoperative. Sediment deposits can affect approach conditions and increase approach velocity in front of weirs, flumes, and orifices. Floating and suspended debris such as aquatic plants, washed out bank plants, and debris such as fallen tree leaves and twigs can plug some flow measurement devices and cause significant flow measurement problems. Many of the measurement devices which are successfully used in closed conduits (e.g., orifices, propeller meters, etc.) are not usable in culverts or inverted siphons because of debris in the water. Attempting to remove this debris at the entrance to culverts is an additional maintenance problem.

**(k) Device Environment**

Any measurement device with moving parts or sensors is subject to failure if it is not compatible with the site environment. Achieving proper operation and longevity of devices is an important selection factor. Very cold weather can shrink moving and fixed parts differentially and solidify oil and grease. Water can freeze around parts and plug pressure ports and passageways. Acidity and alkalinity in water can corrode metal parts. Water contaminants such as waste solvents can damage lubricants, protective coatings, and plastic parts.

Mineral encrustation and biological growths can impair moving parts and plug pressure transmitting ports. Sediment can abrade parts or consolidate tightly in bearing and runner spaces in devices such as propeller meters. Measurement of wastewater and high sediment transport flow may preclude the use of devices that require pressure taps, intrusive sensors, or depend upon clear transmission of sound through the flow. Water measurement devices that depend on electronic devices and transducers must have appropriate protective housings for harsh environments. Improper protection against the site environment can cause equipment failure or loss of accuracy.

**(l) Maintenance Requirements**

The type and amount of maintenance varies widely with different measurement methods. For example, current metering requires periodic maintenance of the current meter itself and maintenance of the meter site to assure that is has a known cross section and velocity distribution. When the flow carries sediment or debris, most weirs, flumes, and orifices require periodic cleaning of the approach channel. Electronic sensors need occasional maintenance to assure that they are performing properly. Regular maintenance programs are recommended to ensure prolonged measurement quality for all types of devices.

**(m) Construction and Installation Requirements**

In addition to installation costs, the difficulty of installation and the need to retrofit parts of the existing conveyance system can complicate the selection of water measurement devices. Clearly, devices which can be easily retrofit into the existing canal system are much preferred because they generally require less down time, and unforeseen problems can be avoided.

**(n) Device Standardization and Calibration**

A standard water measurement device infers a documented history of performance based on theory, controlled calibration, and use. A truly standard device has been fully described, accurately calibrated, correctly constructed, properly installed, and sufficiently maintained to fulfill the original installation requirements and flow condition limitations. Discharge equations and tables for standard devices should provide accurate calibration. Maintaining a standard device usually only involves a visual check and measurement of a few specified items or dimensions to ensure that the measuring device has not departed from the standard. Many standard devices have a long history of use and calibration and, thus, are potentially more reliable. Commercial availability of a device does not necessarily guarantee that it satisfies the requirements of a standard device.

When measuring devices are fabricated onsite or are poorly installed, small deviations from the specified dimensions can occur. These deviations may or may not affect the calibration. The difficulty is that unless an as-built calibration is performed, the degree to which these errors affect the accuracy of the measurements is unknown. All too frequently, design deviations are made under the misconception that current metering can be used to provide an accurate field calibration. In practice, calibration by current metering to within $\pm 2$ percent is difficult to attain.

An adequate calibration for free-flow conditions requires many current meter measurements at several discharges. Changing and maintaining a constant discharge is often difficult under field conditions.

**(o) Field Verification, Troubleshooting, and Repair**

After construction or installation of a device, some verification of the calibration is generally recommended. Usually, the methods used to verify a permanent device (e.g., current metering) are less accurate than the device itself. However, this verification simply serves as a check against gross errors in construction or calibration. For some devices, errors occur as components wear and the calibration slowly drifts away from the original. Other devices have components that simply fail - that is, you get the correct reading or no reading at all. The latter is clearly preferred. However, for many devices, occasional checking is required to assure that they are still performing as intended. Selection of devices may depend on how they fail and how easy it is to verify that they are performing properly.

### (p) User Acceptance of New Methods

Selection of a water measurement method must also consider the past history of the practice at the site. When improved water measurement methods are needed, proposing changes that build on established practice are generally easier to institute than radical changes. It can be beneficial to select a new method that allows conversion to take place in stages to provide educational examples and demonstrations of the new devices and procedures.

### (q) Vandalism Potential

Instrumentation located near public access is a prime target for vandalism. Where vandalism is a problem, measurement devices with less instrumentation, or instrumentation that can be easily protected, are preferred. When needed, instrumentation can be placed in a buried vault to minimize visibility.

### (r) Impact on Environment

During water measurement device selection, consideration must be given to potential environmental impacts. Water measurement devices vary greatly in the amount of disruption to existing conditions needed to install, meet standard upstream and downstream conditions, operate, and maintain. For example, installing a weir or flume constricts the channel, slows upstream flow, and accelerates flow within the structure. These changes in the flow conditions can alter local channel erosion, local flooding, public safety, local aquatic habitat, and fish movement up and down the channel. These factors may alter the cost and selection of a measurement device.

## 4. Selection Guidelines

Selection of a water measurement method can be a difficult, time-consuming process if one were to formally evaluate all the factors discussed above for each measuring device. Of course, this difficulty is one reason that standardization of measurement devices within a district is so popular. However useful devices are sometimes overlooked when similar devices are automatically selected. The purpose of this chapter is to provide some preliminary guidance on selection so that the number of choices can be narrowed down before a more thorough analysis of the tradeoffs between alternatives is performed.

### (a) Short List of Devices Based on Application

Site conditions for a water measurement device quickly narrow the list of possible choices, because most devices are only suitable under a limited number of channel or conduit conditions. Table 4-1 provides a list of the most commonly used measurement methods for each of several applications.

Table 4-2 provides an abbreviated table of selection criteria and general compliance for categories of water measurement devices. The symbols (+), (0), and (-) are used to indicate relative compliance for each selection criteria.

The (+) symbol indicates positive features that might make the device attractive from the standpoint of the associated selection criteria. A (-) symbol indicates negative aspects that might limit the usefulness of this method based on that criteria. A (0) indicates no strong positive or negative aspects in general. A (v) means that the suitability varies widely for this class of devices. The letters (na) mean that the device is not applicable for the stated conditions. A single negative value for a device does not mean that the device is not useful and appropriate, but other devices would be preferred for those selection criteria.

Table 4-1 - Application-based selection of water measurement devices

1. Open channel conveyance system
    1. Natural channels
        1. Rivers
            1. Periodic current metering of a control section to establish
            2. stage-discharge relation
            3. Broad-crested weirs
            4. Long-throated flumes
            5. Short-crested weirs
            6. Acoustic velocity meters (AVM - transit time)
            7. Acoustic Doppler velocity profiles
            8. Float-velocity/area method
            9. Slope-area method
        2. Intermediate-sized and small streams
            1. Current metering/control section
            2. Broad-crested weirs
            3. Long-throated flumes
            4. Short-crested weirs
            5. Short-throated flumes
            6. Acoustic velocity meters (AVM - transit time)
            7. Float-velocity/area method
    2. Regulated channels
        1. Spillways
            1. Gated
                1. Sluice gates
                2. Radial gates
            2. Ungated
                1. Broad-crested weirs (including special crest shapes, Ogee crest, etc.)
                2. Short-crested weirs
        2. Large canals
            1. Control structures
                1. Check gates
                2. Sluice gates
                3. Radial gates
                4. Overshot gates

Table 4-1 - Application-based selection of water measurement devices (Cont.)

        2. Other
            1. Long-throated flumes
            2. Broad-crested weirs
            3. Short-throated flumes
            4. Acoustic velocity meters
    3. Small canals (including open channel conduit flow)
        1. Long-throated flumes
            1. Broad-crested weirs
        2. Short-throated flumes
            1. Sharp-crested weirs
        3. Rated flow control structures (check gates, radial gates, sluice gates, overshot gates)
        4. Acoustic velocity meters
        5. Other
            1. Float-velocity area methods
    4. Farm turnouts
        1. Pipe turnouts (short inverted siphons, submerged culverts, etc.)
            1. Metergates
            2. Current meters
            3. Weirs
            4. Long-throated flumes
            5. Short-throated flumes
        2. Other
            1. Constant head orifice
            2. Rated sluice gates
            3. Movable weirs
2. Closed conduit conveyance systems
    1. Large pipes
        1. Venturi meters
        2. Rated control gates (orifice)
        3. Acoustic velocity meters (transit time)
    2. Small and intermediate-sized pipelines
        1. Venturi meters
        2. Orifices (in-line, end-cap, shunt meters, etc.)
        3. Propeller and turbine meters
        4. Magnetic meters
        5. Acoustic meters (transit-time and doppler)
        6. Pitotmeters
        7. Elbow meters
        8. Trajectory methods (e.g., California pipe method)
        9. Other commercially available meters

Table 4-2. Water measurement device selection guidelines. Symbols +. 0,Care used as relative indicators comparing application of water measurement devices to the listed criteria ("v" denotes device suitability varies widely, "na" denotes not applicable to criteria)

| Device | Accuracy | Cost | Flows >150 $ft^3/s$ | Flows <10 $ft^3/s$ | Flow span | Head loss | Site conditions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lined canal | Unlined canal | Short full pipe | Closed conduit |
| Sharp-crested weirs | 0 | 0 | - | + | 0 | - | - | 0 | na | na |
| Broad-crested weirs | 0 | + | + | + | + | 0 | + | 0 | na | na |
| Long-throated flumes | 0 | 0 | + | + | + | 0 | + | 0 | na | na |
| Short-throated flumes | 0 | - | - | 0 | 0 | - | - | 0 | na | na |
| Submerged orifices (in channels) | 0 | 0 | - | + | - | - | 0 | 0 | na | na |
| Current metering | - | - | + | - | - | + | 0 | - | na | na |
| Acoustic velocity meters n an open channel | - | 0 | 0 | - | 0 | + | 0 | 0 | na | na |
| Radial and sluice gates | - | + | 0 | 0 | - | - | + | + | + | na |
| Propeller meters at pipe exit | - | + | - | 0 | 0 | + | 0 | 0 | + | + |
| Differential head meters for pipe[1] | + | - | - | + | - | V | na | na | 0 | + |
| Mechanical velocity meters for pipe[2] | 0 | + | - | 0 | 0 | + | na | na | 0 | + |
| Magnetic meters for pipe | 0 | 0 | - | 0 | 0 | + | na | na | - | + |
| Acoustic Doppler ultrasonic meters for pipe | - | 0 | - | - | - | + | na | na | - | + |
| Acoustic flowmeter pipe (single path) | 0 | - | 0 | 0 | 0 | + | na | na | - | + |
| Acoustic flowmeter pipe (multipath) | + | - | + | 0 | + | + | na | na | - | + |

[1] Venturi, orifice, pitot tube, shunt meters, etc.
[2] Propeller meters, turbine meters, paddle wheel meters, etc.

Table 4-2 - Water measurement device selection guidelines. Symbols +. 0,Care used as relative indicators comparing application of water measurement devices to the listed criteria ("v" denotes device suitability varies widely, "na" denotes not applicable to criteria) (continued)

| Device | Measurements | | Sediment/Debris | | Longevity | | Maintenance | Construction | Field verify | Standardization |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rate | Volume | Sediment pass. | Debris pass. | Moving parts | Elec-tricity needed | | | | |
| Sharp-crested weirs | + | - | - | - | + | + | 0 | - | 0 | + |
| Broad-crested weirs | + | - | 0 | + | + | + | + | + | + | 0 |
| Long-throated flumes | + | - | 0 | + | + | + | + | 0 | + | 0 |
| Short-throated flumes | + | - | 0 | + | + | + | + | - | - | + |
| Submerged orifices (in channels) | + | - | - | - | + | + | + | 0 | + | 0 |
| Current metering | + | - | + | + | 0 | 0 | 0 | + | 0 | + |
| Acoustic velocity meters in an open channel | + | 0 | + | + | 0 | - | - | + | - | - |
| Radial and sluice gates | + | - | 0 | - | + | 0 | + | + | - | - |
| Propeller meters at pipe exit | 0 | + | 0 | - | - | 0 | - | + | 0 | 0 |
| Differential head meters for pipe[1] | + | - | - | v | + | 0 | 0 | 0 | + | + |
| Mechanical velocity meters for pipe[2] | v | v | - | - | - | 0 | - | 0 | 0 | 0 |
| Magnetic meters pipe | + | 0 | 0 | 0 | 0 | - | - | 0 | - | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Acoustic Doppler ultrasonic meters for pipe | + | 0 | 0 | 0 | 0 | - | - | 0 | - | - |
| Acoustic flowmeter pipe (single path) | 0 | + | 0 | 0 | 0 | - | - | - | - | 0 |
| Acoustic flowmeter pipe (multipath) | + | + | 0 | 0 | 0 | - | - | - | - | + |

[1] Venturi, orifice, pitot tube, shunt meters, etc.
[2] Propeller meters, turbine meters, paddle wheel meters, etc.

The process of narrowing down options might start with table 4-1 to examine the main methods to consider. Table 4-2 can then be used to get an idea of the general positive and negative features of various methods. In narrowing down the options, different applications will place different weight on the selection criteria, so no universally correct selection exists. Finally, a preliminary design for several candidate methods selected should be performed so that details on cost, hydraulics, operations, etc., can be more thoroughly examined C followed by final selection, design, and construction.

**(b) Example**

We want to measure the flow entering a small farm turnout ditch that serves an agricultural field. The ditch is trapezoidal, concrete-lined and has a rectangular metal sluice gate that is opened by hand to divert flow into the ditch from a canal lateral. No power is available at the site. The ditch carries a flow of about 10 cubic feet per second ($ft^3/s$). Field survey measurements taken during an irrigation indicate about a 0.75-ft drop in the water surface from the gate to the downstream channel. The irrigation flow transports fine sediment and numerous tumble-weeds. Water is diverted to the field on a 2-week rotation for a period of about 24 hours. The measurement device will be used to establish a known flow rate through the headgate for crop yield management and water use accounting. Typically, the water surface in the lateral remains fairly constant during an irrigation; therefore, a single measurement per irrigation will meet current needs. However, in the future, more frequent measurements may be desired. The irrigator would like to install a device that costs less than $500.

Table 4-1 identifies a number of devices that are typically used for farm turnouts. Our site requires we select a device or method that can be used in an open channel. Therefore, common measurement devices given for this application are: current meters, weirs, flumes, and rated sluice gates (headgates). Next, the advantages or disadvantages for each of these devices should be considered with respect to the measurement goals and the site conditions. Table 4-2 is used to assist in comparing the attributes of devices.

Typically, only a few selection constraints are high priorities. The selection priorities for the example are likely: meeting available head, cost, accuracy, and debris passage goals. Head loss is the highest priority because it is a physical constraint of the site that must be met to provide good measurement. Current meters provide the least head loss followed by long-throated flumes (including broad-crested weirs), short-throated flumes, and sharp-crested weirs. Sluice gates rate low in terms of head loss; however, for this application, the gate is part of the site and will not provide additional head loss. Based on our highest priority, current metering, a long-throated flume or rating the headgate are good choices. Next, consider the cost of devices including: initial cost, data collection time, and maintenance. Rating the headgate and a long-throated flume are considered to be a lower cost than current metering largely because of the time involved in data collection. Accuracy of measurement and debris passage favor a long-throated flume.

This example selection process identifies a long-throated flume as potentially the best device followed by rating of the headgate. These two methods of measurement are recommended for additional detailed design and evaluation prior to the final selection.

## 5. Bibliography

Bos, M.G., (ed.), *Discharge Measurement Structures*, third revised edition, International Institute for Land Reclamation and Improvement, Publication No. 20, Wageningen, The Netherlands, 1989.

# CHAPTER 5 - INSPECTION OF WATER MEASUREMENT SYSTEMS

## 1. Background and Scope

Irrigation system deterioration can exist for years before becoming apparent to frequent users. However, an observer viewing an installation for the first time or infrequently may spot the deterioration immediately. Thus, water users and providers are often surprised to find that their water measurements are unacceptable because their system and measuring devices have deteriorated. Regular and careful inspections with the specific intent of finding deterioration in early stages will help prevent this unpleasant surprise. These inspections will also help reveal changing delivery needs that require other types of measuring devices and disclose other possible errors of operation. Another problem is that operators do not always know or use proper techniques to obtain accurate measurements. The best way to handle this problem is to provide good training.

This chapter shows water users and providers what to consider and check during system inspections to help maintain accurate water deliveries. Users can protect water rights and prevent overcharging by understanding these same considerations.

The performance of weirs and flumes will be used to illustrate flow and accuracy principles because irrigation operators will likely be more familiar with their use. Also, many of the factors which adversely affect accuracy are visible on these devices but are hidden in closed conduit devices. Many of the factors and principles established for weirs and flumes also apply to other water measuring devices. These principles are elaborated upon in forthcoming sections concerning specific devices.

## 2. Standard Devices Versus Nonstandard Devices

The use of standard devices usually results in lower total costs over the lifetime of a measurement structure. Their long general use has generated more backup data and experience, making them potentially more reliable. A truly standard device has been fully described, accurately calibrated, correctly made or installed, and sufficiently maintained to fulfill the original requirements. Standard discharge equations and tables or curves may then be relied upon to provide accurate water measurements. Maintaining a standard device involves only a visual check and measurement of a few specified items or dimensions to ensure that the measuring device has not departed from the standard.

Even though a standard device might have been selected for a particular measurement situation, water providers and users frequently find themselves unexpectedly stuck with nonstandard and, at times, unusable devices. This situation can occur when a device is installed improperly, is poorly maintained, is operated above or below the prescribed discharge limits, or has poor approach or downstream submergence conditions.

Accurate discharges from nonstandard structures can be obtained only from specially prepared curves or tables based on calibration tests, such as multiple current-meter ratings. The accuracy of a nonstandard device cannot be determined by visual inspection. Accuracy can only be ensured by recalibration, which is costly when properly performed. Ratings must be made at close discharge intervals over the complete operating range.

Then, curves and/or tables must be prepared. Installation and proper inspection and maintenance of standard devices are not difficult and are less costly in the long run. Standard discharge tables may then be used with full confidence.

## 3. Approach Flow

Poor flow conditions in the area just upstream from the measuring device can cause large discharge indication errors. In general, the approaching flow should be tranquil. Tranquil flow is defined as fully developed flow in long, straight channels with mild slopes, free of close curves, projections, and waves. Venturi meters require 10 diameters of straight pipe approach. By analogy, open channel flow would require 40 hydraulic radii of straight, unobstructed approach.

A good example of practical approach criteria taken from Bos (1989) follows:

- If the control width is greater than 50 percent of the approach channel width, then 10 average approach flow widths of straight, unobstructed approach are required.
- If the control width is less than 50 percent of the approach width, then 20 control widths of straight, unobstructed approach are required.
- If upstream flow is below critical depth, a jump should be forced to occur. In this case, 30 measuring heads of straight, unobstructed approach after the jump should be provided.
- If baffles are used to correct and smooth out approach flow, then 10 measuring heads should be placed between the baffles and the measuring station.

Deviation from a normal transverse or vertical flow distribution, or the presence of water surface boils, eddies, or local fast currents, is reason to suspect the accuracy of the measuring device. Errors of 20 percent are common, and errors as large as 50 percent or more may occur if the approach flow conditions are very poor. Sand or gravel bars, weed growths, or slumped riprap obstructions along the banks or in the flow area can cause nonsymmetrical approach flow. Inadequate distance downstream from a drop, check, or slide gate will concentrate flow locally and cause error. A bend or angle in the channel just upstream from the measuring device or a rapid expansion in the flow section can cause secondary flow or large eddies, which tend to concentrate the flow in part of a cross section.

Figure 5-1 shows an example of a poor flow distribution in the approach to a weir. The high-velocity, turbulent stream is approaching the weir at a considerable angle. The high-velocity approach flow and the waves on the surface hinder head measurement. With this poor approach flow, the weir will not produce the same head-discharge relationship as its standard equation and calibration table.

Figure 5-1 -- Example of poor approach flow conditions upstream from weir.

Standard weir proportions for rectangular, Cipoletti, and 90-degree Vnotch weirs are shown on figure 5-2. The approach velocity toward weirs should be less than 0.5 foot per second (ft/s). This velocity value is equivalent to a head error of 0.005 ft. Velocity of approach can be estimated by dividing the maximum discharge by the area at a point 4 to 6 measuring heads upstream from the blade. Excess approach velocity is commonly caused by violating the criteria specified in chapter 7.

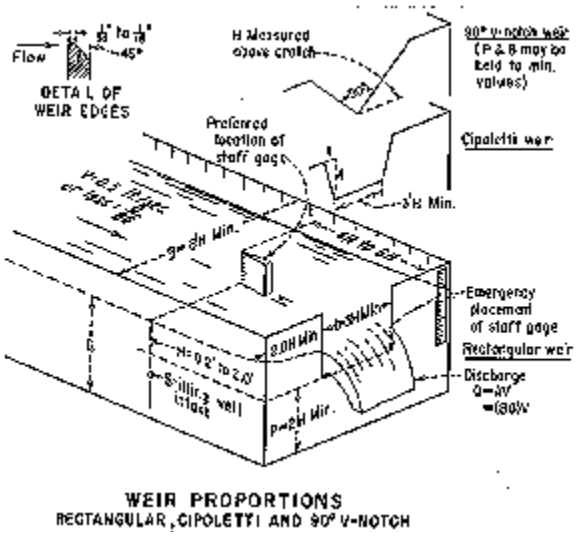



Figure 5-2 -- Weir proportions.

## 4. Turbulence

Turbulence results from relatively small parcels of water spinning in a random pattern within the bulk flow while moving downstream. Turbulence may be recognized as water surface boils or three dimensional eddies which appear and disappear haphazardly. Because of this local motion within the general motion of the bulk flow, any particle of water may, at any given instant, move forward, sideways, vertically, or even backward. In effect, the water is passing a given point with accelerating and decelerating motion superimposed upon the main flow rather than with a uniform, ideal velocity. Thus, more or less water may pass a given point over a short length for short time periods, depending on the observation point chosen (figure 5-1).

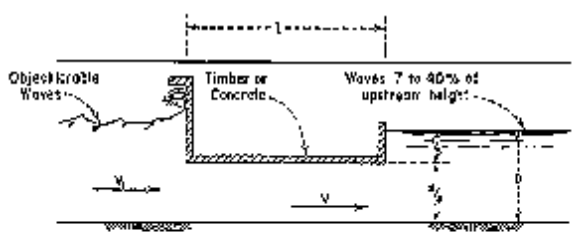
Excessive turbulence will adversely affect the accuracy of any measuring device but is particularly objectionable when using current meters or propeller meters of any kind. Turbulence can be objectionable even without air entrainment or the "white water" often associated with turbulence. Turbulence is commonly caused by stilling basins or other energy dissipaters, by a sudden drop in water surface, or by obstructions in the flow area such as turnouts-- operating or not--that have projections or indentations from the supply canal. Shallow flow passing over a rough or steep bottom can also cause turbulence. Weeds or riprap slumped into the flow area or along the banks, or sediment deposits upstream from the measuring device, also can cause excessive turbulence.

Excessive turbulence can cause measuring errors of 10 percent or more. Therefore, the flow approaching a measuring structure or device should be modified to resemble tranquil canal flow.

## 5. Rough Water Surface

Reducing turbulence or improving approach flow distribution can eliminate rough water surfaces that are not caused by wind. A rough water surface can cause errors in discharge measurements when a staff gage must be read to determine head or cross-sectional area of the flow. A stilling well will help reduce errors in head measurement, but every attempt should be made to reduce the water surface disturbances as much as possible before relying on the well. Errors of 10 to 20 percent are common where a choppy water surface impedes accurate head determination. The area of piping to a stilling well should be about one-hundredth of the well area to dampen water surface oscillations. A larger area of piping may be needed to eliminate debris plugging or increase well response to changes in measuring head. A smaller area may be needed to dampen overly rough flow.

Specially constructed wave damping devices (Schuster, 1970) are often required to obtain a smooth water surface. Figure 5-3 shows a schematic of an underpass type of wave suppressor successfully used in both large and small channels.




| LENGTH L | PERCENT WAVE REDUCTION |
|---|---|
| 1.0 TO 1.50 | 60 TO 75 |
| 1.50 TO 2.50 | 80 TO 88 |
| 3.50 TO 4.00 | 90 TO 93 |

UNDERPASS WAVE SUPPRESSOR SECTION

Figure 5-3 -- Underpass wave suppressor.

The channel may be either rectangular or trapezoidal in cross section. Constructing the suppressor four times as long as the flow is deep can reduce waves as much as 93 percent. The suppressor produces a slight backwater effect for the most effective vertical placement. The suppressor may be supported on piers, can be constructed of wood or concrete, and need not be watertight.

The design of several other suppressor types, along with example cases, is covered in Peterka (1983). Figure 5-4 shows turbulence and waves in a Parshall flume produced by an outlet works stilling basin, which makes accurate discharge determination impossible. The log raft in the foreground was used in an attempt to quiet the flow; however, the raft was later lifted out of the water because of ineffectiveness.

Figure 5-4 -- Turbulence and waves in a Parshall flume produced by an outlet works stilling basin. The log raft failed to quite the flow.

Figure 5-5 shows the water surface after removal of the log raft and installation of an underpass-type wave suppressor. This modification significantly reduced the turbulence and waves, making accurate discharge determination a routine matter.

Figure 5-5 -- Underpass-type wave suppressor reduces turbulence and waves in Parshall flumes.

## 6. Velocity Head in Approach

As flow approaches a weir, the water surface becomes lower due to acceleration of the flow by the force of gravity (figure 5-6).

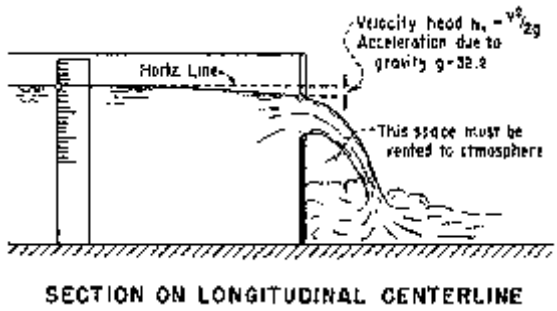


Figure 5-6 -- Weir approach flow.

The water surface is considerably lower at the weir blade than it is at 5 ft upstream. The elevation difference between the two circled points on the surface of the approach flow is called the velocity head and represents the potential required to produce the increase in velocity between the points.

A drop in water surface of 0.1 ft is common just upstream from a weir and (from the equation above) represents an increase in velocity of 0.8 ft/s. If the head on the weir is measured too close to the weir, the head measurement can be up to 0.1 ft too small. For a weir 6 ft long, with a head of 0.45 ft, a discharge of 7 $ft^3/s$ is indicated. If you measured the head too close to the weir, such that the head was reduced by 0.1 ft, a discharge of 5 $ft^3/s$ would be indicated. This difference amounts to an error of about 35 percent based on the reported discharge; and, more importantly, the water provider would be giving away 2 $ft^3/s$.

Standard weir tables are based on the measured head of the weir (velocity head is negligible) and do not compensate for excessive velocity head. Any increase in velocity above standard conditions, therefore, will result in measuring less than the true head on the weir. Therefore, more water will be delivered than is measured. Causes of excessive velocity head include inadequate pool depth upstream from the weir, deposits in the upstream pool (figure 5-7), and poor lateral velocity distribution upstream from the weir.

Figure 5-7 -- Sediment deposits in weir pool.

Figure 5-7 shows sediment deposits, which have reduced the depth of the weir significantly and increased the velocity of the approach to well above the desirable level. Other problems exist as well; the head gage should not be located this close to the weir blade, the weeds should be removed, and the "edge" of the weir should be sharp. Discharges over this weir will be larger than indicated in "standard" tables.

## 7. Poor Flow Patterns

The poor flow distribution which exists upstream from a measuring device often cannot be attributed to any one of the causes discussed above. The best solution, then, is to assume that the poor distribution has several causes. Start with the easy factors, work through the list, and address each probable cause of poor flow patterns until obtaining the desired flow conditions.

Turnouts located close to and upstream from a measuring device may cause poor approach conditions, as may bridge piers, channel curves, or a skewed measuring section. Relocating the measuring device may be the only remedy in these cases.

Submerged weeds or debris can cause excessive turbulence or local high velocity currents. Eddies adjacent to the shoreline can cause the flow approaching the weir to contract into a narrow band. Sediment bars deposited from inflow or from sloughing banks can also produce undesirable flow conditions. More drastic remedial measures include deepening the approach area, widening the approach channel to make it symmetrical, or introducing baffles or other devices to spread the incoming flow over the entire width of the approach. However, 10 channel widths of straight, unobstructed approach should lie between baffles or other devices placed before the measuring device. Surface waves, which are usually difficult to reduce or eliminate by ordinary procedures, may require special treatment, as discussed under "Rough Water Surface" in section 5.

## 8. Exit Flow Conditions

Exit flow conditions can cause as much flow measurement error as approach flow problems. However, these conditions are not encountered as often in practice. In general, ensuring that backwater does not submerge or drown out a device designed for free flow is sufficient. Occasionally, a flume is set too low, and backwater submerges the throat excessively, which can introduce extremely large errors in discharge measurement. The only remedy is to raise the flume, unless some local obstruction downstream can be removed to reduce the backwater. Sharp-crested weirs should discharge freely rather than submerged, although a slight submergence (the backwater may rise above the crest up to 10 percent of the head) reduces the discharge a negligible amount (less than 1 percent). However, a weir operated near submergence may not affect the discharge as much as the possible lack of nappe ventilation resulting from high downstream depth or intermittent waves lapping the underside of the nappe.

The underside of weir nappes should be ventilated sufficiently to provide near atmospheric pressure beneath the nappe, between the under-nappe surface, and the downstream face of the weir. The height of pull-up behind the nappe depends upon the drop, discharge, and crest length. The height that the water raises behind the nappe is a measure of the discharge error. For example, if the measuring head on a 3-ft suppressed weir is 1 ft and the water behind the nappe pulls up 0.3 ft, the error of discharge measurement would be about +6.5 percent. If the water was only pulled up 0.1 ft, the error for the same weir and measuring head would be +2.5 percent.

If the head upstream from the weir is pulled down a significant amount, then the weir is not sufficiently ventilated. An easy test for sufficient ventilation is to part the nappe downstream from the blade for a moment with a hand or a shovel to allow a full supply of air to enter beneath the nappe. After removing the hand or shovel, the nappe should not gradually become depressed (over a period of several or more minutes) toward the weir blade. If the upper nappe profile remains the same as it was while fully ventilated, the weir has sufficient ventilation.

If the nappe clings to the downstream side of the weir and does not spring clear, the weir may discharge up to 25 percent more water than the head reading indicates. This problem is generally a low flow problem with heads near and less than 0.2 ft and occurs more frequently with V-notch weirs. Good practice would involve checking the nappe before and after readings.

Gates calibrated only for free discharge at partial openings should not be submerged, nor should eddies interfere with the jet of water issuing from the gate. Gaging stations should be kept free of deposited sediment bars or other side-projecting obstructions to prevent backflow or eddies from interfering with the uniform flow conditions that should exist in the cross section being measured.

## 9. Weathered and Worn Equipment

Sharp-crested weir blades on older water measuring devices are often in bad condition. Weir blades are seen with dull and dented edges, discontinuous with bulkheads, pitted and covered with rust tubercles, and not vertical. Weir blades have sagged and are no longer level. Staff gages are worn and difficult to read. Stilling well intakes are buried in sediment or partly blocked by weeds or debris. Broad-crested weirs and flumes are frost heaved and out of level. Meter gates are partly clogged with sand or debris, and gate leaves are cracked and warped. These and other forms of deterioration often cause serious errors in discharge measurements. This type of deficiency is difficult to detect because, as mentioned before, deterioration occurs slowly.

Therefore, the person responsible for measuring devices must inspect them with a critical eye. The attitude should be: "I am looking for trouble," rather than: "I will excuse the little things because they are no worse today than they were yesterday." A series of little problems has often accumulated and compounded into large, unknown, and unaccountable errors. Poorly maintained measuring devices are no longer standard, and indicated discharges may be considerably in error. Worn devices should be rehabilitated to ensure true discharge readings.

Repairing or refurbishing a rundown measuring device is sometimes a difficult or impossible task. Fixing small problems as they occur will prevent, in many cases, replacing the entire device on an emergency basis, perhaps at great cost at some later date. Regular preventive maintenance will extend the useful life of measuring devices.

## 10. Poor Installation and Workmanship

Contrasting with the measurement devices that were once accurate and dependable but have deteriorated are those that, because of poor workmanship, were never installed properly. This category includes devices that are installed out of level or out of plumb, those that are skewed or out of alignment, those that have leaking bulkheads with flow passing beneath or around them, and those that have been set too low or too high for the existing flow conditions.

Inaccurate weir blade lengths or Parshall flume throat widths, insufficient or nonexistent weir nappe ventilation, or incorrectly located and zeroed head or staff gages cause measuring errors.

A transverse slope on a sharp-crested weir blade can cause errors, particularly if the gage zero is referenced to either end. The error can be minimized by determining the discharge based on the head at each end and using the average discharge. Errors in setting the gage zero are the same as misreading the head by the same amount. At low heads, a relatively small zero setting error can cause errors of 50 percent or more in the discharge. A head determination error of only 0.01 ft can cause a discharge error of from 5 percent on a 90degree V-notch weir to over 8 percent on a 48inch (in) Cipoletti weir (both for a head of 0.20 ft). The same head error on 6 and 12in Parshall flumes can result in 12- and 6-percent errors, respectively, for low heads.

Out of plumb or skewed weir blades will show flow measurement inaccuracies of measurable magnitude if the weir is out of alignment by more than a few degrees. Rusted or pitted weir blades or those having projecting bolts or offsets on the upstream side can cause errors of 2 percent or more depending on severity of the roughness. Any roughness will cause the weir to discharge more water than indicated. Rounding of the sharp edge of a weir or reversing the face of the blade also tends to increase the discharge. On older wood crests, a well rounded edge can cause a 15- to 25-percent or more increase in discharge (figure 5-8). The well-rounded edge on the once sharp-crested weir on figure 5-8 will increase the discharge to well above "standard." The weeds are also undesirable, as is the weir gage which projects into the flow area.

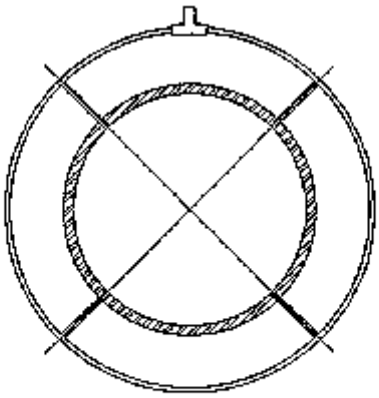
Figure 5-8 -- Poorly maintained weir edge.

Certain types of meters require pressure readings to determine discharges. Piezometers, or pressure taps, as they are sometimes called, must be regarded with suspicion when considering flow measurement accuracy.

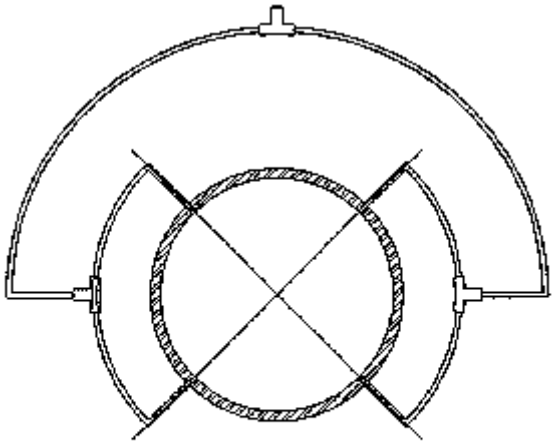
Piezometers or pressure head taps must be installed with care and with a knowledge of how they perform; otherwise, indicated pres-sure values can be in error. For example, as shown on figure 5-9, the four piezometers indicate different pressure readings (water levels) because of the manner in which flow passes the piezometer opening. Piezometer openings are shown larger than they should be constructed in practice. Always use the smallest diameter opening consistent with the possibility of clogging by foreign material. Unless the piezometer is vertical as in Y, the water elevation will be drawn down as in X or increased as in Z. Basically, pressure taps should be perpendicular to the flow boundary, and the flow must be parallel to the boundary. Rough edges or burrs on or near the edges of the piezometer holes deflect the water into or away from the piezometer, causing erroneous indications. The case as in W shows the tube pushed into the flow, causing the flow to curve under the tip which pulls the water level down. Errors caused by faulty piezometer tap installation increase with velocity.

Figure 5-9 -- Examples of piezometer installation.

Sometimes, to obtain a better average pressure reading, four taps around the pipe are manifolded. If unbalanced pressure exists because of velocity distribution, error can be introduced by flow circulation in the manifolding tubing. Two forms of manifolding are shown on figure 5-10. The commonly seen case (a)-circular form-causes circulation errors. Case (b) is the triple tee system, designed to minimize circulation errors. Large tube diameter relative to piezometer hole diameter through the meter wall will reduce circulation error considerably for both cases.



(a) Circular



(b) Triple - Tee

Figure 5-10 -- Examples of piezometer manifold tubing (top: poor arrangement; bottom: good compensating arrangement). Large-diameter tubing relative to piezometer diameter will reduce circulation errors considerably for both cases.

Frequently, pressure taps are connected to manometers and U-tubes (figure 5-11), and air trapped in the tubing can cause large errors. Air travels in bubbles that tend to rise and form large air blockages. Thus, piezometers should not be connected at the top of a pipe. Even with taps on the side, air will come out of solution as water warms. Air in the vertical parts of the tubing causes large errors. Although air in horizontal parts of the tubing does not cause error, a bubble will likely move to a vertical part of the tubing when flow increases or decreases. For bleeding air, flowmeters should be placed at locations where the pipelines are under positive pressure; that is, where the hydraulic grade line is well above the pipe and manometry system as shown on figure 5-11.

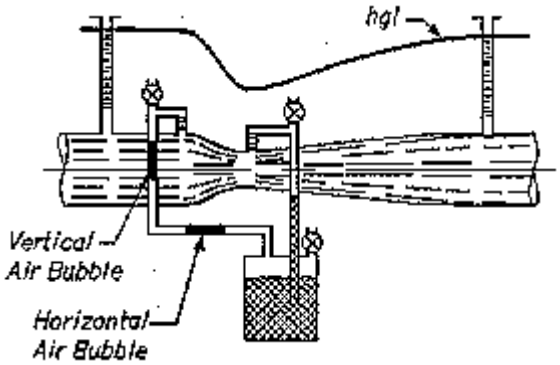



Figure 5-11 -- Manometry system below the hydraulic grade line is desirable.

If the meter and/or manometer are above the grade line as shown on figure 5-12, then pressure is negative. Negative pressure causes air to come out of solution and accumulate. Also, air can leak through pipe fittings and flange gaskets into the pipe and manometer system. Air can leak through openings that water cannot leak through.

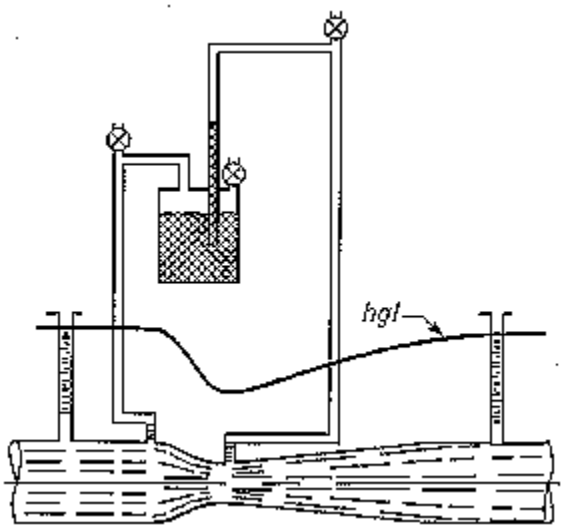



Figure 5-12 -- Manometry system above the hydraulic grade line is undesirable.

Care in designing the system should be taken to make sure that the hydraulic grade line is above the tubing system at maximum water delivery. Otherwise, bleeding will have to be done frequently with separate water source purging, or water delivery will have to be shut off to provide positive pressure during bleeding. When the hydraulic grade line is below the system, the negative pressure causes air to accumulate faster. This condition should be avoided if at all possible.

The effect of a few deficiencies often found in measuring devices has been given to illustrate the degree of error to be expected in making ordinary measurements under ordinary conditions. Other effects have not or cannot be stated in terms of percent error without an exact definition of the degree of fault or deterioration. The examples given should be sufficient to emphasize the importance of careful and exact installation practices as well as regular and prompt repair or rehabilitation of the devices after they have been installed.

## 11. Measuring Techniques Reducing Accuracy of Measurement

Regularly maintained equipment, properly installed in an ideal location, will still give inaccurate discharge measurements if the operator uses poor measuring techniques. Head measurement is very important. The techniques in use often are not compatible with the relationships between head and discharge known to exist. Operators should make sure that calibration curves or tables match devices being used both in size and kind.

### (a) Faulty Head Measurement

Measurement of the head on a sharp-crested weir, a seemingly simple matter, can be difficult under all but ideal conditions. The head is the height of water above the blade edge or the bottom of a V-notch, measured at a point where the velocity head (or approach velocity) is negligible (figure 5-6). In practice, this point is located four to six times the measuring head upstream from the center of the weir blade. If the head is measured too far upstream, a head not related to the water surface profile at the weir can be measured. If the head is measured closer to the weir blade, some drawdown (caused by increased velocity near the weir) may occur and less than the true head will be measured. If the head is measured at the side of the approach channel, more or less than the true head may be measured depending on the geometry of the approach pool (figures 5-2 and 5-13).

Figure 5-13 -- Cipoletti weir operating with good flow conditions in the approach pool.

Figure 5-13 shows a Cipoletti weir performing properly for the discharge shown. Flow is well distributed across the wide pool and shows no evidence of excessive turbulence. Accurate or "standard" discharges can be expected under these conditions. At larger discharges, the nonsymmetrical approach may produce undesirable conditions.

The principles described above also apply to head measurements on broad-crested weirs and flumes, meter gates, or any other device dependent on a head measurement for discharge determination.

Improper gage location, or an error in head measurement in a flume, can result in large discharge errors because of water surface curvature. Incorrect flume throat width dimensions and weir lengths can also produce errors. The relative ease of making accurate length measurements usually keeps these errors small. However, operators should check lengths in the field rather than rely on values stated or shown on drawings.

Readings obtained from stilling wells, whether visual or recorded, should be questioned unless the operator is certain that the well intake pipe is not partially or fully clogged with sediment or air pockets. Data from an overactive stilling well can also be misleading, particularly if long-period surges occur in the head pool. In fact, all head determinations should be checked to ensure that the reading is not part of a long period surge. A sufficient number of readings, about 10, should be taken at regular time intervals of about 15 seconds, and averaged to obtain the average head. More readings may be required if consecutive readings indicate that the pool is continuing to rise or fall. If this process takes too much time, the cause of the instability should be determined and eliminated.

Readings from gages or staffs which may have slipped or heaved should be avoided. Periodic rough checks can sometimes be made with a carpenter's level or square from a reference point on another structure. A still-ponded water level at the weir crest height is a valuable check on the staff gage zero.

Each operator should understand the desired measurement and then critically examine each operation to ensure that the correct measurement is being taken. The operator should try to find fault with every step in the head measurement process and attempt to improve techniques wherever possible.

**(b) Infrequent Measurement**

When a head or velocity measurement is taken, the operator must assume that the resulting discharge occurred only at the moment of the measurement. The operator cannot conclude that the same discharge occurred 5 minutes or even 5 seconds earlier. Therefore, accurate water deliveries can be ensured only if enough measurements are made to establish the fact that the discharge did or did not vary over the period that water was delivered.

In many systems, measurements are taken only once a day, or only when some physical change in supply or delivery has been made. Problems introduced by falling head, rising backwater, gate creep, or hunting are often ignored when computing a water delivery. The problem is not simple; many factors must be considered in determining the number of readings to be made per day or other unit of time. If the discharge in the supply system is increasing or decreasing, multiple readings will be required. If the rate of rise is uniform, the average of two readings, morning and night, would be better than one. Erratic rates of change will require frequent readings. A need for many readings may justify the use of a recording device.

When the discharge in the supply system remains constant, the water level or velocity reading may change because of a change in control or because checks have been placed in operation. Temporary changes in the main supply system discharge may occur; for example, because water, in effect, is being placed in storage as a result of the rising water level. Conversely, the discharge may temporarily increase in parts of the system if the operating level is being lowered. The changing water level may require more frequent head readings. If accurate, instantaneous recording of highly variable flows is required, then stilling wells may need larger connecting pipe diameters to reduce time lag. In some situations, weir pooling volumes need accounting.

Here again, the operator should try to visualize the effect of any change in discharge in the supply system, upstream or downstream from a measuring device, and attempt to get more than enough readings to accurately compute the quantity of water delivered.

**(c) Use of Improper Measuring Device**

Every water measuring device has unique limitations; thus, a single type cannot be used in all locations under all possible conditions. Therefore, several devices might be suitable for a given set of conditions, but none could be considered entirely satisfactory. If flow conditions change considerably for any reason because of modified operations, a formerly suitable device may become totally inadequate. A formerly marginally suitable device may become useless for a small change of operation needs. An incorrect device may have been selected in the first place, and no matter how much care the operator takes, accurate measurements cannot be obtained. The operator should call attention to such situations and attempt to have remedial measures taken. Chapter 4 gives guidance for selection.

For example, with sharp-crested weirs, accuracy cannot be expected if the head is appreciably less than 0.2 ft or greater than about one third of the weir blade length. Large measurement errors can be expected (departure from standard) if these limits are exceeded appreciably.

Large errors are introduced if a sharp-crested weir blade is submerged by backwater. Designing a device that is to be submerged throughout all or part of its flow range requires using a calibration related to a measuring head differential. Having a second or downstream measuring head station doubles the chance for wrong readings. Despite the appearance of handbook submergence discharge determination methods, discharge is related to small differences in measuring heads. Small imprecisions in water elevation measurement cause large errors. As submergence increases, the measuring head differentials decrease and approach values that are about the same magnitude as for minor variations of form and friction loss. Thus, corrections for large submergence are very inaccurate.

Propeller meter devices should not be permanently installed where weeds, moving debris, or sediment are apt to foul the meter or wear the bearings. Submerged devices, such as meter gates and other types of orifices, should not be used where a moving bedload can partly block the openings.

The flow conditions at a particular site must be analyzed. Only then can the measuring device be selected that can best cope with conditions to be encountered. The user of irrigation-type measuring devices should not expect accuracy to exceed about $\pm 2$ percent, even for standard devices that have been properly selected, set, and maintained.

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# CHAPTER 6 - MEASURING AND RECORDING WATER STAGE OR HEAD

## 1. Introduction

The stage of a stream, canal, or lake is the height of the water surface above an established datum (Buchanan and Somers, 1965). The head in a water measurement structure or device can be defined similarly. The stage, or gage height, of the water is usually expressed in feet and hundredths of a foot. Records of stage are important in stream gaging because the rate of flow is plotted against stage in preparing discharge curves. After a curve has been established for a stable channel, rate of flow can be directly determined from stage reading. Reliability of the stage reading is, therefore, of great importance. Head measurements in all types of water measurement structures, including various flumes, weirs, and gates, are equally important. Records of gage height may be obtained from a series of systematic readings on nonrecording gages or from automatic water-stage recorders. Laser, satellite, microwave, and electronic systems can be used to transmit gage readings from either nonrecording or recording gages.

## 2. Datum of Gage

A convenient and meaningful elevation datum should be selected for the station. The operating datum for the station should be set below the water-stage elevation for zero flow. The operating datum can be referenced to mean sea level. The datum should be permanent for the expected life of the station and should be referenced to at least two or three other benchmarks that are independent of the gaging structure.

## 3. Measurement Method

Two basic philosophies can be used to determine stage or gage height-direct and indirect. Direct methods involve a measurement of the height from the liquid level to a datum line; an indirect method infers the stage level from some other characteristic, such as the head read by a pressure transducer.

## 4. Nonrecording Gages

Two general types of nonrecording gages are in use: (1) staff gages, on which readings of stage are made directly; and (2) chain, wire weight, float-type, and hook gages, with which measurements are made from fixed points.

Staff gages may be either vertical or inclined. The inclined type should be carefully graduated and accurately installed to ensure correct stage readings. Most permanent gages are enameled steel plates bolted in sections to the staff. This kind of staff gage is shown on figure 8-4 in chapter 8. Care should be taken to install the gages solidly to prevent errors caused by changes in elevation of the supporting structure.

A chain gage is a substitute for the staff gage and consists of a horizontal scale and a chain that passes over a pulley to attach to a hanging weight (figure 6-1). Chain gages may be mounted on a bridge that spans (or any other structure that overhangs far enough) over the stream. Water stage is indicated by raising or lower the weight until it just touches the water surface and reading the position of the chain index mark on the horizontal scale.

Chain gages are affected by settling of the structure that supports them, changes in load on the structure, temperature changes, and changes in length as the chain links wear. Wind may also introduce errors by not allowing the weight to remain in a vertical position.

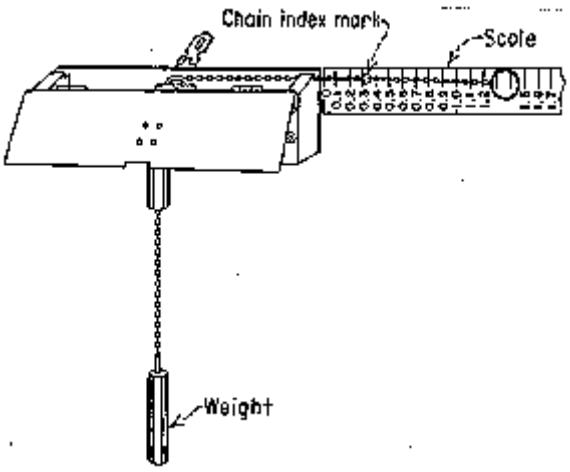


Figure 6-1 -- Chain gage.

The wire weight gage is a modification of the chain gage and uses a wire or small cable wound on a reel. The reel is graduated, or a counter is used to give readings to tenths and hundredths of a foot. A check bar of known elevation is often provided so that lowering the weight onto the bar will produce a reading on the counter or reel, which can be compared with the reference elevation. A wire weight gage is shown on figure 6-2.

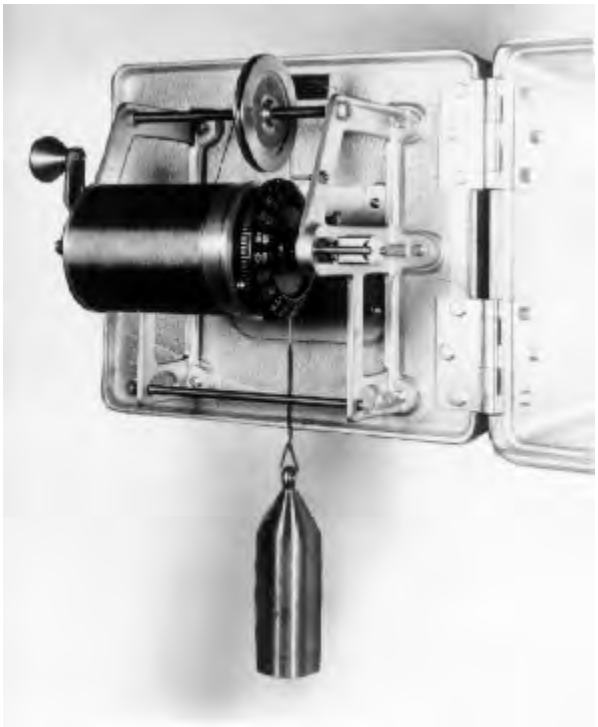

Figure 6-2 -- Nonrecording wire and weight-type gage.

## 5. Recording Gages

Water-stage recorders consist of a group of instruments that produce a record of water surface elevation with respect to time. The output can be analog (providing a graphical result) or digital (punched paper tape or stored or transmitted values). Important advantages of recorders over nonrecording staff gages are:

(1) In streams having daily fluctuations, continuous records provide the most accurate means of determining the daily average gage height.

(2) Maximum and minimum stage are recorded, and the time they occurred can be noted.

(3) Records can be obtained at stations where observers are not always available.

### (a) Analog-Graphical Recorders

In general, analog or graphical recorders consist of two main elements: a clock mechanism actuated by a spring, weight, or electric motor and a gage height element actuated by a float, cable or tape, and counterweight. Four basic types of recorders use these elements. Figure 6-3 shows a horizontal drum recorder, in which the clock positions the pen along the drum axis, and the gage height element rotates the drum. This recorder is also available with a vertical drum. Another type of recorder also has a vertical drum, but the time and height elements have been reversed so that the clock mechanism rotates the drum.

Figure 6-3 -- Horizontal drum water-stage recorder. The time element records parallel to the axis of the drum. (courtesy Leupoild and Stevens Instruments, Inc.).

These types of recorders usually operate using 8-day, spring-driven clocks. Electrical drives could also be used if a reliable source were readily available. The stylus, usually either a capillary pen or a pencil of proper hardness, must be capable of operation for the full 8 days without attention. To accommodate various water-stage differentials, ratios of water-stage change to recorder-chart change are available from 1:1 to 10:1 and should be specified at the time the recorder is ordered. The standard width of recorder paper is 10 inches (in), and all recorders come equipped with metal covers.

The fourth type of graphic recorder is shown on figures 6-4 and 6-5. The time element, consisting of a compensated, balanced, weight-driven clock, drives two parallel rolls, one of which holds the supply paper. The paper unrolls from the supply roll at a uniform rate and with constant tension and is taken up on the receiving roll. Speed of travel may be adjusted from 0.3 to 9.6 in per day on any standard instrument, and other chart speeds are available on special order. The normal chart length is 75 feet (ft).

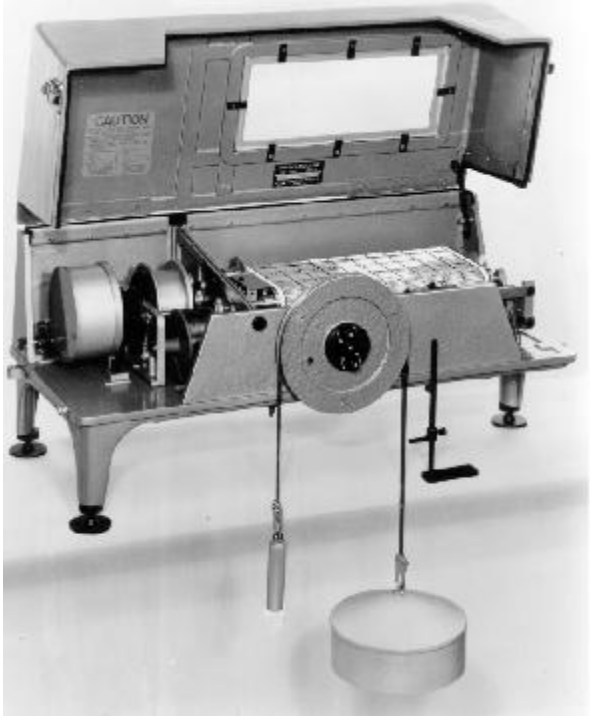

Figure 6-4 -- Continuous recording water-stage recorder with cover raised. The time element rotates the rolls, and the height element records parallel to the axis of the rolls. (courtesy Leupoild and Stevens Instruments, Inc.).

Figure 6-5 -- Typical installation of a continuous water-stage recorder in a wooden shelter.

The float activates a pen stylus which moves parallel to the axis of the rolls so that 1 in of travel represents a change in water stage of 1 ft. The stylus is designed so that it can be accurately set for gage height. The ratio of water surface change to stylus travel can also be adjusted to accommodate small to large ranges of depth. The range of the recorder is limited only by the length of the float cable because the stylus reverses direction at the point of maximum deflection. Capacity of the ink reservoir is sufficient for the recorder to operate for 60 days or longer.

**(b) Digital Recorders**

Digital recorders used in water stage measurements usually include two types: punched-paper tape (figure 6-6) and analog-to-digital data loggers. Both types are electrically operated (usually by batteries) and record numbers either on the paper tape or in memory at selected time intervals.

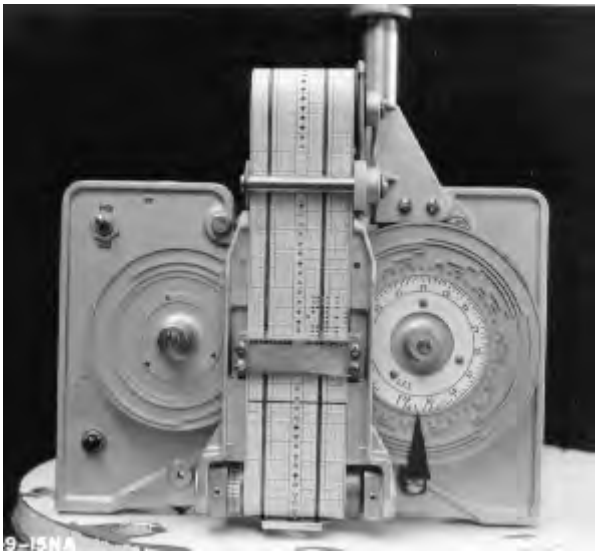

Figure 6-6 -- Digital recorder.

Water stage is transmitted to the punched-paper tape recorder, usually through shaft rotation on a float and pulley arrangement. Shaft rotation is converted by the recorder into coded punch-tape records (figure 6-7). The code consists of four groups of four punches each. In each group, the first punch represents "1"; the second, "2"; the third, "4"; and the fourth, "8." Thus, a combination of 1, 2, or 3 appropriate punches in a given group represents digits from 1 to 9. A blank (no punch) represents zero. Together, the four groups of punches represent all numbers from 0 to 9999.

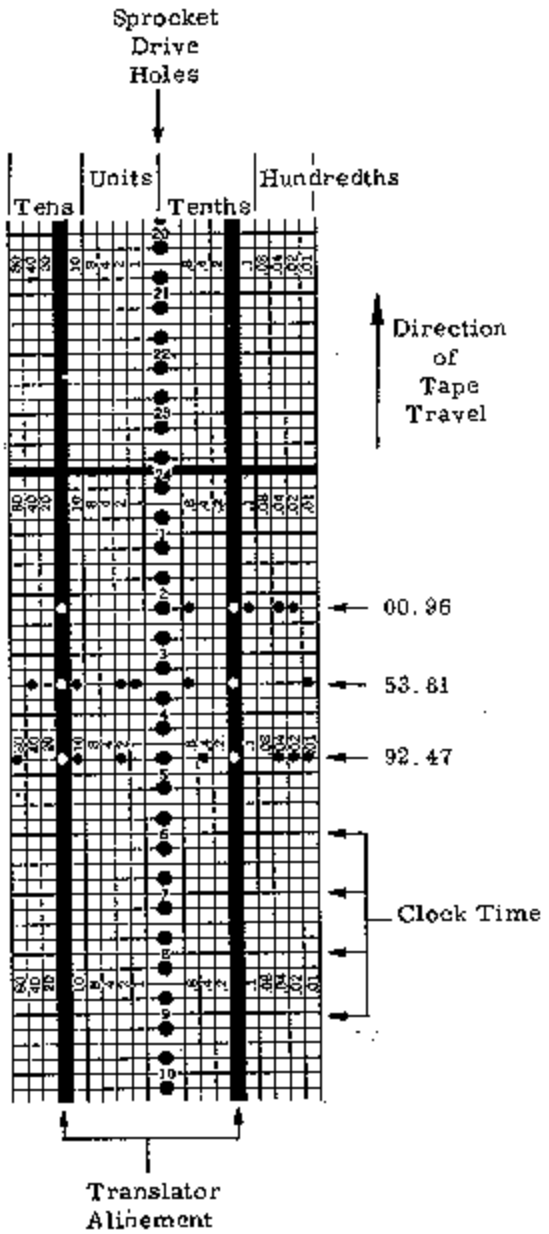


Figure 6-7 -- Digital recorder punched tape. (courtesy U.S. Geological Survey).

Coding is done by either one or two identical disks that have raised ridges on the faces. Figure 6-6 shows a digital recorder with only one disk, which produces 2-digit numbers ranging from 0 to 99. Two disks would be used if 3- or 4-digit numbers are required. The right-hand disk is connected directly to the input shaft, and the left-hand disk is driven from the first disk by a 100-to-1 worm-gear reducer. One-hundred revolutions of the input shaft and the first disk cause one revolution of the second disk. A paper tape is moved upward through the punch assembly in the center of the instrument. The punch block contains a row of 18 pins or punches-16 for information and 2 for feeding the tape. At the selected intervals of time, the punch assembly is pivoted on a shaft at the bottom, so the punch, paper, and pins are moved toward the disks. Those pins that strike raised ridges on the disks are forced through the paper, punching neat round holes. The pins that do not strike ridges do not punch holes. This record reflects the position of the disks, which is proportional to the water stage, all as a function of time.

The mechanically punched tape is still widely used at this time (1996) and is considered very practical for field use where temperature, moisture, and power conditions are widely variable. Electronic translators can convert punched tape records into suitable input for digital computers.

The most recent advances have been in the area of data loggers. This group of electronic instruments has evolved quickly over the last 10 years. Small, battery-operated, fully programmable units offer many features in addition to data recording (figure 6-8). Some type of transducer is required to sense the water stage with this type of recorder. Options range from a pressure transducer sensing water level in a stilling well to a pressure transducer on a bubbler system, to an angular transducer sensing shaft rotation on a float-driven system. In all cases, an analog (voltage or current) output is sensed, digitally recorded, and stored by the data logger. This type of system is perhaps best suited to the transmission of data via satellite or microwave, providing a central control location with current water stage information. Remote sites are very well suited to being powered by batteries which are charged through small solar cells. However, vandalism of the solar panels can be a problem because they must be exposed. Concealing solar panels in some way (such as in the top of a tree) can help.

Figure 6-8 -- Programmable battery operated recording unit.

## 6. Installation of Water-Stage Recorders

Important considerations in the installation of a water-stage recorder are the proper sizing and installation of a stilling or float well (if used) and the establishment of the reference datum for the site. The gage must be accessible at all times and substantially constructed for security and reliability. The recorder should be protected from the environment. The reference datum should be below the lowest stage of the stream or structure, and the instrument used to measure the stage must have the capability to cover the full range of water surface changes.

## 7. Stilling Well Considerations

Head readings on staff gages attached directly to the inside channel walls are often only estimates because of waves and turbulent fluctuations on the scale face. If the wall of a flume is relatively thin, the flume channel is connected directly by an orifice through the wall shared by the flume and stilling well to improve head reading. Separate or more remote wells are connected by pipes through thicker walls and embankments. Thus, the average water surface outside the well is translocated into the well, and the waves and fluctuations are dampened.

Polyvinyl chloride, polyethylene, and galvanized-iron pipes, sealed on the lower end with an opening in the side, make excellent wells.

Some older stilling wells were made from tongue-and-groove creosoted lumber and worked satisfactorily. Sewer pipe of suitable size with tightly sealed joints has also been used. On a flume, stilling wells are often formed of the same material as the flume. Because the primary purpose of the stilling well is to prevent oscillations of the float caused by surging water or wave action, the well must be firmly anchored to prevent movements that could introduce oscillations within the well.

Surges and wind waves of the outside water surface can be dampened by restricting the area of an inlet port through a relatively thin wall to about 1/1,000 of the inside horizontal cross-sectional area of the well. If the stilling well is served by a long connecting pipe, the diameter should be increased to produce the same effective dampening. Thin wall port diameters are about 1/30 the diameter of the wells, and connecting pipeline diameters are about 1/20 the diameter of the well. Thin wall port and connecting pipe diameters for different sized stilling wells for full dampening are tabulated below:

Table 6-1. Stilling well dimensions for full dampening

| Stilling well size | Thin through walls or short inlet pipes Diameter (in) | Connecting pipes 20 to 30 ft long diameter (in) |
|---|---|---|
| 12-in diameter | 1/2 | 1/2 |
| 16-in diameter | 1/2 | 3/4 |
| 20-in diameter | 5/8 | 3/4 |
| 24-in diameter | 3/4 | 1 |
| 30-in diameter | 1 | 1-1/2 |
| 36-in diameter | 1-1/4 | 2 |
| 3- by 3-ft square | 1-1/4 | 2 |
| 3- by 4-ft rectangular | 1-1/2 | 3 |
| 4- by 5-ft rectangular | 2 | 4 |

These table dimensions are used for connecting reservoirs and flumes where head remains relatively steady during reading and lag time is unimportant.

Frequently, for actively changing discharge systems or very remote wells, connecting pipes must be large enough to allow recorder floats to respond quickly and to follow the water level changes. Usually, this pipe diameter is about 1/10 the diameter of the stilling well. Also, the connecting pipe can be oversized, and a gate valve that has the same head loss for flow in both directions can be provided for throttling. The gate valve allows throttling to the required amount of dampening. However, the piping system from the inside wall of the flume channel to the inside wall of the well must have the same form and friction losses for pulses of flow in both directions. The gate valve must be located so that a distance of at least 20 pipe diameters exists on both sides of the valve. The gate valve should be centered.

If required, the gate valve could be opened fully for cleaning or to closely follow continually changing water level, or the valve could be throttled to prevent wide oscillation of ink pens. The pipe connection to the stilling well wall and flow channel wall should be perpendicular and carefully cut flush with the inside walls of the well and flume flow channel. Otherwise, the translocated water surface elevation in the well can deviate considerably from the actual mean elevation in the flume because of velocity impact and unbalanced head losses.

The size of the stilling well depends on the method used to measure the head. The diameter, if circular shaped, could range from a recommended minimum size of 4 in for hand-inserted dipsticks to 18 in to accommodate larger diameter floats. Wells may be much larger to provide access for cleaning or to make the reading of wall attached staff gages at sight angles at least as flat as 30 degrees. An overly steep sight angle will hinder accurate reading of water surface elevation on the staff gradations. It is recommended that well walls have a 2-in clearance from floats used with recorders. Weights should have adequate clearance from well walls.

A stilling well may need to house the float and recorder system or other surface detecting equipment. The wells may need to be tall enough to provide convenient access to recorders for reading, reference setting, and maintenance. The wells may need to be tall enough to keep counterbalance weights from interfering with float movement.

Before making a measurement, the wells should be flushed with fresh water to be sure they are free of sediment, foreign material, or blockages, which could cause erroneous head readings. Recording equipment should be checked and serviced regularly. Cross checks should be made between the staff gages, hook gages, plumb bobs, recorder values, and any other discharge indicators to expose system errors. Thus, even when using stilling wells, staff gages should still be used on the inside walls of flumes for cross checking. Further details on stilling wells can be found in table 8.1 of chapter 8 (Bos et al., 1991; Brakensiek, 1979).

Figures 6-9 and 6-10 show designs of typical installations of a more permanent nature. Installation cost is an important consideration in the selection of a structure. Shelters often become attractive targets for firearms, so higher initial costs of permanent installations may be offset by savings in undamaged equipment and complete records. Figure 6-11 shows a current meter gaging station with cable, car, corrugated steel shelter house, and stilling well.

Figure 6-9 -- Stilling well and recorder house made of wood.

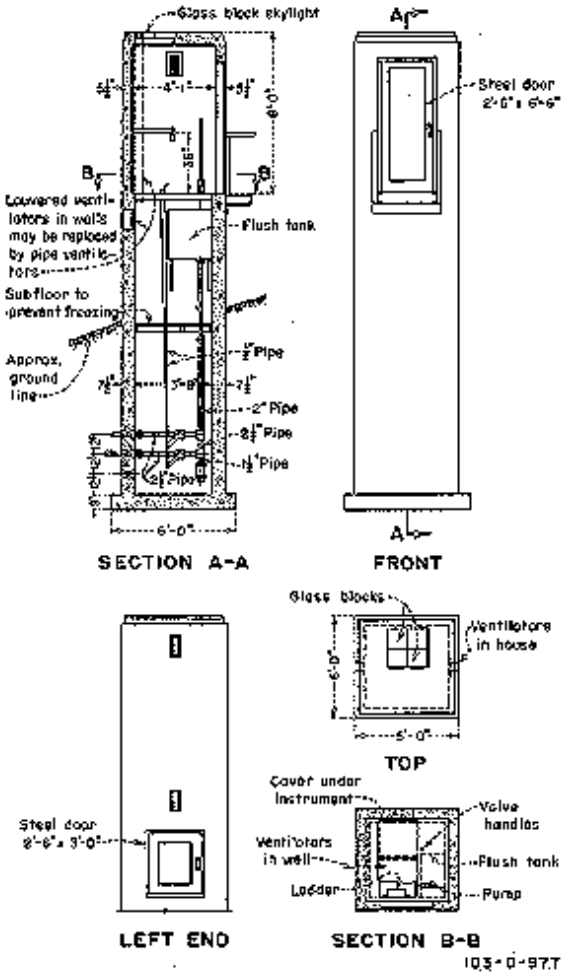


Figure 6-10 -- Plans for reinforced concrete recorder house and stilling well.

Figure 6-11 -- Current-meter gaging station with cable car, corrugated steel shelter house, and stilling well.

If a continuous record of water stage is required at a particular location, the cost of a concrete gage house and stilling well is usually justified. Figure 6-12 shows plans for a typical concrete structure used by the U.S. Geological Survey (Wahl et al., 1995). Considerable care must be used in construction to minimize settling or cracking of the concrete.

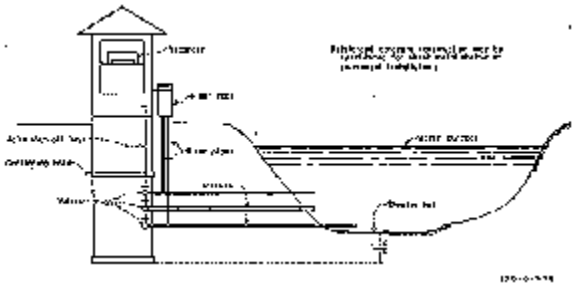

Figure 6-12 -- Plans for smooth and corrugated steel pipe recorder housing and stilling wells (sheet 1 of 2).

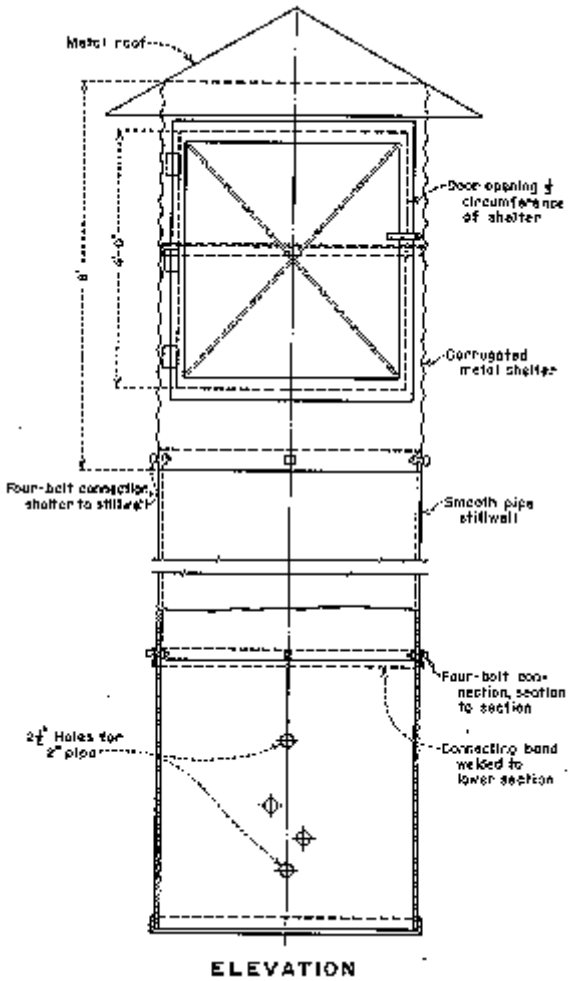


Figure 6-12 -- Plans for smooth and corrugated steel pipe recorder housing and stilling wells (sheet 2of 2).

The intake pipes on most stilling wells require occasional cleaning, especially on streams and canals carrying sediment. A flushing tank and pump cannot be justified on any but permanent installations (figure 6-9). The tank is filled with a hand pump, and a sudden release of the tank water will usually flush out the intake piping. For tightly clogged pipes or temporary or semi-permanent stilling wells, a sewer rod or "snake" provides the most satisfactory means for cleaning. The use of plugged crosses instead of tees and elbows in the piping system allows for the easy insertion of the cleaning rods or "snakes."

## 8. Setting the Datum

Setting the zero or datum elevation is one of the most important tasks when setting up a gaging station in a stream, river, or on a measurement structure. Care must be taken to ensure that the datum is below the zero flow level and that it can be independently located from points outside of the gaging structure. Datums are typically set using surveying techniques, often relating the datum elevation to mean sea level. A staff gage is usually located nearby to verify that the gaging station is operating correctly. Periodic checks on the datum elevation should be performed to ensure that no movement or settling of the stilling well or structure has occurred.

Erroneous readings from a gaging station are many times directly related to the setting or shifting of the datum.

## 9. Operation, Maintenance, and Care of Water-Stage Recorders

Standard procedures for operation of water-stage recorders should include verifying correct operation of the type of recorder present, checking that water elevations inside and outside of the stilling well match, inspecting and cleaning the intake pipe to the stilling well, and verifying that clocks (if so equipped) are operating properly. Inspections at regular, short intervals are generally required to keep breaks in data at a minimum. Persons installing and servicing water-stage recorders should follow manufacturers' recommended instructions for that particular instrument. These instructions should be placed conspicuously inside the instrument case or shelter.

Recorder enclosures should be well ventilated to prevent excessive humidity from affecting operation. Moist air can be excluded from the recorder by a partition over the stilling well. Instrumentation for detecting and correcting errors caused by high humidity is available if necessary.

Condensation within the recorder cover and metal shelters can be alleviated by gluing or spraying a resistant coating (such as cork) inside of each. Silica gel can be used as a desiccator, but it must be replaced occasionally or the moisture must be removed from the gel by heating in an oven at 300 degrees Fahrenheit.

The well and shelter must be maintained in good condition, the intake pipes must be kept open, and the well must be protected from ice and drift. Freezing weather may require heating the well with an electric heater or a cluster of lights. A layer of low-freezing-point, environmentally safe oil in the float well equal to the greatest thickness of ice expected can also be effective. In the past, oils such as kerosene or fuel oil were used; however, because of the possibility of the oil spilling into the water supply, only nontoxic, environmentally safe oils should be considered for this use.

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# CHAPTER 7 - WEIRS

## 1. Background

The weir is one of the oldest structures used to measure the flow of water in open channels. Several rating equations were developed for standard rectangular contracted weirs by different investigators. Generally, the data of each investigator are within ±1.5 to ±2.5 percent with respect to their individual equations, but comparisons of the various equations differ as much as several percent (King and Brater, 1976; Ackers et al., 1978).

In the past, user organizations selected an equation, called it standard, and specified construction requirements and limitations of use. However, Kindsvater and Carter (1959) developed an improved method for computing rates of flow through rectangular, thin-plate weirs. Their method also applies to fully side suppressed, partially contracted, and fully contracted rectangular weirs. Kulin and Compton (1975) discuss the method and equation for rating fully contracted V-notch weirs with any angle between 25 degrees and 100 degrees. This method also rates partially contracted 90-degree, V-notch weirs. Sections 6 and 7 give references and discuss these improved rating methods in more detail.

The Kindsvater approach accounts for velocity of approach effects and the accompanying variation of discharge coefficient caused by changes of effective width and head. This method is preferred for calibrating or rating rectangular and triangular weirs. Also, this method will correct for excess approach velocity in standard weirs. Thus, this newer approach will accurately recalibrate some of the older weirs that are no longer operating as standard, as well as some that never were standard.

The previous editions of this manual presented considerably less accurate methods to correct for velocity of approach, all of which assumed that all the correction was accountable as a head adjustment alone. The Kindsvater relationships clearly show the defect of this assumption. Velocity of approach affects the effective crest length and the effective contraction coefficient, as well as the effective measuring head, all of which are accounted for in the Kindsvater approach. Thus, the older methods for correcting for velocity of approach are not contained in this edition of the manual.

## 2. Definition of Weirs

A **measuring weir** is simply an overflow structure built perpendicular to an open channel axis to measure the rate of flow of water. Inspecting and checking the critical parts of weir structures for degradation and improper operation are easy.

A properly built and operated weir of a given shape has a unique depth of water at the measuring station in the upstream pool for each discharge. Thus, weirs can be rated with respect to an upstream head relative to the crest elevation versus discharge, and equations or tables which apply to the particular shape and size weir can be generated. The crest overflow shape governs how the discharge varies with head measurement.

## 3. Weir Nomenclature and Classification

The overflow section shape cut with a sharp upstream corner into a thin plate is the weir **notch**, sometimes called the **overflow section**. If the notch plate is mounted on the supporting bulkhead such that the water does not contact or cling to the downstream weir plate or supporting bulkhead, but springs clear, the weir is a **sharp-crested** or **thin-plate** weir.

A weir in the form of a relatively long raised channel control crest section is a **broad-crested** weir. The flow control section can have different shapes, such as triangular or circular. True broad-crested weir flow occurs when upstream head above the crest is between the limits of about 1/20 and 1/2 the crest length in the direction of flow. For example, a thick wall or a flat stoplog can act like a sharp-crested weir when the approach head is large enough that the flow springs from the upstream corner. If upstream head is small enough relative to the top profile length, the stoplog can act like a broad-crested weir. Wide, flat, triangular weirs exist that have wall sills with beveled corners. These **short-crested** weirs are in frequent use for hydrologic watershed research. Section 14(f) discusses these weirs.

Weirs are commonly named by the shape of their blade overflow opening shape (figure 7-1) for sharp-crested weirs or the flow control section shape for broad-crested weirs. Thus, weirs are partially classified as rectangular, trapezoidal, triangular, etc. In the case of sharp weirs, the triangular weir is also called a **V-notch** weir, and one kind of trapezoidal weir is the **Cipolletti** weir. In the case of rectangular or Cipolletti weirs, the bottom edge of the notch in the thin plate is the **crest**, and the side edges (which are vertical or flare up and outward) are the sides or ends (figure 7-1). The point of the triangle is the crest of a V-notch weir. The lowest elevation of the overflow opening of the sharp-crested weirs or the control channel of broad-crested weirs is the head measurement **zero reference** elevation.

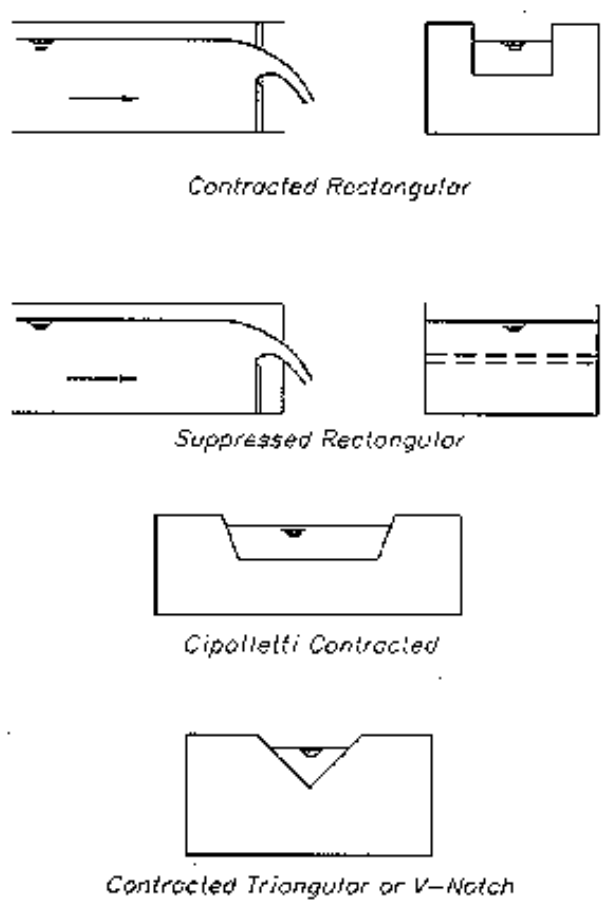



Figure 7-1 -- Different kinds of sharp-crested weirs.

When the distances from the sides of the weir notch to the sides of the weir pool are greater than two measurement heads, the water will flow relatively slowly along the bulkhead face toward the overflow opening. As the water from the sides of the channel nears the notch, it accelerates and has to turn to pass through the opening. This turning cannot occur instantaneously, so a curved flow path or **side contraction** results in which the water springs free to form a jet narrower than the overflow opening width.

Flow coming along the bottom of the weir pool and up a sufficiently high bulkhead and weir plate springs upward and forward in the curved, underside jet surface or **crest contraction**. The falling sheet of water springing from the weir plate is the **nappe**.

After passing the head measuring station or about a distance of two head measurements upstream from the overflow opening, the water surface drops more and more as flow approaches the crest. This continuing drop of water surface or **drawdown** results from the acceleration of the water as it approaches the weir. The drop in water surface between the measuring station and the notch is equal to the change of **velocity head**, or $\boldsymbol{V^2/2g}$, between these stations as explained in section 7 in chapter 2.

The term **vertical contraction** includes both crest contraction and drawdown at the weir plate. When approach conditions allow full contractions at the ends and at the bottom, the weir is a **contracted weir**. For **full contraction**, the ends of the weir should not be closer to the sides and bottom of the approach channel than a specified distance.

Full side contractions on a thin-plate Cipolletti weir are shown on figure 7-2. If the specified distances are not met, then the weir is **partially contracted**.

Figure 7-2 -- Cipolletti weir operating with full contractions at the end and on the crest.

When sides of the flow channel act as the ends of a rectangular weir, no side contraction exists, and the nappe does not contract from the width of the channel. This type of weir is a **suppressed weir** and is shown on figures 7-1 and 7-3. To reproduce the full vertical rating, contraction of the suppressed weir that existed during its calibration requires full air ventilation under the nappe and the proper crest elevation.

Figure 7-3 -- Suppressed rectangular weir at a canal drop.

**Velocity of approach** is equal to the discharge divided by the flow section area at the head measuring station. Velocity of approach is important because it can change weir calibrations by effectively reducing the crest length and/or measuring head. In addition, a variable discharge coefficient results as increasing velocity changes the curvature of flow springing from the weir plates.

**Free flow** occurs when a thin-plate weir allows free access of air under the falling jet sheet or **nappe**. With free flow, head measurements at one upstream location determine discharge with knowledge of weir size and shape.

Downstream water rising above the weir crest elevation produces a **submerged weir** condition. When the downstream water surface is near or above the crest elevation of a sharp-crested weir, accuracy of measurement should not be expected. "Submerged flow correction methods" or "submerged calibrations" only produce estimates of discharge.

The use of a submerged weir as a water measurement device is not good practice and should only be done as a temporary, emergency procedure. Because of the large loss of accuracy, designing thin-plate weirs for submergence should be deliberately avoided. However, submergence may happen unexpectedly or may be temporarily necessary. In such cases, flow can be estimated using special techniques discussed in Skogerbe et al. (1967), but not on a long-term basis.

A **weir discharge measurement** consists of measuring depth or **head** relative to the crest at the proper upstream location in the weir pool, and then using a table or equation for the specific kind and size of weir to determine discharge. Commonly, a **staff gage**, described in chapter 6, having a graduated scale with the zero placed at the same elevation as the weir crest, measures head. Putting staff gages in stilling wells dampens wave disturbances when reading head. Using vernier hook point gages in stilling wells produces much greater accuracy than staff gages. These staff gages must be zero referenced to the weir crest elevation. Section 7 in chapter 8 provides more information regarding measuring head and related errors.

## 4. Different Sharp or Thin-Plate Weir Types

The types of traditional fully contracted weirs commonly used and considered standard for measuring irrigation water are:

- Rectangular weirs
- V-notch weirs from 25 degrees to 100 degrees
- Cipolletti (trapezoidal) weirs

Common partially contracted weirs are:

- Partially contracted rectangular weirs
- Partially contracted 90-degree V-notch weirs

Equations for weirs determine discharge values used to produce tables for field use. However, users and designers must pay due respect to specific limits such as calibration range, velocity of approach, setting requirements, dimension tolerances, and operating techniques. A few weir tables are extended by measured data outside of equation limits.

## 5. Conditions Needed for All Types of Sharp-Crested Weirs

Certain requirements are common to all sharp-crested weir measurement structures. Extensive experiments on weirs and long-term experience show that the following conditions are necessary for accurate measurement of flow (see also, Fig. 5-2):

(a) The upstream face of the weir plates and bulkhead should be plumb, smooth, and normal to the axis of the channel.

(b) The entire crest should be level for rectangular and trapezoidal shapes, and the bisector of V-notch angles should be plumb.

(c) The edges of the weir opening should be located in one plane, and the corners should have proper specified angles.

(d) The top thickness of the crest and side plates should be between 0.03 and 0.08 inch (in).

(e) All weir plates should have the same thickness for the entire boundary of the overflow crest. If the plates are thicker than specified in condition (d), the plate edges shall be reduced to the required thickness by chamfering the downstream edge of the crest and sides to an angle of at least 45 degrees; 60 degrees is highly recommended for a V-notch to help prevent water from clinging to the downstream face of the weir.

(f) The upstream edges of the weir opening plates must be straight and sharp. Edges of plates require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasive cloth or paper. Avoid knife edges because they are a safety hazard and damage easily.

(g) The bottom edge plates and fastener projection upstream should be located a distance of at least two measuring heads from the crest. If not, the plates must be inset flush with the upstream face of the supporting bulkhead, and the fasteners must be countersunk on the upstream pool side. Upstream faces of the plates must be free of grease and oil.

(h) The overflow sheet or nappe should touch only the upstream faces of the crest and side plates.

(i) Maximum downstream water surface level should be at least 0.2 foot (ft) below crest elevation. However, when measuring close to the crest, frequent observations are necessary to verify that the nappe is continually ventilated without waves periodically filling the under nappe cavity.

(j) To prevent the nappe from clinging to the downstream face of the weir, the head measurement should be greater than 0.2 ft. Conditions (d), (e), and (f) also help to prevent clinging. If measurements must be made at heads approaching this value for substantial periods, operators must ensure the head measuring system has commensurate precision with respect to needed accuracy and must continually check for clinging.

(k) The measurement of head on the weir is the difference in elevation between the crest and the water surface at a point located upstream from the weir a distance of at least four times the maximum head on the crest.

(l) Keep the approach to the weir crest free of sediment deposits. All the approach flow conditions as discussed in section 17 of chapter 2 of this manual apply.

Additional requirements and limitations specific to different types of weirs follow.

## 6. Partially and Fully Contracted Rectangular Weirs

Kindsvater and Carter (1959) developed an improved method for calibration rating of rectangular thin-plate weirs. The method applies to both fully and partially contracted rectangular weirs. The method also rates the equivalent of a suppressed weir. The capability of rating partially contracted weirs provides design versatility, especially in selection of low crest heights to reduce head drop and side contraction needed to measure flow. Thus, these weirs can reduce head loss and conserve delivery head. These weirs have coefficients that vary with measuring head as well as geometry. The resulting calibrations are at least as accurate as the equations and tables for "standard" fully contracted weirs. Weir use and dimension limits are defined by the curves for determining the calibration ratings.

The basic equation for the Kindsvater-Carter method is:

$$Q = C_e L_e h_{1e}^{3/2} \quad (7\text{-}1)$$

where:

$Q$ = discharge, cubic feet per second ($ft^3/s$)
$e$ = a subscript denoting "effective"
$C_e$ = effective coefficient of discharge, $ft^{1/2}/s$
$L_e = L + k_b$
$h_{1e} = h_1 + k_h$

In these relationships:

$k_b$ = a correction factor to obtain effective weir length
$L$ = measured length of weir crest
$B$ = average width of approach channel, ft
$h_1$ = head measured above the weir crest, ft
$k_h$ = a correction factor with a value of 0.003 ft

The factor $k_b$ changes with different ratios of crest length, $L$, to average width of approach channel, $B$. Values of $k_b$ for ratios of $L/B$ from 0 to 1 are given on figure 7-4. The factor $k_h$ is a constant value equal to 0.003 ft.

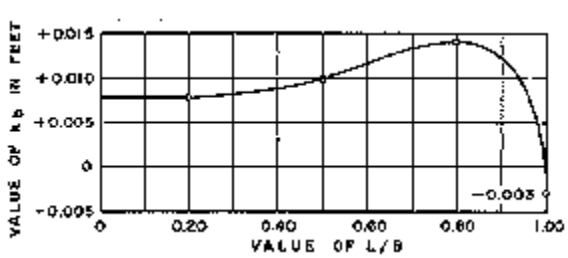



Figure 7-4 -- Value of width-adjustment factor from Georgia Institute of Technology tests (courtesy of American Civil Society of Engineers).

The effective coefficient of discharge, $C_e$, includes effects of relative depth and relative width of the approach channel. Thus, $C_e$ is a function of $h_1/p$ and $L/B$, and values of $C_e$ may be obtained from the family of curves presented on figure 7-5. $p$ is the vertical distance from the weir crest to the approach pool invert.

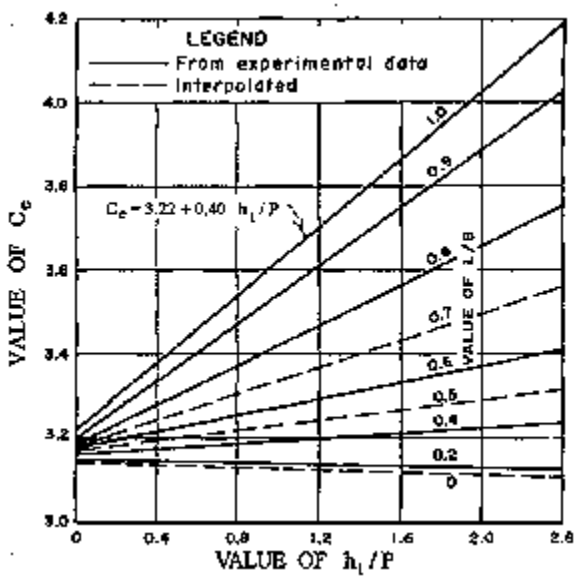



Figure 7-5 -- Effective coefficient of discharge, $C_e$, as a function of $L/B$ and $h_1/p$, from Georgia Institute of Technology tests (courtesy of American Civil Society of Engineers).

The straight lines on figure 7-5 have the equation form:

$$C_e = C_1\ (h_1/p) + C_2 \quad (7\text{-}2)$$

where:

$C_e$ = effective coefficient of discharge
$C_1$ = equation coefficient
$h_1$ = head on the weir (ft)
$p$ = height of crest above approach invert (ft)
$C_2$ = equation constant

For convenience, the coefficients and constants for straight lines of each $L/B$ on figure 7-5 are given in the following tabulation for interpolation:

| Table 7-1. Coefficient and constants used in determining the effective coefficient of discharge for the Kindsvater-Carter method | | |
|---|---|---|
| *L/B* | $C_1$ | $C_2$ |
| 0.2 | -0.0087 | 3.152 |
| 0.4 | 0.0317 | 3.164 |
| 0.5 | 0.0612 | 3.173 |
| 0.6 | 0.0995 | 3.178 |
| 0.7 | 0.1602 | 3.182 |
| 0.8 | 0.2376 | 3.189 |
| 0.9 | 0.3447 | 3.205 |
| 1.0 | 0.4000 | 3.220 |

The straightforward, comprehensive, and accurate Kindsvater-Carter method of determining discharges for rectangular weirs is well suited for discharge rating use. It is particularly useful for installations where full crest contractions or full end contractions are difficult to achieve.

Traditional rectangular weirs that do not meet crest height limits or that are using the older methods of correcting for velocity of approach should be recalibrated using the Kindsvater-Carter method. Weirs that fall out of the limits of the Kindsvater-Carter rating curves need replacement or field calibration by thorough current metering.

Limits on usage and dimensions are:

- The calibration relationships were developed with rectangular approach flow and head measurement sections for these weirs. For applications with other flow section shapes, the average width of the flow section for each $h_1$ is used as $B$ to calculate discharges.
- The crest length, $L$, should be at least 6 in.
- The crest height, $p$, should be at least 4 in.
- Like all weirs used for head measurement, $h_1$ should be at least 0.2 ft .
- Values of $h_1/p$ should be less than 2.4.
- All the requirements in section 5 apply.
- The downstream water surface elevation should be at least 2 in below the crest.
- All the approach flow conditions in chapter 2 apply .

## 7. V-Notch Weirs of Any Angle

The Kindsvater-Shen relationship can be used for fully contracted notches of any angle between 25 degrees and 100 degrees (Kulin and Compton, 1975). The equation which includes the angle $\theta$ as a variable is written as:

$$Q = 4.28\, C_e \tan\left(\frac{\theta}{2}\right) h_{1e}^{5/2} \quad (7\text{-}3)$$

where:

$Q$ = discharge over weir in $ft^3/s$

$C_e$ = effective discharge coefficient

$h_1$ = head on the weir in ft

$h_{1e} = h_1 + k_h$

$\theta$ = angle of V-notch

The head correction factor, $k_h$, is a function of $\theta$ (figure 7-6a). However, for fully contracted traditional 90-degree V-notch weirs, equation 7-6 and the rating table discussed later produce comparable accuracy.

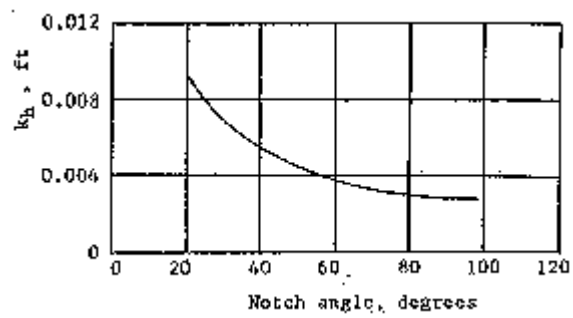



Figure 7-6a -- Head correction factor, $k_h$, for V-notches of any angle (courtesy of National Bureau of Standards, Kulin et al. [1975]).

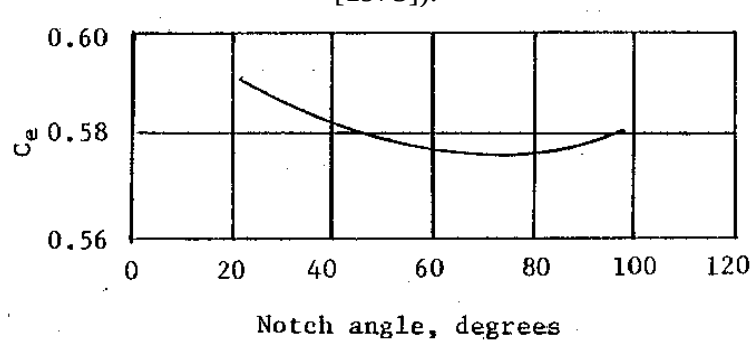



Figure 7-6b -- Effective coefficient, $C_e$, for fully contracted V-notches of any angle (courtesy of National Bureau of Standards, Kulin et al. [1975]).

For fully contracted V-notch weirs, the value of $k_h$ is related to $\theta$ as given on figure 7-6a, and values of $C_e$ are read from figure 7-6b. Partially contracted 90-degree V-notches only can be rated using figure 7-7 to obtain $C_e$ values. The calibration relationships were developed with rectangular approach flow and head measurement sections for these weirs. For applications with other flow section shapes, the average width of the flow section for each $h_1$ is used as $B$ to determine coefficients.

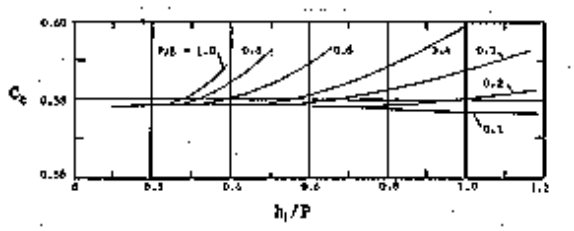



Figure 7-7 -- Effective coefficient, $C_e$, for partially contracted 90-degree V-notches (courtesy of National Bureau of Standards, Kulin et al. [1975]).

Bos (1989) and International Organization for Standardization (1983) explain and define limits basic to the use of these figures. Precautions and restrictions concerning the use of V-notch weirs are as follows:

(a) V-notch weirs should not be designed beyond the range of the parameters plotted on figures 7-6 and 7-7. Only the 90-degree V-notch weir can be made partially contracted through the use of figure 7-7.

(b) The water surface downstream from the weir should always remain at least 0.2 ft below the notch. Lower discharge readings should be rejected if the contraction is not springing underneath for the entire nappe length.

(c) The measuring head should be greater than 0.2 ft because precision of head measurement error is large relative to smaller head depths, and the nappe may cling to the weir plate.

(d) For the fully contracted V-notch, the maximum measuring head should be less than 1.25 ft.

(e) For the partially contracted V-notch, the maximum head should be less than 2 ft.

(f) For fully contracted V-notches, the $h_1/B$ ratio should be equal to or less than 0.2.

(g) For the partially contracted 90-degree notch, $h_1/B$ should be equal to or less than 0.4.

(h) The average width of the approach channel, $B$, should always be greater than 3 ft for the fully contracted V-notch.

(i) For the partially contracted 90-degree V-notch, the approach channel width should be greater than 2 ft.

(j) The V-notch of the weir should always be located at least 1.5 ft above the invert of the weir pool for fully contracted weirs.

(k) Only the 90-degree V-notch can be partially contracted, but the point of the notch must be located at least 4 in from the channel invert.

(l) All the requirements in section 5 apply.

(m)All the approach flow conditions in chapter 2 apply.

## 8. Some Traditional Standard Irrigation Weirs

In the past, user organizations selected specific equations from a choice of many, called them "standard," and specified requirements in construction and use to assure full contraction and nearly constant coefficients. Thus, equations and tables for "standard" weirs have strict limits and construction requirements, mainly in terms of the distance of the crest from the approach channel boundaries. In contrast, weir discharge calculated using Kindsvater methods will account for changes in velocity of approach caused by proximity of approach flow boundaries to crests. Thus, a weir designed with the Kindsvater methods can measure and deliver flow with less head loss than a similar "standard" weir mentioned above.

## 9. Standard Contracted Rectangular Weirs

The fully contracted rectangular weir (figure 7-1) is the most frequent standard weir used in irrigation. To be fully contracted, all overflow plate sides and ends must be located at least a distance of $2h_{1max}$ (two maximum measurement heads) from the approach flow boundaries. Head is measured at a distance of at least $4h_1$ from the weir.

### (a) Discharge Equation for Standard Fully Contracted Rectangular Weirs

The Francis (1883) equation is convenient for weirs operating under favorable prescribed conditions. The Francis equation is:

$$Q = 3.33h_1^{3/2}(L\text{-}0.2h_1) \quad (7\text{-}4)$$

where:

$Q$ = discharge in $ft^3/s$ neglecting velocity of approach
$L$ = the length of weir in ft
$h_1$ = head on the weir in ft

The Francis equation has a constant discharge coefficient which facilitates computations without the use of tables. However, the coefficient does not remain constant for a ratio of head-to-crest length greater than one-third, and the actual discharge exceeds that given by the equation. Francis' experiments were made on comparatively long weirs, most of them with a 10-ft crest and heads ranging from 0.4 ft to 1.6 ft. Thus, these equations apply particularly to such weirs. The Bureau of Reclamation (Reclamation) experiments on 6in, 1ft, and 2-ft weirs on the Boise Project in Idaho show that the equation also applies fairly well to shorter crest lengths, provided the head of water on the weir is not greater than about one-third the length of the weir.

### (b) Discharge of Standard Contracted Rectangular Weirs

Most of the discharges in tables A7-2 through A7-5[1]were calculated using equation 7-4.

[1] – The prefix “A” indicates that the tables(s) are located in the Appendix.

For most sizes of these weirs, the values of discharge in table A7-2 end when the measurement head reaches one-third of the crest length, the limit of the equation. Reclamation, Boise Project, calibrated weirs to extend the head range of contracted rectangular weirs. Their calibrations are included in the table for the 6-in, 1-ft, and 2-ft crest lengths and are indicated by shaded entries in the tables.

**(c) Limits of Standard Fully Contracted Rectangular Weir**

Equation 7-4 should not be used beyond the maximum discharges shown in table A7-2 or for measuring heads greater than one-third the crest lengths. All the requirements in section 5 apply. All the approach flow conditions in chapter 2 apply. The crest height, *p*, should be at least equal to $2h_{1max}$. The side contractions should also be located a distance of $2h_{1max}$ from the approach channel boundary.

Head is measured upstream at a distance of at least $4h_{1max}$ from the weir crest. Should any of these criteria be violated, discharge rating using the Kindsvater-Carter method is still possible.

## 10. Standard Suppressed Rectangular Weir

A standard suppressed rectangular weir has a horizontal crest that crosses the full channel width. The elevation of the crest is high enough to assure full bottom crest contraction of the nappe. The vertical sidewalls of the approach channel continue downstream past the weir plate, preventing side contraction or lateral expansion of the overflow jet.

Special care must be taken with suppressed weirs to secure proper aeration beneath the overflowing sheet at the crest. Aeration is usually accomplished by placing vents on both sides of the weir box under the nappe (figure 7-8).

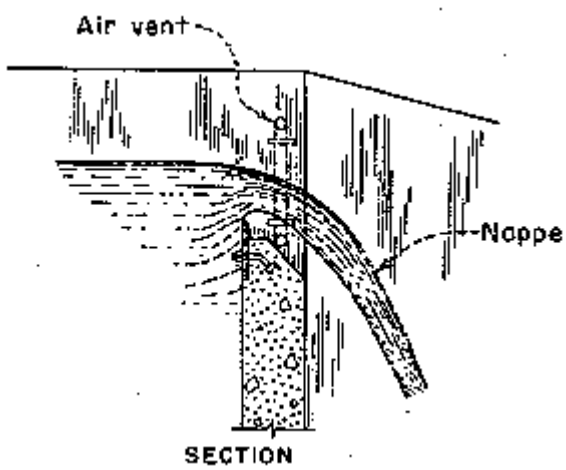



Figure 7-8 -- Section through suppressed weir with air vent in wall.

Other conditions for accuracy of measurement for this type of weir are identical to those of the contracted rectangular weir, except those relating to side contraction and the crest height. The crest height should be equal to at least $3h_{1max}$. A suppressed weir in a flume drop is illustrated on figure 7-3.

### (a) Equation for Standard Suppressed Rectangular Weirs With Full Bottom Contraction

The Francis equation for the standard suppressed rectangular weir (figure 7-1) is:

$$Q = 3.33\ L\ h_1^{3/2} \quad (7\text{-}5)$$

The variables in this equation have the same significance as in the equations for contracted rectangular weirs discussed in section 9. Francis obtained the coefficient of discharge from the same general set of experiments as those stated for the contracted rectangular weir. No extensive tests have been made to determine the applicability of these equations to weirs less than 4 ft in length. Similar to the contracted rectangular weir, heads less than 0.2 ft do not give accurate flow readings because the nappe of water going over the crest may not spring free of the crest. Also, at smaller head depths, heads that are large, relative to precision of head measurement, cannot be measured. The equation should not be used to compute discharges for heads less than 0.2 ft or greater than one-third the crest length.

### (b) Discharge of Standard Suppressed Rectangular Weirs

Table A7-3 contains discharges in cubic feet per second for full bottom contracted suppressed rectangular weirs. These discharges were computed from the Francis equation for lengths and heads commonly used in measuring small quantities of irrigation water.

### (c) Limits of Standard Suppressed Rectangular Weirs

Equation 7-5 must not be used beyond the maximum discharges shown in table A7-3 or for measuring heads greater than one-third the crest lengths. All the requirements in section 5 apply. All the approach flow conditions in chapter 2 apply. The crest height, $p$, should be at least equal to $3h_{1max}$ (three maximum heads). Head is measured at an upstream distance of at least $4h_{1max}$ from the weir. The sidewalls must extend at least a distance of $0.3h_{1max}$ down-stream from the crest, and the overflow jet must be adequately ventilated to the atmosphere.

However, the Kindsvater-Carter method discussed in section 6 is ideally suited for use with suppressed rectangular weirs. This method provides the capability of using partially bottom contracted suppressed weirs and automatically corrects for velocity of approach. This method is recommended for general use and is discussed in section 6. This method provides the opportunity to conserve delivery head by using crest heights less than $3h_{1max}$, within limits.

## 11. Fully Contracted Standard 90-Degree V-Notch Weir

The triangular or V-notch, thin-plate weir is an accurate flow measuring device particularly suited for small flows.

### (a) Traditional Equation for Standard 90-Degree Contracted V-Notch Weirs

The Cone equation is commonly used for 90degree V-notch weirs. This equation is reliable for small, fully contracted weirs generally encountered in measuring water for irrigation.

The Cone equation is:

$$Q = 2.49\ h_1^{2.48} \quad (7\text{-}6)$$

where:

$Q$ = discharge over weir in $ft^3/s$
$h_1$ = head on the weir in ft

**(b) Discharge of 90-Degree Contracted V-Notch Weirs**

Table A7-4 contains discharges in cubic feet per second for the standard 90-degree, fully contracted V-notch weir (figure 7-1) from the Cone equation for a range of heads ordinarily used in measuring small flows. To be fully contracted, all the overflow plate edges and the point of the notch must be located at least a distance of $2h_{1max}$ from the approach flow boundaries.

**(c) Limits of 90-Degree Contracted V-Notch Weirs**

The crest of the weir consists of a thin plate beveled 45 degrees or greater from the vertical to produce an edge no thicker than 0.08 in. If heads will be frequently near the 0.2-ft lower limit, then the beveling should be 60 degrees. This weir operates as a fully contracted weir, and all conditions for accuracy stated for the standard contracted rectangular weir apply. To be fully contracted, all the overflow plate edges and the point of the notch must be located at least a distance of two measuring heads from the approach flow boundaries. The head measuring station is located a distance of at least four measuring heads upstream from the weir crest. This 90degree V-notch weir should only be used for discharges between 0.05 and 4.25 $ft^3/s$ and should not be used consistently near the high end of this range because a 2-ft fully contracted rectangular weir will deliver the same flow at 40 percent less head for the same approach channel width. All the requirements of section 5 apply. All the approach flow conditions in chapter 2 apply.

The use of the Kindsvater-Shen method for rating V-notched weirs can considerably extend the limitations described above.

## 12. Cipolletti Weir

A standard Cipolletti weir is trapezoidal in shape. The crest and sides of the weir plate are placed far enough from the bottom and sides of the approach channel to produce full contraction. The sides incline outwardly at a slope of 1 horizontal to 4 vertical. A Cipolletti weir is shown on figures 7-1 and 7-9.

Figure 7-9 -- Cipolletti weir with a well-type head-measuring station.

**(a) Equation for Cipolletti Weirs**

The Cipolletti weir is a contracted weir. However, its discharge calibration resembles that of a suppressed weir because the effects of side contractions are intentionally compensated for by sloping the sides of the weir plate outward. Thus, discharge calibrations are nearly equivalent to suppressed weirs of the same crest lengths.

The Cipolletti equation, neglecting velocity of approach, is:

$$Q = 3.367\ L\ h_1^{3/2} \quad (7\text{-}7)$$

where:

$L$ = length of weir crest in ft
$h_1$ = head on weir crest in ft

The accuracy of measurements obtained by use of Cipolletti weirs and the above equation is considerably less than that obtainable with suppressed rectangular or V-notch weirs (Shen, 1959). The accuracy of the discharge coefficient is $\pm$5 percent.

**(b) Discharge of Cipolletti Weirs**

Table A7-5 contains discharges in cubic feet per second for standard Cipolletti weirs neglecting velocity of approach, for heads and lengths of weirs generally used in measuring small quantities of irrigation water. For the 0.5-ft, 1ft, 2-ft, and 3-ft weirs, and heads greater than one-third the crest length, the discharges have been taken from experiments performed at the Boise Project. All other discharges were computed from the Cipolletti equation. The data in the table may be considered accurate to $\pm$5 percent for weirs of the above listed lengths. The same accuracy applies to weirs of other lengths which are listed on the table with heads not over one-third the crest length.

**(c) Limits of Cipolletti Weirs**

All conditions for accuracy stated for the standard contracted rectangular weir apply to the Cipolletti weir. The height of the weir crest above the bottom of the approach channel should be at least twice the maximum head over the crest, and the distances from the sides of the notch to the sides of the channel should also be at least twice the maximum head. This weir should not be used for heads less than about 0.2 ft or for heads greater than one-third the crest length unless calibrations exist beyond this range for specific size weirs. The head is measured at least a distance of four measuring heads upstream from the crest.

All the requirements in section 5 apply. All the approach flow conditions in chapter 2 apply.

## 13. Special Weirs

**(a) Compound Weirs**

Unusual situations may require special weirs. For example, a V-notch weir might easily handle the normal range of discharges at a structure; but occasionally, much larger flows would require a rectangular weir. A compound weir, consisting of a rectangular notch with a V-notch cut into the center of the crest, might be used in this situation. A weir of this type is shown on figure 7-10.

Figure 7-10 -- Compound weir with 90-degree notch and suppressed rectangular crest used by U.S. Forest Service.

The compound weir, as described, has a disadvantage. When the discharge begins to exceed the capacity of the V-notch, thin sheets of water will begin to pass over the wide horizontal crests. This overflow causes a discontinuity in the discharge curve (Bergmann, 1963). Therefore, the size and elevation of the V-notch should be selected so that discharge measurements in the transition range will be those of minimum importance.

Determining discharges over compound weirs has not been fully investigated either in the laboratory or in the field. However, an equation has been developed on the basis of limited laboratory tests on a 1-ft-deep, 90-degree V-notch cut into rectangular notches 2, 4, and 6 ft wide to produce horizontal extensions of L=0, L=2, and L=4 ft, respectively (Bergmann, 1963). The weirs were fully contracted, and heads up to 2.8 ft above the notch point were used. The equation is as follows:

$$Q = 3.9h_1^{1.72} - 1.5 + 3.3Lh_2^{1.5} \quad (7\text{-}8)$$

where:

$Q$ = discharge in $ft^3/s$

$h_1$ = head above the point of the V-notch in ft

$L$ = combined length of the horizontal portions of the weir in ft

$h_2$ = head above the horizontal crest in ft

When h1 is 1 ft or less, the flow is confined to only the V-notch portion of the weir, and the standard V-notch weir equation 7-6 is used.

Further testing is needed to confirm this equation before it is used for weirs beyond the sizes for which it was developed.

**(b) Short Weir Box Turnouts**

A simple and inexpensive irrigation turnout structure regulates rate of flow and provides a relatively quiet headwater pool in a short approach distance from canal pipe outlets into weir boxes. These measurement structures overcome defects in approach conditions not accepted by standard weir pools by using a combination of baffles and a shelf type gage stilling basin. This concept was first developed on the Yakima Project in Washington using Cipolletti weirs. One of the structures used for discharges up to about 1.5 $ft^3/s$ is shown on figure 7-11. This weir box was used to measure flows where the head differences between the canal water surface and the weir pool surface were as much as 4 ft. Discharges were determined by using the standard Cipolletti weir calibration in table A7-5.

Figure 7-11 -- Weir box turnout with Cipolletti weir.

Simmons and Case (1954) and Palde (1972) studied this concept further to improve approach flow velocity distribution, still the water surface at the gages, and increase discharge measuring capacity, accuracy, and head differential between the supply canal head elevation and weir pool. To achieve narrower box widths, suppressed rectangular weirs were installed for full size laboratory tests. These tests developed system arrangements, box and weir dimensions, and stilling baffle arrangements (figures 7-12c and 7-13) and calibrations for discharges up to 12 $ft^3/s$ and for canal and weir pool head differences up to 6 ft. Suppressed rectangular weirs 3 and 4 ft long were used rather than Cipolletti weirs to simplify the structure and increase capacity.

To meet three different conditions likely to be encountered in the field, the three designs for 5.0-$ft^3$/s maximum measuring capacity shown on figure 7-12 were prepared.

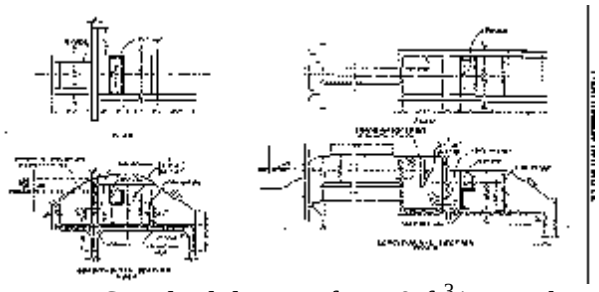


Figure 7-12a -- Standard designs for 5.0-$ft^3$/s weir box turnout (sheet 1 of 3).

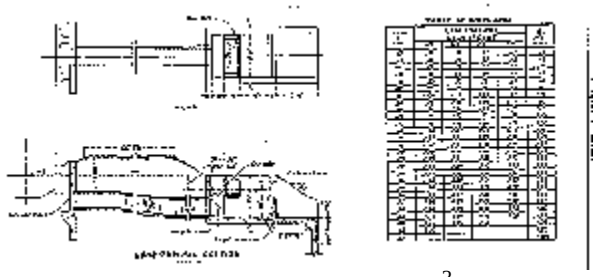


Figure 7-12b -- Standard designs for 5.0-$ft^3$/s weir box turnout (sheet 2 of 3).

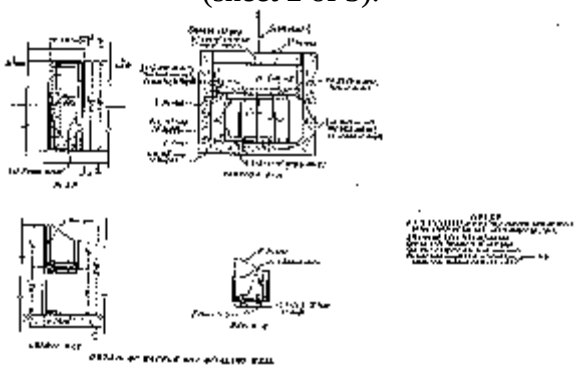


Figure 7-12c -- Standard designs for 5.0-$ft^3$/s weir box turnout (sheet 3 of 3).

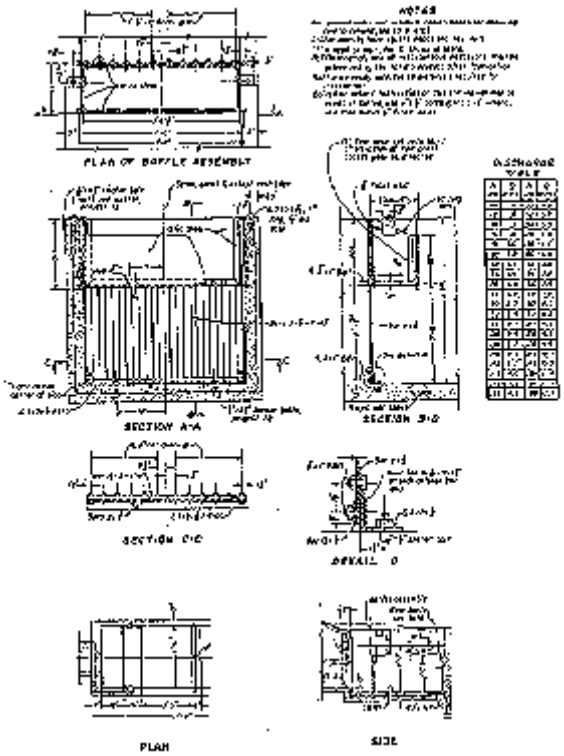



Figure 7-13 -- Baffle arrangement and rating table for 12-ft$^3$/s weir box turnout.

The type 1 turnout weir box (figure 7-12a) is placed immediately adjacent to the supply canal with the turnout inlet recessed into the side of the canal. The type 2 turnout (figure 7-12a) is placed farther from the canal. Maximum discharge for turnout types 1 and 2 is 5.0 ft$^3$/s with a maximum head drop between the canal water surface and the weir pool surface of 3.0 ft. The type 3 (figure 7-12b) turnout is designed for 5.0 ft$^3$/s with a head drop of up to 6.0 ft. Instead of having the square bottom gate at the weir pool headwall, the gate is moved to the canal pipeline inlet.

Discharges through types 1 and 2 weir box turnouts are determined by measuring the weir pool head, $h_1$, on the weir gage provided just above the baffles and wave suppressor, measuring the head drop, $Y$, using the weir gages both upstream and downstream from the gate, and using the table of discharge on figure 7-12b. Both weir gages should be set at the same elevation. Discharges through type 3 turnouts are determined by the single measurement of weir pool head, $h_1$, and the table of discharge on figure 7-12b, depending on maximum design discharge measurement capacity.

The baffle arrangement and rating table for the 12-ft$^3$/s maximum capacity weir box developed by Palde (1972), shown on figure 7-13, incorporates a suppressed weir. This weir box is installed in gate, pipe, and box configuration similar to the smaller discharge capacity weir box in the type 3 turnout using the dimensions and baffle arrangement shown on figure 7-12b, which also shows the calibration chart.

All four designs are arranged to permit easy construction as in-place structures or as precast units. All use reinforced concrete for the main box and headwalls and use separate, easily replaced, wooden or metal baffle assemblies in the weir pool.

A space is left open at the upstream face of the baffle so any accumulations of weeds and debris can be removed. Design and construction details for the 5- and 12-$ft^3/s$ weir boxes are given in Aisenbrey et al. (1978).

**(c) Broad-Crested Weirs**

A broad-crested weir is a raised overflow crest, commonly a flat horizontal block. However, a variety of crest shapes can be used to establish flow control in boundaries that are horizontal in the direction of flow. Broad-crested weirs often have special approach transitions ahead of and up to the crest surface, such as nose treatments like ramps and rounded corners. Crest length in the direction of flow is generally long enough, relative to the measuring head, to make the effect of flow curvature insignificant and short enough to prevent friction from controlling depths. These weirs can be computer calibrated when flow curvature is insignificant.

Broad-crested weirs are about as accurate as sharp thin-plate

weirs and also have some advantages, such as:

- Broad-crested weirs can be computer calibrated.
- A broad-crested weir could be considered if rusting, impact, abrasion, etc., might cause maintenance problems with a flat-plate weir.
- Specially shaped weirs can be designed to fit more complicated channel cross sections better, and the shape control section can be selected to provide special discharge ranging and variation needs with respect to head.
- Some forms of broad-crested weirs pass floating debris and sediment better than sharp thin-plate weirs, especially those with round nose or ramp approach transitions.
- Submergence does not affect broad-crested weirs up to about 80 percent with a vertical downstream drop and up to about 90 percent with sloped downstream transitions.

No clear-cut classification distinction or hydraulic difference exists between broad-crested weirs and long-throated flumes. Computer calibrations of broad-crested weirs use the principles and theories that are used for long-throated flumes. Thus, broad-crested weirs such as flat crests across trapezoidal and circular flow channels are covered in chapter 8.

**(d) Movable Weirs and Adjustable Weirs**

Movable weirs are weir assemblies mounted in metal or timber frames that can be moved from one structure to another. The frames fit freely into slots provided in the structures and are not fastened in place. Adjustable weir assemblies are mounted in metal frames permanently fastened to the structures. The weir blades in both the movable and the fixed frames can be raised or lowered to the desired elevations, usually by threaded stems with handwheels.

An adjustable weir used at a fixed frame location is shown on figure 7-14. A sufficiently large pool must be provided upstream from the weir to slow and quiet the flow before it reaches and overflows the weir blade. A fixed head gage is not recommended for flow measurement if the weir is to be moved up or down because the gage zero will not coincide with the weir crest elevation.

Figure 7-14 -- Adjustable Cipolletti weir in a division box.

A form of a movable crest broad-crested weir is discussed in Bos (1984) and Bos et al. (1991). This publication also shows how movable weirs can be arranged to provide shutoff and sediment sluicing provided enough channel drop is available.

**(e) Flow Measurement Using an Overshot Gate**

Overshot gates (figure 7-15), or leaf gates as they are sometimes called, are increasingly used for controlling water levels in open channels. This application is used partly because of the ability of the gates to handle flow surges with limited depth changes and the ease with which operators can understand their hydraulic behavior. With an overshot gate, a 6-in drop in the gate height corresponds closely to a 6-in drop in upstream water level. The main purpose of most main canal control gates is to maintain a constant water depth for turnouts located upstream. Thus, the turnouts will deliver water at nearly constant flow rates regardless of the flow rate in the main canal. If the water level in a main canal is constant, then turnout controls can be either weirs or orifice-based gates, such as sluice or radial gates. Generally, weirs are able to control main canal water surfaces more closely than orifice gates because the water level upstream varies with the three-halves power of the head over the weir compared to the one-half power for orifices.

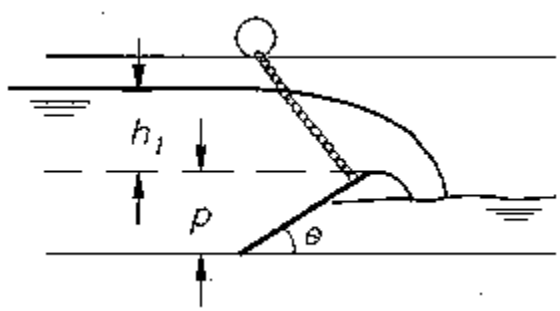



Figure 7-15 -- Sectional view of an overshot gate.

Although water level control is useful, operators also need to know the flow rate at each gate to better operate systems. Wahlin and Replogle (1994) further developed the Kindsvater and Carter (1959) calibration approach for a sloping leaf gate as a weir by modifying equation 7-1 with a gate angle correction coefficient, $C_a$, as follows:

$$Q = C_a C_e L_e h_e^{1.5} \quad (7\text{-}9)$$

where:

$C_a$ = correction factor for angle of the gate

$C_e$ = effective discharge coefficient for a vertical weir from figure 7-5 or equation 7-2

$L_e$ = effective crest length

$h_e$ = effective measurement head

An empirical plot (figure 7-16) for $C_a$ was determined from laboratory tests. For values of $h_1/p$ less than 1.0 and for gate angles between 16.2 degrees and 63.4 degrees, the relationship for $C_a$ is:

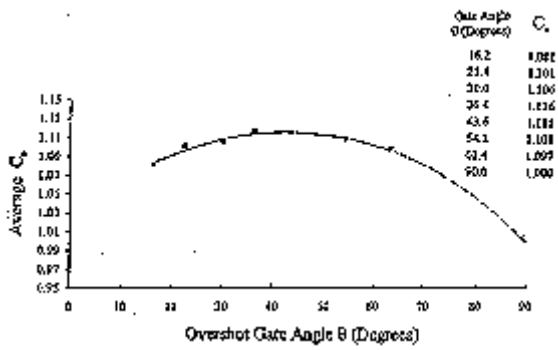



Figure 7-16 -- Correction factor, $C_a$, versus gate leaf angle, $\theta$, for use in equation 7-9.

The angle, $\theta$, is measured in the direction of the flow between the channel invert and the underside of the gate leaf in degrees.

$$C_a = 1.0333 + 0.003848\theta - 0.000045\theta^2 \quad (7\text{-}10)$$

These equations can determine the flow rate in the field of a properly ventilated free-flow leaf gate to within about 6.4 percent. These equations were tested against hydraulic laboratory modeling and field data. Eventually, with further testing, these authors expect to verify that their derived submergence functions will provide submerged flow calibrations to within about 10 percent. This accuracy estimation for submerged flow rate does not include errors associated with head measurement.

An example computation of free overshot discharge follows.

> For a leaf gate that is 6.5 ft wide and 9.75 ft long, sloping at 40 degrees, mounted with the hinge point about 3 in above the invert, and a measurement head, $h_1$, of 3.25 ft, calculate the free flow discharge.

The overfall edge of a leaf gate is in a region of no side contraction; therefore, the effective discharge coefficient can be calculated assuming no side contractions of the weir. Thus, figure 7-7 or equation 7-2 with a $C_1$ of 0.40 and $C_2$ of 3.22 are used to calculate a value for the effective discharge coefficient, $C_e$, as 3.42 at $h_1/p$ of 0.5.

Because no effects caused by side contractions were assumed, a value of -0.003 ft is assigned to $K_b$ (figure 7-4). Kindsvater and Carter (1959) also recommend that a constant value of 0.003 ft be assigned to $K_h$ regardless of the flow rate or gate height. Thus, $L_e$ is 6.497 ft, and $h_e$ is 3.253 ft.

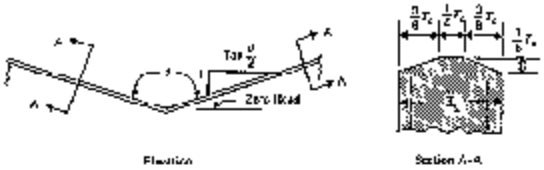
Because $h_1/p$ is less than 1.00, and the gate angle is between 16.2 and 63.4 degrees, equation 7-8 can be used to determine that $C_a$ is 1.115. Then, equation 7-7 is used to calculate discharge as below:

$$Q = (1.115)(3.42)(6.497)(3.253)^{1.5} \quad (7\text{-}0)$$

$$Q = 145.3 \text{ ft}^3/\text{s}$$

**(f) Short-Crested Triangular Weirs**

The Soil Conservation Service, now the Natural Resources Conservation Service, (Brakensiek et al., 1979) (U.S. Department of Agriculture, 1962) developed a triangular short-crested weir (referred to by some investigators as a triangular broad-crested weir) in the 1930's. The short-crested triangular design was adopted to provide a precalibrated meter installation that is economical, durable, and accurate over a wide flow range. The weirs are typically constructed entirely of reinforced concrete. The standard dimensions of the weir crest are given on figure 7-17. Triangular weirs with crest slopes of 2 to 1, 3 to 1, and 5 to 1 are standard. A concrete apron is recommended downstream from the weir for a distance of two measuring heads to prevent erosion. Water stage is measured relative to the weir V-notch at a location 10 ft upstream from the centerline of the crest profile. The U.S. Natural Resources Conservation Service recommends the channel upstream from the weir be nearly straight and level for 50 ft. The weir notch must be located a minimum of 0.5 ft above the upstream channel bed. Deposition of material immediately upstream from the notch will cause flow measurement inaccuracies that are greatest at low measuring heads. The side slope of the triangular weir should be selected based on natural streambank topography. The weir must provide sufficient upstream ponding such that velocity head at the stage measurement station can be neglected for the desired accuracy. The discharge equation for a short-crested triangular weir is given on figure 7-17.




$$Q = \left(C_a + C_1 \operatorname{Log}_{10} \frac{h}{T_c}\right)\sqrt{g}\tan\frac{\theta}{2}\left(h + \alpha\frac{v^2}{2g}\right)^{2.5}$$

$\alpha$ = 1.33

$v$ = average velocity in cross section 10 feet (3.048 m) upstream from center of crest

$h$ = head (water surface elevation − zero head) 10 feet (3.048 m) upstream from center of crest

$T_c$ = crest thickness (16 in or 0.4064 m)

| $T\tan\frac{\theta}{2}$ | Range $\frac{h}{T_c}$ | $C_a$ | $C_1$ |
|---|---|---|---|
| 2 | 0.790 – 1.627 | 0.4708 | 0.06703 |
| 2 | 1.628 – 3.716 | 0.4906 | 0.01688 |
| 2 | 3.717 – 4.500 | 0.5142 | -0.02450 |
| 3 | 0.790 – 2.379 | 0.4734 | 0.07075 |
| 3 | 2.380 – 3.765 | 0.4925 | 0.02092 |
| 3 | 3.766 – 4.500 | 0.5117 | -0.01338 |
| 5 | 0.790 – 1.456 | 0.4706 | 0.07910 |
| 6 | 1.456 – 3.769 | 0.4976 | 0.01017 |
| 6 | 3.770 – 4.500 | 0.5688 | -0.12692 |

Figure 7-17 -- Discharge equation for short-crested triangular weir (SCS Agriculture Handbook No. 244).

## 14. Velocity of Approach Corrections

If the traditional standard weirs need correction for excessive velocity of approach, then their limits, as expressed in the previous sections, have been exceeded. Velocity cannot be effectively corrected by adjusting head alone as done with older procedures. Recognizing this limitation is probably the reason for the development of the Kindsvater equations and methods, which account for velocity of approach caused by allowing partial contraction. Thus, Kindsvater methods will directly recalibrate most rectangular and triangular weirs with excess approach velocity. Correcting a Cipolletti weir reading is more difficult, and $(1/4)h_1$ must be added to the crest length to approximate a rectangular overflow opening. Then, the Kindsvater-Carter relationship is used to calculate discharge for both the fully contracted discharge case and the partially contracted case, causing the excess velocity of approach to determine the correction discharge ratio to apply to the Cipolletti table or equation value for discharge.

## 15. Weir Submergence

Accurate measurements of submerged sharp-crested weir discharges cannot be made because of the spread of measured data when determining correction factors for drowned or submerged weirs. Skogerboe et al. (1967) show plots of correction factor curves for several weirs with actual data points plotted around them. The range of data spread of submergence corrected discharge is "15 percent. Besides complicated hydraulics, submerged weirs also have the problem of precision of head reading relative to head measurement. Despite the form of the correction procedures, discharge is actually based on the difference of two heads.

These differential heads are small relative to the ability to measure head precisely. Therefore, submergence correction procedures should be only a temporary emergency procedure to provide estimates. The need for submergence correction should be eliminated directly by maintenance and cleaning of weeds, sediment, and other debris from the downstream channel, changing system operations, raising the crest, or installing another kind of measuring device since correction estimates are only within ±15 percent.

Flow cannot be estimated for submerged partially contracted Kindsvater-Carter and Kindsvater-Shen calibrated weirs discussed in sections 6 and 7.

## 16. Weir Selection

If, after applying the concepts in chapter 4, the selection of a weir is indicated, discharge capacity and range should be considered next. Each weir has characteristics suited for particular operating conditions.

To conserve delivery head and reduce head loss, the rectangular and wide V-notch weirs rated by Kindsvater methods should be selected. These weirs provide the capability to use shorter heights from the approach channel invert to the crest. However, the downstream water surface should be sufficiently below the crest to prevent the nappe from clinging to the blade and to provide proper ventilation. If higher head through pipe outlets must be handled, then the short weir box can be used to reduce concentrated velocities and measure the flow.

For higher accuracy, a rectangular weir or triangular weirs down to a 20-degree V-notch weir should be used. Because the V-notch weir has no horizontal crest length, the head required for a small flow through it is greater than that required with the other weir types. This greater head is an advantage because nappes of smaller discharges will spring free of the crest. Nappe clinging to the crest of any type of weir makes measurement inaccurate. Although sharp-crested Cipolletti and rectangular weirs of 6-in crest length are sometimes used for measuring small flows, they are not as accurate or as sensitive as the V-notch weir for such flows and are not recommended where the V-notch weir can be used.

Cipolletti weirs have modified end contractions and have not been investigated experimentally as thoroughly as the rectangular and V-notch weirs. However, they have been usefully adopted by some water districts.

The range of flows to be measured by a weir usually can be estimated in advance. With this range in mind, other factors should be considered in selecting type and size of weir. If regulation is needed, then movable weir crests, including the overshot weir discussed in section 4, can be used.

The weir should be sized to prevent measuring at heads less than 0.2 ft to prevent surface tension effect on discharge and to keep the nappe from clinging to the crest. Also, at smaller depths, gage readings accurate enough to calculate reliable flow quantities are difficult to obtain.

Designing a weir for head as high as the allowable one-third of the crest length is not necessarily a good practice because the higher head may require a larger stilling basin and riprap protection downstream.

A sill at the downstream end of the basin will help prevent bottom shear flow on the channel bed downstream from the basin. Bos (1989) has discussion of designing basins for water measurement structures and designing riprap with proper underbase material.

Chapter 4 has further information on weirs but may indicate selection of a device other than a weir.

## 17. Sharp-Crested Weir Construction and Installation

Portable sharp-crested weirs may be used temporarily to provide approximate measurements of small flows in earth channels, lined tunnels, etc. For small earthen channels, the weir may be made from a piece of stiff sheet metal cut in the approximate shape of the cross section of the channel, but somewhat larger with a carefully cut weir notch in the top edge. To set this weir, the metal plate is forced firmly into the soft bottom and sides of the channel normal to the direction of flow. The crest is then adjusted to a level position by tapping down the higher side. Portable long-throated flumes can be used where head is insufficient for sharp-crested operation.

For larger channels and lined tunnels, a weir plate may be installed in a bulkhead that has been sandbagged and sealed in place. The opening in the bulkhead for a weir notch should be cut about 3 in longer than the crest length. This opening will allow insertion of metal crest plates to form the sharp crest and sides of the weir. Some approximate measurements have been made successfully with a combined weir and canvas dam. The bulkhead structure is used to fasten the canvas and bulkhead, which form a dam when held in place across the canal section by piling earth on the lower edge of the canvas.

For simple temporary weirs placed across channels, a flat-topped stake or post may be driven into the bed of the weir pool until its top is at the same elevation as the weir crest. The stake should be located in tranquil water close enough to the channel bank to be accessible. The depth of the water over this post is the head on the crest.

Designing weir structures requires consideration of all the general limits in section 5 and the limits specific to the type of weir crest selected. The approach flow conditions should be as described in chapter 2. In the past, many organizations developed sets of weir box structures for convenience. These weir sets commonly used standard weir equations for fully contracted weirs. However, for economy of structure, these weir boxes skimped on crest height and side contractions and used head-to-crest length ratios of 1 to 1. Some of these preselected weir boxes, when compared with the improved Kindsvater relationships in section 6, indicated errors as high as 20 percent. With today's computers, calculators, and the improved Kindsvater relationships, economy of structure such as smaller structures and less head loss in certain cases can be achieved without loss of accuracy. The only disadvantage is that generating tables is more complex, but the task is easy with computers.

Frequently, suppressed weirs deliver much more water than operators think they have measured. This inaccuracy happens when air vents are not installed, are fully or partially plugged, or are undersized. Suppressed weirs must have proper ventilation of the cavity underneath their nappes. This ventilation is commonly done by installing properly sized pipes in the walls to vent the cavity under the nappe. Another way of providing air is to use the corner of an angle iron pointed upstream in the nappe to spread the water, forming an open airway.

Standard equations and tables are valid only when sufficient ventilation is provided. The weir will deliver more water than indicated by the tables and equations when ventilation is inadequate.

This inaccuracy occurs because the nappe sheet seals with the sidewalls, and the falling jet aspirates air from the cavity. The exiting flow carries the aerated water away, causing a negative pressure under the nappe. The negative pressure and some jet backflow raise the water behind the nappe sheet higher than the water exiting just downstream.

The height of pullup behind the nappe depends upon the drop, discharge, and crest length. The height that the water is pulled up behind the nappe is an estimate of the discharge error. For example, if the measuring head on a 3-ft suppressed weir is 1 ft, and the water behind the nappe pulls up 0.3 ft because of air demand, the error of discharge measurement would be about +6.5 percent. If the water was only pulled up 0.1 ft, the error for the same weir and measuring head would be +2.5 percent. However, some of the rise of water behind the nappe is due to backflow from the falling jet.

The design of pipe size to introduce sufficient air depends on the discharge, drop, and the loss of accuracy that is tolerable. Sizing air piping and air vents requires some knowledge of fluid mechanics and is difficult to do. Bos (1989) gives the equations to compute the undernappe pressure and a plot of discharge error versus under-nappe pressure for sizing air vents.

The weir structure should be set in a straight reach of the channel, perpendicular to the line of flow. The weir crest must be level and the bulkhead plumb. Adequate cutoff walls well tamped in place should be used on the weir structure to prevent undermining of the structure. The average width of the approach channel should be set to approximately conform to the size of the box for a distance of 10 to 20 ft upstream for the smaller structures and from 50 to 70 ft or more for the largest structures.

The weir box may accumulate sand and silt to such an extent that discharge measurements will be incorrect. For sluicing silt and sand deposits, an opening may be provided in the weir bulkhead at the floor line beneath the weir notch. This sluiceway should be provided with a suitable cover or gate to prevent leakage. If sediment is a severe problem, then sediment-excluding vortex tubes that bypass bed load with a small continuous flow may be more desirable than inaccuracies resulting from silt and sand.

## 18. Care of Weirs

The weir and weir pool should be kept free of weeds and trash. The weir pool should be cleaned of sediment as it accumulates. Frequent trimming of the channel and cleaning of the weir box structure or approach channel with shovel or scraper are necessary to maintain accurate flow measurement. This cleaning should extend from the bulkhead to upstream past the head measuring station. The invert of the pool must be kept low enough to maintain at least the minimum distance below the crest of the weir. This minimum distance is twice the maximum head on contracted weirs and three times the maximum head on suppressed weirs.

Frequent inspections should be made to determine whether leakage is occurring around the weir structures and through any sluicing clean out gate or cover.

If leakage does occur, remedial action should be immediately followed with careful rechecking to see that the weir is level and that its elevation corresponds to the zero elevation of the measuring gage. In any case, the crest of the weir should be checked periodically to verify that it is level and to verify correspondence to gage zero.

Care must be taken to avoid damaging the weir notch itself. Even small nicks and dents can reduce the accuracy of an otherwise good weir installation. Any nicks or dents that do occur should be carefully dressed with a fine-cut file or stone, stroking only in the plane of the upstream face of the weir plates or the plane of the beveled surface of the weir plates. Under no circumstances should any attempt be made to completely remove an imperfection, which will result in a change to the shape of the weir opening. Instead, only those portions of the metal that protrude above the normal surfaces should be removed.

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# CHAPTER 8 - FLUMES

## 1. General

Flumes are shaped, open-channel flow sections that force flow to accelerate. Acceleration is produced by converging the sidewalls, raising the bottom, or a combination of both. When only the bottom is raised with no side contractions, the flume is commonly called a broad-crested weir. When the downstream depth is shallow and enough convergence exists between the upstream and downstream channels, the flow passes through critical depth. Therefore, flumes are sometimes called critical-depth flumes. When flow passes through critical depth, a unique water surface profile occurs within the flume or broad-crested weir for each discharge. This condition is known as free flow. For this case, upstream heads at one location relative to the control bottom elevation near the region of critical depth can be used to determine a usable head versus discharge relationship for flow measurement.

Flumes range in size from very small-1 inch (in) wide-to large structures over 50 feet (ft) wide that are installed in ditches, laterals, and large canals to measure flow. These flumes cover a corresponding discharge range of 0.03 to over 3,000 cubic feet per second ($ft^3/s$) although no particular upper size limit exists. Commonly, irrigation channels are designed to operate at near bank full to extend delivery coverage and, when the landscape is flat, to minimize earthwork involved in bank height construction. Therefore, some flumes have been calibrated for the condition when the critical depth has been nearly drowned by downstream backwater either purposely or by later increase of downstream flow resistance. To measure discharge with high levels of submergence, two head measurements are required, which results in significant loss of accuracy compared to free-flow measurements.

Flume head loss is less than about one-fourth of that needed to operate a sharp-crested weir having the same control width, and in some long-throated flumes, may be as low as one-tenth. Another advantage compared to most standard weirs is that for a properly designed and installed flume, the velocity of approach is a part of the calibration equations. Unauthorized altering of the dimensions of constructed flumes to obtain an unfair share of water is difficult and, therefore, not likely. Velocity of flow can usually be designed to minimize sediment deposition within the structure. Gradual convergence sections at the entrance tend to improve velocity distribution of approach flow and the passage of floating debris. Some flumes can be more expensive than sharp-crested weirs or submerged orifices in unlined channels.

## 2. Flume Classes

Many kinds of flumes are in use. The two basic classes or forms of flumes are discussed below.

### (a) Long-Throated Flumes

Long-throated flumes (figure 8-1) control discharge rate in a throat that is long enough to cause nearly parallel flow lines in the region of flow control. Parallel flow allows these flumes to be accurately rated by analysis using fluid flow concepts. The energy principle, critical depth relationships, and boundary layer theory are combined to rate flumes and broad-crested weirs by Ackers et al. (1978) and Bos et al. (1991). Thus, the long-throated flumes and modified broad-crested weirs are amenable to computer calibrations.

Long-throated flumes can have nearly any desired cross-sectional shape and can be custom fitted into most canal-site geometries. The modified broad-crested weirs (Replogle, 1975; Bos et al., 1991), also called ramp flumes (Dodge, 1983), are styles of long-throated flumes.

(a) Long-throated flume (broad-crested weir) under construction.

(b) The long-throated flume (broad-crested weir) with approximatly 1,200 ft3/s.

Figure 8-1 -- Large long-throated flume for left to right flow in Arizona canal (courtesy of U.S. Water Conservation Laboratory, Phoenix, Arizona).

**(b) Short-Throated Flumes**

Short-throated flumes are considered short because they control flow in a region that produces curvilinear flow. Although they may be termed short throated, the overall specified length of the finished structure, including transitions, may be relatively long. The Parshall flume is the most common example of this type of flume (figure 8-2). These flumes would require detailed and accurate knowledge of the individual streamline curvatures for calculated ratings, which is usually considered impractical. Thus, calibrations for short-throated flumes are determined empirically by comparison with other more precise and accurate water measuring systems.

Figure 8-2 -- Four-foot, short-form Parshall flume, discharging 62 $ft^3/s$ under free-flow conditions. Scour Protection is needed for this much drop.

## 3. Other Special Flumes

Many flumes have been designed for organizational preferences and special uses. Many of these are considered short-form flumes. Some examples are shown on figure 8-3, and some are briefly discussed in this section.

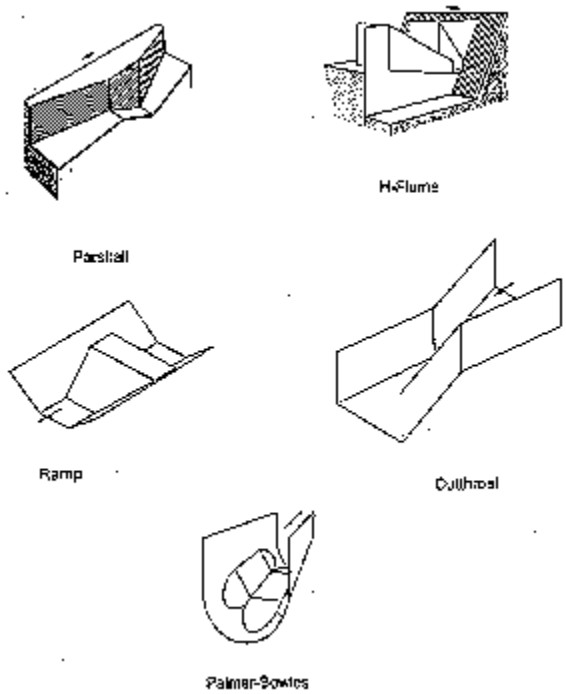



Figure 8-3 -- Some typical flumes.

**(a) H-Flumes**

H-flumes, developed by the Natural Resources Conservation Service (former known as the Soil Conservation Service) (Brakensiek, et al., 1979; Kulin et al., 1975), are made of simple trapezoidal flat surfaces. These surfaces are placed to form vertical converging sidewalls. The downstream edges of the trapezoidal sides slope upward toward the upstream approach, forming a notch that gets progressively wider with distance from the bottom. These flumes should not be submerged more than 30 percent. This group of flumes, including H-flumes, HS-flumes, and the HL-flumes (Brakensiek et al., 1979; Gwinn and Parsons, 1976) have been used mostly on small agricultural watersheds and have not found extensive use in irrigation flow measurements.

**(b) Cutthroat Flumes**

Cutthroat flumes are so named because they resemble Parshall flumes with the throat "cut out." They are formed by directly connecting a 6:1 converging section to a similar diverging section. Thus, they consist of a converging level inlet section with vertical sidewalls and a diverging level outlet section also with vertical sidewalls. They do not have any parallel walls

forming a straight throat (Skogerboe et al., 1973) and, thus, belong to a class of throatless flumes. The converging and diverging walls do not necessarily match those of other flumes in either converging or diverging slope or length. The primary objective of their development was construction simplicity compared to Parshall flumes.

However, the prescribed head measuring location, which may be in a zone of separation, and conditions of the upstream channel in which it is placed, along with variable conditions of the sharp connection of the convergence and the divergence, have caused considerable variability in calibrations. Because of these complexities in hydraulic behavior, several authors do not recommend their use (Ackers et al., 1978; Bos, 1989).

**(c) Palmer-Bowles Flumes**

Palmer-Bowles flumes (Wells and Gotaas, 1958) are frequently made as inserts with circular bottoms that conveniently fit into U-shaped channels or partially full pipes. These flumes make a transition from a circular bottom section to a raised trapezoidal throat and transition back to a circular bottom section. These flumes are of the long-throated type and can be calibrated by theoretical analysis.

**(d) Flat-Bottomed Trapezoidal Flumes**

Flat-bottomed trapezoidal short-form flumes were first developed to be placed in canals and to conform more closely to usual small canal shapes (Robinson and Chamberlain, 1960). Therefore, if possible, the cross section of the canal and the start of the converging portion of the flume should match. They were designed to set flush with respect to the bottom of the incoming channels in an effort to assist sediment movement and allow the canal to drain dry between uses. Although the latter objective was achieved, the authors did not establish whether sediment movement was a function of upstream velocity or floor configuration.

Although these early versions were laboratory calibrated, more recently, they were found to conform to the analysis procedures for long-throated flumes for heads less than about 50 percent of maximum. For higher depths, their throats become too short for precise long-throated flume analysis, and the laboratory ratings should be used. Except for those already in existence, and for which the user may need calibrations, these flumes are generally being replaced with versions having longer throats, making them long-throated flumes that can be calibrated by analysis.

**(e) Special Flumes for Passing Sediment**

Where sediment is a major problem, special flume types have been designed to obtain flow measurements in these adverse conditions. Included in these devices are the trapezoidal supercritical-flow flume, the Walnut Gulch flume, and the San Dimas flumes which slope in the direction of flow (Brakensiek et al., 1979). These flumes are considered to be a class of supercritical flumes. Usually, they are characterized as requiring extensive head drop to operate and find limited application in irrigation.

## 4. Submergence

All flumes have a minimum needed head loss to assure that free flow exists and that only an upstream head measurement is needed to determine discharge rate. This required head loss is usually expressed as a submergence limit defined by the ratio of the downstream head to the upstream head, both referenced to the flume throat bottom. The term "modular limit" is defined as this limiting submergence ratio for a particular flow module, which causes no more than a 1-percent deviation in the upstream head reading for a given discharge. When these limits are exceeded, an additional downstream head measurement is sometimes used to extend the measurement range of a flume, particularly for Parshall and cutthroat flumes, but at considerable loss of accuracy. Submergence also increases upstream channel depth, decreasing the upstream velocity, which may aggravate sedimentation problems.

Long-throated flumes can tolerate high submergence in some cases. Trying to extend their measurement range with a downstream head measurement is not recommended. They can be designed to have submergence limits (modular limits) ranging from 65 to 95 percent, depending on discharge rate, shape, and exit channel energy conditions. For example, a flume discharging into a channel that is similar in size and shape to the approach channel can have submergence limits that calculate to exceed 82 to 95 percent for minimum to maximum flow rate, provided an expansion section is used, and from about 72 to 93 percent without an expansion section. The same flume, when discharging into a lake, may have submergence limits of only 65 to 80 percent, decreasing further to about 60 to 70 percent if there is no expansion section. Thus, some knowledge of the installation site is needed before a required head loss can be assigned.

Visual determination of limiting submergence for most flumes can be difficult. However, for long-throated flumes, this condition is relatively easy to recognize. Several references offer guidelines in terms of standing diagonal wave locations to aid visual determination of flow submergence (Bos et al., 1991; Clemmens et al., 1993). In general, if the downstream hydraulic jump causes a frothy wave line across the channel that is at or beyond the end of the contracted throat section, the flume has not reached its limiting submergence-the modular limit. If the wave is on the throat, or no wave is visible, the flume is beyond its submergence limit, and the measurement would be invalid.

For long-throated flumes, painting lines projecting up the channel walls to denote the downstream end of the crest to aid visual distinction is suggested (Bos et al., 1991). Distinction in terms of wave location in Parshall flumes is not so clear. In the absence of visual observation in any of the flumes, automatic recording operations may need a second downstream head measurement if the opportunity for excessive backwater exists. This measurement would warn of invalid data.

Some states have laws that require Parshall flumes by name for certain situations. Past designs for Parshall flumes tended to overuse submergence for economic savings with the only caveat that submergence should not exceed 95 percent. However, today, designing for this level of submergence is not considered good practice in view of accuracy loss and a hysteresis discontinuity in the submergence correction function described in the section on Parshall flumes in this chapter.

## 5. Site Characteristics Related to Locating, Selecting, and Setting Flumes

Proper location of the flume is important from the standpoint of accuracy and ease of operation. For convenience, the flume should be located near the diversion point and near the regulating gates used to control the discharge. Flumes should be readily accessible by vehicle for both installation and maintenance purposes. All structures for measuring or regulating the rate of flow should be located in a channel reach where an accurate head can be measured. The survey of a channel to find a suitable location for a structure should also provide information on a number of relevant factors that influence the performance of a future structure.

### (a) Approach Conditions

Flumes should not be installed too close to turbulent flow, surging or unbalanced flow, or a poorly distributed velocity pattern. Poor flow conditions in the area just upstream from the measuring device can cause large discharge indication errors. In general, the approaching flow should be tranquil. Tranquil flow is defined as fully developed flow in long straight channels with mild slopes, free of curves, projections, and waves.

Studies of approach requirements for closed conduits have led to the acceptance of 10 diameters of straight pipe as sufficient for pipe meters claiming to be accurate to within 0.5 to 1 percent. By the usual hydraulic analogy, open channel flow would require 40 times the hydraulic radius of straight, unobstructed approach channel. The hydraulic radius is the area of flow section divided by the wetted perimeter, which becomes $d/4$ for full pipes; hence, the suggested 40 times hydraulic radius approach distance. These requirements can probably be relaxed because open channel measuring flumes claim accuracy to a wider margin of 2 to 5 percent. However, for a rectangular channel that is twice as wide as it is deep, 40 times the hydraulic radius is numerically equal to 10 top widths.

Bos et al. (1991) gives approach length requirements stated in various terms of flow depths, head readings, and widths as follows:

> (1) If the control width is greater than 50 percent of the approach channel, then 10 average approach flow widths of straight unobstructed approach are required.

(2) If the control width is less than 50 percent, then 20 control widths of straight unobstructed approach are required.

(3) If upstream flow exceeds critical velocity, a jump should be forced to occur. In this case, 30 measuring heads of straight unobstructed approach after the jump is completed should be provided.

(4) If baffles are used to correct and smooth approach flow, then 10 measuring heads should be placed between the baffles and the measuring station.

Approach velocities less than 1 foot per second (ft/s) encourage aquatic pests, insects, and sediment deposition, so the approach velocity should exceed 1 ft/s if at all practical. To prevent wave interference of head measurement, the Froude number of the approaching channel flow should be less than 0.5 for the full range of anticipated discharges and should not be exceeded over a distance of at least 30 times the measurement head before the structure.

It is recommended that a check be made of the approach velocity condition by current meter measurements, especially when using baffles. In any case, approach condition should be verified visually. Visual inspection should be made for obvious boils and backflows and unstable surface conditions.

**(b) Channel Flow Characteristics and Operational Needs**

For accurate measurements, sufficient head loss must be created to obtain a unique discharge versus head relationship. This relationship assures that submergence limits have not been exceeded and modular flow exists. To prevent submergence altogether or to assure that excessive submergence does not occur, the designer needs to know whether the downstream water surface elevation relationships are consistent and do not change with season or whether they are influenced by operation of gates, reservoir operation, or other laterals. The channel water levels greatly influence the sill height necessary to keep the downstream water surface below the submergence limit, thus obtaining modular flow for the needed discharge range.

The amount of downstream flow resistance and, hence, the water surface elevation, is likely to vary with sediment deposits, debris, canal checking operations, vegetative growth, and aging. For a new design, careful assessment of friction, including the effects of relative roughness, is required. A thorough appraisal of needed canal operations is required to determine the frequency of measuring different discharges, including the normal design flow and the maximum design flow.

To select or design an appropriate flume for installation in an existing channel, full advantage should be taken of making field measurements at different discharges to obtain thorough knowledge of channel performance at the site. After tentatively selecting the flume location, information should be obtained on the maximum and minimum flows to be measured, the corresponding flow depths, the maximum velocity, and the dimensions of the channel at the site. These measurements should include channel widths, side slopes, depths, and the height of the upstream banks with special attention to their ability to contain the increased depth caused by the flume installation.

### (c) Erosion And Scour

Ideally, the selected channel reach should have a stable bottom elevation. In some channel reaches, sedimentation occurs in dry seasons or periods. These sediments may be eroded again during the wet season. Sedimentation may change approach velocity or may even bury the structure, and the erosion may undercut the foundation of the structure.

Based on the channel water levels and the required sill height, in combination with the discharge versus head relationship of the structure, ponding at the upstream structure should be assessed. Excessive ponding commonly causes sedimentation difficulties because of the subsequent reduction in the approach flow velocities. To avoid upstream sedimentation, the sill height plus the measuring head should be about the same as for the approach channel over as much of the discharge measuring range as practical. This arrangement will help reduce sedimentation upstream from the structure.

The required drop may exceed the capacity of soil lined channels to resist scour, and foundations may scour. Thus, rock armoring may be needed to prevent undermining. For more details on sediment handling, see Bos (1989) or Bos et al. (1991).

## 6. Workmanship

Flumes require accurate workmanship for satisfactory performance. Short flumes will provide reasonably accurate flow measurements if the standard dimensions are attained during construction. For accurate flow measurement, the flow surfaces must be correctly set or placed at the proper elevation, the crest must be properly leveled, and the walls must be properly plumbed. Although long-throated flumes can be computer recalibrated using as-built dimensions to correct for moderate form slipping or errors of construction, correcting for throat-section slope in the direction of flow is not always satisfactory. In any case, adequate care during construction is preferable. The modified broad-crested weir flume has only one critical flow surface, and it is level.

Flumes should be set on a solid, watertight foundation to prevent leakage around and beneath the flume and prevent settlement or heaving. Collars or antiseep walls should be attached to either or both the upstream and downstream flanges of the flume and should extend well out into the channel banks and bottom to prevent bypass flow and foundation settlement caused by erosion. A stable foundation without significant settling or leakage must be secured at reasonable costs.

The flumes can be built of wood, concrete, galvanized sheet metal, or other materials. Large flumes are usually constructed on the site, but smaller flumes may be purchased as complete flumes and placed in one piece. Others are provided in bolt-together pieces which are assembled onsite. Some of these flumes are made of lightweight materials, which are then made rigid and immobile by careful earth backfill or by placing concrete outside of the walls and beneath the bottom.

When making a number of relatively small concrete flumes of the same size, use of portable and knockdown reusable forms is economical and practical. These forms require high quality design and workmanship.

Good construction practice should be used in placing footings, setting the forms, and pouring and tamping wall concrete to provide smooth surface finishes. Accuracy of the short flumes depends on correct flume dimensions, proper setting, and proper use. As flume size decreases, the influence of a small dimensional error becomes more prominent, and the importance of this care increases.

## 7. Head Measurements

The head is usually sensed either in the channel itself or in a stilling well located to one side of the channel. The stilling well is connected by a small pipe to the channel. Many methods can be used to detect the water surface in a stilling well or in the flume channel. Some methods exploit the electrical conductance of water and capacitance of immersed insulated wires. Sonic sensors depend on timing sound pulses reflected from the water surface. Measurement heads can also be determined with a variety of pressure sensing devices. The most frequently used methods are wall-mounted staff gages in the entrance section of the flume or in a stilling well or float-operated recorders placed in a stilling well.

### (a) Location for Head Measurement

The measuring station for short-form flumes must be installed as specified to match closely the location used when the flume was empirically calibrated. For example, the measuring station of a Parshall flume is in the convergence water surface drawdown. For long-throated measurement structures, the gaging or head-measuring station should be located sufficiently far upstream to avoid detectable water surface drawdown, but close enough for the energy losses between the gaging station and approach section to be negligible. This placement is particularly critical if the ratings are based on coefficient values in a discharge equation as discussed in Bos (1989). In the computer derived ratings, drawdown and friction losses caused by the gage location are an integral part of the calculation. Therefore, the gage should be located as indicated in the pre-computed long-throated structure design and selected tables.

### (b) Selection of Head-Measurement Device

The success or failure of the structure and the value of the collected data depend closely on the proper selection of a suitable head measurement device. The three most important factors that influence this selection are: (1) frequency of discharge measurement, (2) allowable error in the head detection, and (3) type of measurement structure under consideration.

The usual expected reading errors in the sill-referenced head are listed in table 8-1 for some common head measurement devices. The listed errors are higher than the expected random errors, partly to compensate for the effects of several systematic errors, such as zero-setting, instrument lag, reading error, temperature, and stilling well leakage. If no device with sufficient accuracy is found from this procedure, two choices are available: (1) allow greater error in the measured discharge for the minimum required head loss or (2) redesign the structure with a narrower bottom width, resulting in a higher value of minimum measurement head.

**(c) Staff Gages**

Periodic readings on a calibrated staff gage may serve adequately when continuous information on the flow rate is not required. Examples are canals where the flow changes are gradual. The gage should be placed so that the water level can be read from the canal bank. The gage should be easy to clean.

| Table 8-1. Common reading errors in flat crest reference head as detected by various devices | | | |
|---|---|---|---|
| Device | Reading error $\Delta h_1$, ft<br>*If head detection is in* | | Remarks |
| | Open channel | Stilling well | |
| Point gage | Not applicable | 0.0015 | Commonly used for research |
| Dipstick | Not applicable | 0.003 | Good for research/field use |
| Staff gage | 0.013<br>0.023<br>> 0.050 | 0.013<br>0.016<br>0.023 | $F_1 \leq 0.1$<br>$F_1 = 0.2$<br>$F_1 = 0.5$ |
| Pressure bulb + recorder | 0.066 | Not required | Suitable for temporary installations (Error = $\pm$2% $h_{1max}$). |
| Bubble gage + recorder | 0.033 | Not required | Stilling well is not required but can be used |
| Float-operated recorder | Not applicable | 0.016 | Stilling well is required |
| Float totalizer attached to recorder | - | - | Some additional random and systematic error is possible |

For concrete-lined canals, the gage can be mounted directly on the canal wall. The value for measuring head on the sloping walls of trapezoidal-shaped canals must be appropriately converted to vertical head values before entering the discharge tables. These tables are usually made for stilling well use or vertical gage applications. The sloping gage can be marked to read direct values or equivalent values of vertical head. Sometimes, sloping staffs are marked to display discharge directly, but the discharge gradations are not equally spaced. The gage may be mounted onto a vertical support for unlined canals.

Most permanent gages are enameled steel, cast aluminum, or some type of plastic resin. Enameled linear scales marked in metric or English units are available from commercial sources. An example staff gage is shown on figure 8-4. Important flow rates can be noted on these scales by separate markings, allowing convenient adjustment of control gates to desired discharges without requiring tables. For convenience, the gages can be marked directly in discharge units rather than in measuring head units.

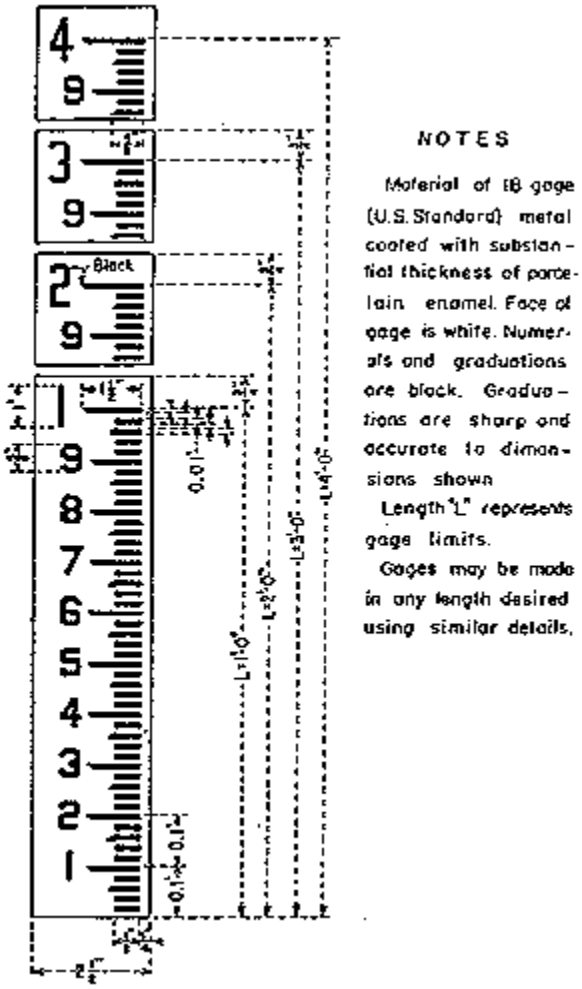



Figure 8-4 -- Typical staff gage for measuring head or water stage.

**(d) Stilling Wells**

For accurate discharge measurements, the effective head in flumes, accurately referenced to a known elevation in the flume, must be measured. Head readings on staff gages attached directly to the inside channel walls may be only estimates because of waves and turbulent fluctuations on the scale face. Thus, stilling wells are connected by holes and pipes to the body of water at the measuring station to translocate head and dampen water surface fluctuations by throttling, which increases head measurement accuracy.

The pipe connecting the stilling well to the flume/canal should be large enough to allow the stilling well to respond quickly to water level changes. Usually, this pipe diameter is about one-tenth the diameter of the stilling well. However, special cases may require more dampening using smaller connecting pipe diameters.

The pipe connection to the stilling well should be perpendicular and carefully cut flush with both the canal and the stilling well walls. Otherwise, the translocated water surface elevation in the well can deviate considerably from the actual elevation in the flume because of flow velocity impact or aspiration.

Connections that are not flush and/or have rough edges have different head losses depending on direction of flow in the connecting piping. This causes buildup or reduction of head in stilling wells compared to the actual head in the measurement device.

The size of the stilling well depends on the method used to measure the head. The diameter, if circular shaped, ranges from a recommended minimum size of 4 in for hand-inserted dipsticks to 18 in to accommodate larger diameter floats. Wells may be much larger to provide access for cleaning or to make the reading of wall attached staff gages at sight angles at least as flat as 30 degrees. It is recommended that well walls have a 2-in clearance from floats and weights used with recorders.

A stilling well may need to house the float and recorder system or other surface detecting equipment. The wells may need to be tall enough to provide convenient access to recorders for reference setting and maintenance. The wells may also need to be tall enough to keep counterbalance weights from interfering with float movement.

Before making a measurement, the wells should be flushed with fresh water to be sure they are free of sediment, foreign material, or blockages, which could cause erroneous head readings. Recording equipment should be checked and serviced regularly. Cross-checks should be made between the staff gages, hook gages, plumb bobs, recorder values, and any other discharge indicators to expose system errors. Thus, even when using stilling wells, staff gages should still be used on the insidewalls of flumes for cross-checking. Further details on stilling wells can be found in chapter 6 and Bos (1989), Bos et al. (1991), and Brakensiek et al. (1979).

**(e) Gage Installation and Zero Setting**

The most important factor in obtaining accurate discharge measurements is the accurate determination of the sill-referenced head, $h_1$. The upstream sill-referenced head can be measured by a gage or recorder only if the observed water level is known with respect to the weir sill (or flume crest) level at the control section. The method used to set (zero register) the gage, recorder, etc., depends on the structure size, the flow rate in the channel during the setting procedure, and available equipment. Standard surveying techniques are practical for accurate setting of most wall or staff gages.

The canal side slopes usually only approximate the intended slope. Mounting sloped gages so that a selected scale reading in the most frequently used range of the gage coincides with the corresponding elevation for that reading will partially compensate for deviation from design slope. Thus, the greatest reading errors will occur in the flow ranges that are seldom used. If this procedure causes the zero end of the scale to be displaced by more than about 0.015 ft, the actual side slope should be determined for adjustments to the calibration. This determination also should be made if accuracy over the full flow range is required.

Several methods can be used to zero a water level recorder; three are particularly suitable. The recorder can be set: (1) when the canal is dry, (2) when water is ponded over the flume, or (3) when water is flowing through the flume. These zero-setting methods assume that the sill-referenced elevation can be determined during the procedure. This determination is not always possible, especially on wide structures.

A stable and permanent surveying bench mark, such as a bronze cap placed in concrete, should be added in an acceptable location near the measuring structure. Its elevation should have been previously established relative to the sill elevation. More detailed information on zero-setting procedures is presented in Clemmens et al. (2001) and Bos et al. (1991).

## 8. Long-Throated Measurement Flumes

Long-throated flumes are coming into general use because they can be easily fitted into complex channel shapes as well as simple shapes (Replogle, 1975; Bos et al., 1991). Long-throated flumes have many advantages compared to other measuring devices, including Parshall flumes. Long-throated flumes are more accurate, cost less, have better technical performance, and can be computer designed and calibrated. Thus, long-throated flumes are preferred over Parshall flumes for new installations. However, some states may have laws or compact agreements mandating the use of Parshall flumes in certain situations.

### (a) Characteristics of Long-Throated Flumes

The cross-sectional flexibility of long-throated flumes allows them to fit various channel shapes more conveniently than short-throated flumes, which have fixed sizes and shapes. Because of the ability to match the channel shape, the construction of forms is usually simplified. In contrast, the fixed geometry of short-throated (including Parshall) flumes usually makes upstream and downstream transitions necessary and may require long wingwalls. Because of their flexibility and capability to fit any channel shape, long-throated flumes have more gradual transitions. Thus, floating debris presents fewer problems. Also, field observations have shown that the structure can be designed to pass sediment transported by channels with subcritical flow.

A simple type of long-throated flume developed and described by Replogle et al. (1991) consists of a flat raised sill or crest across a trapezoidal channel with an approach ramp transition from the approach channel invert. The crest drops vertically at the downstream end back to the downstream canal invert. These flumes (figure 8-5) have been called Replogle flumes, modified broad-crested weirs, and ramp flumes. This simple version of the long-throated flume is formed with only two bottom planes. An optional third plane can be used for maximum head recovery. The lined canal shape serves as the flume approach section, compared to constructing 9 to 12 planes for Parshall flumes. It is usually easier to construct the two to three planes of the long-throated flumes.

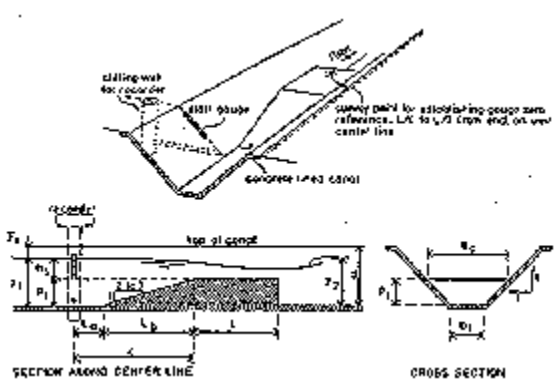



Figure 8-5 -- Flat-crested, long-throated flume in concrete-lined canal.

Some confusion of terminology exists here. Some investigators would consider the ramp flume a broad-crested weir because the flow constriction is produced from a bottom transition alone, whereas a flume would depend to some extent on side convergence. Both long-throated flumes and broad-crested weirs can be accurately rated by analysis using fluid flow concepts. The energy principle, critical depth relationships, and boundary layer theory are combined when computer calibrating these flumes and weirs. Because of this close connection, this manual will consider and call both the long-throated flumes and broad-crested weirs longthroated measurement structures.

Cost estimates for a large 930ft$^3$/s ramp flume varied from about 45 to 60 percent of that for a Parshall flume in a retrofit situation. Clemmens and Replogle (1980) cited costs of onetenth to onethird of equivalent Parshall flumes for a small ramp-type, long-throated flume. Some of the cost differences between small and large structures result from the need for service roads, foundation differences, and repair of approach channel surfaces in retrofit designs.

Long-throated flumes can be computer calibrated to within $\pm$2 percent plus head measurement error and have submergence limits up to 90 percent. Even when the listed submergence limits are near 70 percent, the absolute head loss or water surface drop through the long-throated flumes may be smaller than the older structures, depending on the particular design selection from among the many choices of shape.

Short-throated flumes can measure free flow accurately in the range of $\pm$3 to $\pm$5 percent plus head measurement error and have submergence limits from 50 to 80 percent. Increased uncertainty occurs when using flow corrections to obtain discharge rates beyond submergence limits commonly up to 95 percent. However, Peck (1988) found large correction errors caused by hysteresis shifts of the downstream wave front at a submergence of 90 percent. Correction is frequently done above 90-percent submergence with Parshall flume measurements. Using submergence corrections commonly results in discharge errors ranging from 7 to $\pm$20 percent, and possibly much more, as differences in upstream and downstream measuring heads become small.

With most flumes, close adherence to tolerances during construction is required to rely on empirical equations and calibrations provided for each specific short-throated flume. Dimensional errors and slippage of the forms frequently cause unacceptable errors that are difficult to resolve without laborious field calibrations. Field calibrations for submergence correction are very cumbersome and time consuming because of the usual project operational limitations, difficulties of controlling heads, and the need for long lag times for heads to settle to asymptotic levels. However, long-throated flumes can usually be computer recalibrated using as-built dimensions if form slippage has not caused crest slope in the direction of flow. Even then, crest correction may be practical and relatively inexpensive.

The measured heads in the short-throated flumes do not always indicate system head loss. For example, the upstream measured head of a Parshall flume is located about one-third of the way into its converging crest section, and the water surface may have a considerable drawdown from the approach canal surface elevation. This factor makes size selection and crest elevation setting more complicated than for long-throated flumes that approximate existing channel dimensions and shape.

Because long-throated flumes have greater tolerance to submergence than short-form flumes and weirs, they can deliver more discharge without having to consider the effects of submergence, which usually requires observation of a downstream depth. For example, Parshall flumes require 3 to 4 times the absolute water surface fall through the structure for free-flow measurements than long-throated flumes (Bos et al., 1991). Long-throated flumes, with tolerances for high submergence ratios, require only one head measurement. They are considered to be more accurate and economical than, for example, extending Parshall flume measurement range by submerging up to comparable long-throated flume submergence limits and making corrections using two head measurements.

Because long-throated flumes fit nicely into existing flow channels, they are convenient for making portable measurement devices. Portable long-throated devices for flow rates up to about 2 $ft^3/s$ are described in Bos et al. (1991), for trapezoidal and rectangular cross sections.

**(b) Summary of Long-Throated Flume Advantages**

The main advantages of long-throated flumes are:

(1) Provided that critical flow occurs in the throat (not excessively submerged), a rating table can be calculated with an error less than $\pm 2$ percent. This calculation can be done for any combination of a prismatic throat and an arbitrarily shaped approach channel.

(2) Long-throated flumes can have nearly any desired cross-sectional shape and can be custom fitted into most canal-site geometries. The throat cross section can be shaped in such a way that the complete range of discharge can be measured accurately.

(3) Long-throated flumes can be made into portable devices that fit conveniently into open channels with considerably less complicated construction forming.

(4) The required head loss over the long-throated flume to obtain a unique relationship between the upstream sill-referenced head and the discharge is small. This head-loss requirement may be estimated with sufficient accuracy for any of these flumes placed in any channel.

(5) Because of their gradual converging transition, these flumes have few problems with floating debris and sediment. Field observations have shown that the flume can be designed to pass sediment transported by channels with subcritical flow.

(6) Provided that the throat is horizontal in the direction of flow, a rating table can be produced that is based on post-construction dimensions. This horizontal orientation is required to allow an accurate rating table to be made to compensate for deviations from design.

(7) Under similar hydraulic and other boundary conditions, long-throated flumes are usually the most economical of all structures for accurately measuring flow.

(8) Long-throated flumes are amenable to selection, design, and calibration by computer techniques.

### (c) General Design Procedures for Long-Throated Flumes

The major steps of the design process for long-throated flumes are: (l) selection of site, (2) selection of head measurement techniques previously discussed, and (3) selection of an appropriate structure. Design is an iterative process between these steps. The order and importance of these steps depend on the specific conditions encountered.

To properly select and design a measurement structure, all demands and operational requirements to be made on the structure should be listed and matched with the properties of the known structures. These demands and operational requirements originate from four sources: (1) the hydraulic performance, (2) the construction or installation cost, (3) the ease with which the structure can be operated, and (4) the cost of maintenance. The imposed demands will be discussed in more detail. Factors that affect design and selection such as submergence, site characteristics, workmanship, and head measurement systems are discussed earlier in this chapter.

### (d) Determining Shape and Size of the Structure

Long-throated flumes operate by using a channel contraction to cause critical flow. Insufficient contraction will prevent critical flow. Under this condition, flow is then non-modular or submerged and gage readings are meaningless. Too much contraction may raise the water surface upstream and cause canal overtopping or sediment deposition problems. The designer's problem is to select the shape of the control section or throat such that critical flow occurs through-out the full range of discharge measurement and produces required accuracy. Also, the designer must provide acceptable head reading sensitivity. Usually, the sensitivity of the structure at maximum flow is selected such that a change in measurement head, $h_1$, of about 0.03 ft causes less than a 10-percent change in discharge. Achieving these design requirements may seem difficult, but existing design aids and rating tables make this task more manageable.

### (e) Computer Design Versus Sets of Pre-calibrated Long-Throated Flumes

A thorough treatment of the computational process and several pre-computed, standard-size, long-throated flumes for a variety of canals and natural channels are presented in Bos et al. (1991). The U.S. Water Conservation Laboratory, Agriculture Research Service, U.S. Department of Agriculture, developed the first computer programs for designing and calibrating long-throated flumes.

WinFlume (Wahl et al. 2000) is the most advanced software for analysis of long-throated flumes. The program is Windows-based and can be downloaded from http://www.usbr.gov/pmts/hydraulics_lab/winflume/. Ratings are determined by numerical solution of the critical-flow equations, accounting for boundary friction and other losses. The program includes a module that simplifies and accelerates the process of developing acceptable flume designs.

Clemmens et al. (2001) and Bos et al. (1991) provides calibration tables in metric (S.I.) and English units for a set of long-throated flume dimensions that covers a discharge range from about 2.8 to 280 $ft^3/s$ for trapezoidal channel shapes with side slopes of 1:1 to 1:1.5 horizontal and with bottom widths from about 1 to 5 ft. They also provide instructions for construction and field placement. Calibration tables for long-throated rectangular flumes are also presented.

The S.I. tables are reproduced in Cheremisinoff et al. (1988). Statistically fitted equations in S.I. units that closely reproduce the computed tables are presented in Hoffman et al. (1991).

The above references and this manual provide design and calibration tables for selecting and sizing long-throated structures from sets of predetermined, dimensioned, and precalibrated structures or from dimensionless design tables for some special structures. However, computer techniques are much preferred for all installations, designs, and calibrations for long-throated flumes. Thus, when practical, long-throated flumes should be designed using the WinFlume computer program (http://www.usbr.gov/pmts/hydraulics_lab/winflume/). Using restricted sets of dimensions reduces the capability of more exact custom fitting to shapes of existing channels, which can make it difficult to attain discharge range requirements. The need for computer techniques becomes much more important for large long-throated structures.

## 9. Pre-computed Design and Selection Tables for Long-Throated Flumes

Pre-computed designs and selections are provided in tables 8-2 through 8-5. These tables are provided for the convenient design and selection of long-throated structures in the field or office without use of a computer. These tables provide long-throated flume selections that can be fitted into lined trapezoidal, rectangular, circular, and earthen channels. All of the structure choices provided in the design tables consist of a simple ramp rising from the channel bottom followed by a flat horizontal crest or sill to form a broad-crested weir and ending in an abrupt drop. Tables 8-2 and 8-3 are for lined trapezoidal channels. Table 84 is for lined rectangular channels or earthen channels. Table 8-5 is for long-throated flumes that fit into circular conduits flowing partially full.

Long-throated V-shaped flumes which are used in natural channels are not included in this manual. Structures for natural streams are discussed in more detail in Brakensiek et al. (1979). Also, trapezoidal flumes with side contractions which are not generally selected for usual irrigation situations are not included in design tables. These flumes are usually more difficult to construct, more expensive, and increase head loss.

The calibration equations were developed from discharge tables computed with WinFlume and its predecessors (Clemmens et al., 1987 and 1993). Two equation forms are commonly used: a third-degree polynomial and a power form. The power form is selected here because it looks similar to the historical equations for weirs and flumes. It should be remembered that these equations are simply curve-fit results with no theoretical derivation. The equation coefficients, exponents, and constants are provided in tables 8-2 through 85. The pre-calibrated flumes in the tables have been sorted from innumerable possible choices based on practical experience and theory and reduced to a relatively few selected structures from which the designer may choose.

Table 8-2. — Long-throated flume sizes and discharge ranges for lined trapezoidal canals (English units)[a c]

| Canal Shape | | Maximum canal depth[b], $d$ (ft) | Range of Canal Capacities | | Weir selection (table 8-3) | Weir Dimensions | | Minimum head loss, $\Delta H$ [a] (ft) |
|---|---|---|---|---|---|---|---|---|
| Side slope $Z_1$ | Bottom width, $b_1$ (ft) | | $Q_{min}$[c] ($ft^3/s$) | $Q_{max}$ ($ft^3/s$) | | Crest width, $b_c$ (ft) | Sill height, $p_1$ (ft) | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| 1.0 | 1.0 | 2.5 | 1.9 | 8[d] | $A_e$ | 2.0 | 0.50 | 0.06 |
| | | | 4.2 | 16[d] | $B_e$ | 2.5 | 0.75 | 0.08 |
| | | | 4.8 | 19 | $C_e$ | 3.0 | 1.00 | 0.10 |
| | | | 5.6 | 15 | $D_e$ | 3.5 | 1.25 | 0.12 |
| | | | 6.2 | 11 | $E_e$ | 4.0 | 1.50 | 0.13 |
| 1.0 | 2.0 | 3.0 | 5.6 | 27[d] | $D_e$ | 3.5 | 0.75 | 0.10 |
| | | | 6.2 | 40 | $E_e$ | 4.0 | 1.00 | 0.12 |
| | | | 6.8 | 33 | $F_e$ | 4.5 | 1.25 | 0.14 |
| | | | 7.4 | 27 | $G_e$ | 5.0 | 1.50 | 0.15 |
| | | | 8.2 | 22 | $H_e$ | 5.5 | 1.75 | 0.16 |
| 1.25 | 1.0 | 3.0 | 5.0 | 19[d] | $I_e$ | 3.0 | 0.8 | 0.08 |
| | | | 6.4 | 35 | $J_e$ | 4.0 | 1.2 | 0.11 |
| | | | 7.6 | 26 | $K_e$ | 5.0 | 1.6 | 0.14 |
| 1.25 | 2.0 | 4.0 | 6.4 | 31[d] | $J_e$ | 4.0 | 0.8 | 0.10 |
| | | | 7.6 | 64[d] | $K_e$ | 5.0 | 1.2 | 0.13 |
| | | | 8.9 | 78 | $L_e$ | 6.0 | 1.6 | 0.16 |
| | | | 10.1 | 62 | $M_e$ | 7.0 | 2.0 | 0.18 |
| | | | 11.4 | 46 | $N_e$ | 8.0 | 2.4 | 0.20 |
| 1.5 | 2.0 | 4.0 | 8. | 49[d] | $P_e$ | 5.0 | 1.00 | 0.11 |
| | | | 9. | 82[d] | $Q_e$ | 6.0 | 1.33 | 0.13 |
| | | | 11. | 86 | $R_e$ | 7.0 | 1.67 | 0.16 |
| | | | 12. | 72 | $S_e$ | 8.0 | 2.00 | 0.18 |
| | | | 13. | 60 | $T_e$ | 9.0 | 2.33 | 0.20 |
| 1.5 | 3.0 | 5.0 | 9. | 66[d] | $Q_e$ | 6.0 | 1.00 | 0.12 |
| | | | 11. | 108[d] | $R_e$ | 7.0 | 1.33 | 0.14 |
| | | | 12. | 140[d] | $S_e$ | 8.0 | 1.67 | 0.17 |
| | | | 13. | 160 | $T_e$ | 9.0 | 2.00 | 0.20 |
| | | | 14. | 140 | $U_e$ | 10.0 | 2.33 | 0.22 |
| | | | 17. | 98 | $V_e$ | 12.0 | 3.00 | 0.25 |

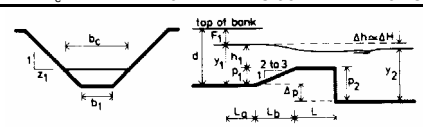
NOTES:

[a] $L_a \geq \Delta H_{1max}$; $L_b$=2 to $3p_1$; $x=L_a+L_b$>2 to 3 $H_{1max}$

$L$>1.5 $H_{1max}$

$d$>1.2 $h_{1max}+p_1$

$\Delta H$>0.1$H_1$




[b] Maximum recommended canal depth

[c] Limited by sensitivity

[d] Limited by Froude number; otherwise limited by canal depth

[e] Calibrations developed with WinFlume and the preceding computer models.

Table 8-3. — Rating equation parameters and ranges of application for flat-crested, long-throated flumes in lined trapezoidal canals[a]

| Parameters | Weir $A_e$ | Weir $B_e$ | Weir $C_e$ | Weir $D_e$ | Weir $E_e$ | Weir $F_e$ | Weir $G_e$ |
|---|---|---|---|---|---|---|---|
| $K_1$ | 9.29 | 10.53 | 11.99 | 13.73 | 14.51 | 16.18 | 17.83 |
| $K_2$ | 0.03 | 0.04 | 0.033 | 0.035 | 0.053 | 0.035 | 0.026 |
| $U$ | 1.878 | 1.883 | 1.822 | 1.824 | 1.855 | 1.784 | 1.725 |
| $h_1$, min. | 0.12 | 0.14 | 0.125 | 0.13 | 0.19 | 0.175 | 0.16 |
| $h_1$, max. | 0.92 | 1.22 | 1.25 | 1.4 | 1.69 | 1.45 | 1.24 |
| $Q$, min. | 0.26 | 0.42 | 0.42 | 0.51 | 1.05 | 1.00 | 0.98 |
| $Q$, max. | 8.44 | 16.3 | 18.9 | 26.5 | 40.7 | 32.8 | 26.8 |

| Parameters | Weir $H_e$ | Weir $I_e$ | Weir $J_e$ | Weir $K_e$ | Weir $L_e$ | Weir $M_e$ | Weir $N_e$ |
|---|---|---|---|---|---|---|---|
| $K_1$ | 19.44 | 12.81 | 15.34 | 17.13 | 20.17 | 23.62 | 27.17 |
| $K_2$ | 0.017 | 0.034 | 0.055 | 0.075 | 0.06 | 0.044 | 0.026 |
| $U$ | 1.674 | 1.868 | 1.897 | 1.907 | 1.845 | 1.766 | 1.692 |
| $h_1$, min. | 0.15 | 0.125 | 0.185 | 0.254 | 0.228 | 0.205 | 0.19 |
| $h_1$, max. | 1.05 | 1.19 | 1.485 | 1.904 | 2.007 | 1.675 | 1.34 |
| $Q$, min. | 0.97 | 0.41 | 1.02 | 2.06 | 2.03 | 2.05 | 2.01 |
| $Q$, max. | 21.7 | 18.7 | 34.8 | 63.60 | 77.0 | 61.5 | 46.0 |

| Parameters | Weir $P_e$ | Weir $Q_e$ | Weir $R_e$ | Weir $S_e$ | Weir $T_e$ | Weir $U_e$ | Weir $V_e$ |
|---|---|---|---|---|---|---|---|
| $K_1$ | 18.95 | 20.96 | 23.94 | 25.61 | 28.13 | 31.29 | 38.44 |
| $K_2$ | 0.05 | 0.07 | 0.056 | 0.072 | 0.072 | 0.062 | 0.034 |
| $U$ | 1.874 | 1.906 | 1.856 | 1.866 | 1.841 | 1.8 | 1.709 |
| $h_1$, min. | 0.162 | 0.225 | 0.21 | 0.25 | 0.275 | 0.3 | 0.3 |
| $h_1$, max. | 1.6 | 2.0 | 2.2 | 2.5 | 2.5 | 2.25 | 1.7 |
| $Q$, min. | 1.0 | 2.0 | 2.1 | 3.1 | 4.0 | 5.0 | 5.9 |
| $Q$, max. | 48.4 | 83.9 | 108 | 149 | 160 | 141 | 98.5 |

[a] Calibrations developed with WinFlume and preceding computer models.

$$Q = K_1(h_1+K_2)^U$$

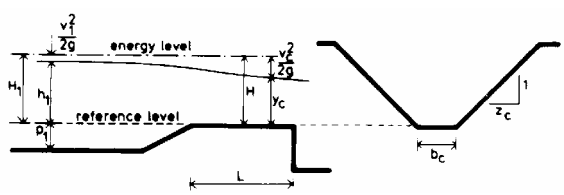


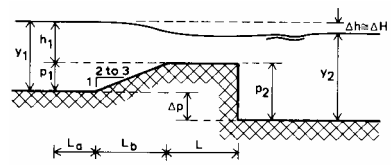
Table 8-4. — Rating equation parameters and ranges of application for flat-crested, long-throated flumes with rectangular throat sections (see Figure 8-6).

$q = K_1(h_1+K_2)^U$ where $q$ is the unit discharge in cubic feet per second per foot of width of the throat.
$Q = qb_c$

| Parameters | $0.35 \le b_c \le 0.65$ ft, $L = 0.75$ ft | | | $0.65 \le b_c \le 1.0$ ft, $L = 1.0$ ft | | | $1.0 \le b_c \le 1.5$ ft, $L = 1.5$ ft | | |
|---|---|---|---|---|---|---|---|---|---|
| | $p_1 = 0.125$ ft | $p_1 = 0.25$ ft | $p_1 = \infty$ | $p_1 = 0.25$ ft | $p_1 = 0.5$ ft | $p_1 = \infty$ | $p_1 = 0.25$ ft | $p_1 = 0.5$ ft | $p_1 = \infty$ |
| $K_1$ | 3.996 | 3.610 | 3.126 | 3.696 | 3.385 | 3.089 | 3.686 | 3.400 | 3.059 |
| $K_2$ | 0 | 0 | 0 | 0.004 | 0 | 0 | 0 | 0 | 0 |
| $U$ | 1.612 | 1.581 | 1.526 | 1.617 | 1.562 | 1.518 | 1.598 | 1.569 | 1.515 |
| $h_1$, range | 0.06 – 0.46 | 0.06 – 0.48 | 0.05 – 0.5 | 0.08 – 0.7 | 0.8 – 0.7 | 0.08 – 0.8 | 0.1 – 0.9 | 0.1 – 1.0 | 0.1 – 1.0 |
| $q$, range | 0.04 – 1.15 | 0.04 – 1.14 | 0.03 – 1.08 | 0.07 – 2.1 | 0.07 – 1.95 | 0.07 – 1.8 | 0.09 – 3.1 | 0.09 – 3.4 | 0.09 – 3.1 |
| $\Delta H$ | 0.04 | 0.06 | 0.19 | 0.06 | 0.10 | 0.26 | 0.07 | 0.11 | 0.67 |

| Parameters | $1.5 \le b_c \le 3.0$ ft, $L = 2.25$ ft | | | | $3.0 \le b_c \le 6.0$ ft, $L = 3.0$ ft | | | |
|---|---|---|---|---|---|---|---|---|
| | $p_1 = 0.25$ ft | $p_1 = 0.5$ ft | $p_1 = 1.0$ ft | $p_1 = \infty$ | $p_1 = 0.5$ ft | $p_1 = 1.0$ ft | $p_1 = 1.5$ ft | $p_1 = \infty$ |
| $K_1$ | 3.662 | 3.375 | 3.19 | 3.036 | 3.362 | 3.169 | 3.167 | 3.027 |
| $K_2$ | 0.008 | 0.011 | 0.009 | 0 | 0.013 | 0.013 | 0 | 0 |
| $U$ | 1.643 | 1.625 | 1.587 | 1.514 | 1.636 | 1.605 | 1.557 | 1.519 |
| $h_1$, range | 0.15 – 1.0 | 0.15 – 1.5 | 0.15 – 1.5 | 0.15 – 1.5 | 0.21 – 1.84 | 0.22 – 1.93 | 0.21 – 1.98 | 0.2 – 2.04 |
| $q$, range | 0.18 – 3.2 | 0.17 – 6.6 | 0.17 – 6.1 | 0.17 – 5.6 | 0.29 – 9.24 | 0.29 – 9.28 | 0.29 – 9.26 | 0.26 – 9.24 |
| $\Delta H$ | 0.07 | 0.13 | 0.2 | 0.5 | 0.13 | 0.22 | 0.29 | 0.63 |

| Parameters | $b_c \ge 6.0$ ft, $L = 4.0$ ft | | | |
|---|---|---|---|---|
| | $p_1 = 1.0$ ft | $p_1 = 1.5$ ft | $p_1 = 2.0$ ft | $p_1 = \infty$ |
| $K_1$ | 3.125 | 3.150 | 3.105 | 2.999 |
| $K_2$ | 0.017 | 0.016 | 0 | 0 |
| $U$ | 1.621 | 1.575 | 1.563 | 1.521 |
| $h_1$, range | 0.3 – 3.0 | 0.3 – 2.6 | 0.3 – 2.64 | 0.3 – 3.0 |
| $q$, range | 0.48 – 19 | 0.48 – 14.2 | 0.48 – 14.2 | 0.48 – 16 |
| $\Delta H$ | 0.25 | 0.33 | 0.40 | 0.85 |




$L_a = h_{1max}$ and $L_b$ = 2 to 3 times $p_1$ and $L_a + L_b$ = 2 to 3 times $h_{1max}$
$\Delta H = 0.1H_1$, or value listed, whichever is greater, for flumes discharging into a rectangular tailwater channel of the same width as the crest, $b_c$
$\Delta H = 0.4H_1$, or value listed, whichever is greater, for flumes with an abrupt expansion into a tailwater channel wider than the crest width, $b_c$

Table 8-5. — Equation and flow range parameters for flat-crested, long-throated flumes in partially full circular conduits ($K_1$ and $K_2$ values are valid for units of feet and ft$^3$/s only).

| $p_1/D$ | $L_a/D$ | $L_b/D$ | $L/D$ | $K_1$ | $K_2$ | $U$ | range of $h_1/D$ | range of $Q/D^{5/2}$ | $b_c/D$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.20 | 0.50 | 0.60 | 0.700 | 4.176 | 0.007 | 1.750 | 0.080 - 0.43 | 0.056 - 0.980 | 0.800 |
| 0.25 | 0.60 | 0.75 | 1.125 | 3.970 | 0.004 | 1.689 | 0.070 - 0.60 | 0.048 - 1.689 | 0.866 |
| 0.30 | 0.55 | 0.90 | 1.050 | 3.780 | 0 | 1.625 | 0.070 - 0.55 | 0.050 - 1.434 | 0.917 |
| 0.35 | 0.50 | 1.05 | 0.975 | 3.641 | 0 | 1.597 | 0.065 - 0.50 | 0.046 - 1.202 | 0.954 |
| 0.40 | 0.45 | 1.20 | 0.900 | 3.507 | 0 | 1.573 | 0.060 - 0.45 | 0.042 - 0.991 | 0.980 |
| 0.45 | 0.40 | 1.35 | 0.825 | 3.378 | 0 | 1.554 | 0.055 - 0.40 | 0.037 - 0.807 | 0.995 |
| 0.50 | 0.35 | 1.50 | 0.750 | 3.251 | 0 | 1.540 | 0.050 - 0.35 | 0.032 - 0.640 | 1.000 |

Pregage distance, $L_{pg} \ge h_{max}$ — Sill height = $p_1$
Approach, $L_a \ge h_{max}$ — Dimensionless sill height = $p_1$/D
Converging, $L_{cv} = 3\,p_1$ — $h_{min} = 0.07D$
Control, $L_c \ge 1.5\,D - p_1$ — $h_{max} = [0.85\,D - p_1]$
$\Delta H = 0.1H_1$ for flumes with a 6:1 downstream transition
$\Delta H = 0.2H_1$ for flumes with a vertical drop downstream from the crest

$$Q = D^{2.5}K_1\left(\frac{h_1}{D} + K_2\right)^U$$

Note: The length values shown are minimum lengths in direction of flow, and may be increased 30 percent with only a slight change in calibration.

Note: These values represent minimum lengths in direction of flow, may be increased 30 percent with only slight change in calibration, and should be suitable for most applications.

Besides selecting shape and size, the tables help to determine head-discharge characteristics, obtain proper measurement range, obtain sufficient sensitivity, meet the Froude number limit, and provide a final calibration.

The equation coefficients, exponents, and constants included in the tables were developed with the assumption of a known approach channel cross-sectional shape and area. However, any particular control section size and shape can be used with any approach section size and shape. But discharges must be adjusted with the approach velocity coefficient, $C_v$ (Bos et al., 1991). The rating equations with use limits are given in design and selection tables that automatically limit the Froude number. However, if smaller approach areas are used, the designer must determine that the Froude number remains less than about 0.5.

Frequently, the site conditions may call for flumes that would have dimensions beyond the ranges provided by the ratings in this chapter. To extend beyond these limits and for further information, refer to Bos et al. (1991), Clemmens et al. (1993), Ackers et al. (1978), and Bos (1989). The designer has the option of designing a flume shape or size not presented here by using the theoretically based computer program (Clemmens et al., 1987; 1993).

**(a) Long-Throated Flumes for Lined Trapezoidal Channels**

Pre-computed calibration tables for selected long-throated trapezoidal flumes suitable for use in some common canal sizes are included in tables 8-2 and 8-3. In selecting these standard canal sizes and slopes and their related flow rates for these design tables, consideration was given to proposals by the International Commission on Irrigation and Drainage (ICID), to the construction practices of the Bureau of Reclamation, and to design criteria for small canals used by the United States Natural Resources Conservation Service (formerly the Soil Conservation Service) (Bos et al., 1991).

Present practice dictates side slopes of 1:1 for small, monolithic, concrete-lined canals with bottom widths less than about 3 ft, and depths less than about 3 to 4 ft. Deeper and wider canals tend toward side slopes of 1.5 horizontal to 1 vertical. When the widths and depths are greater than about 10 ft, the trend is more toward 2:1 side slopes. This trend is particularly observed if canal operating procedures may allow rapid dewatering of the canal. In some soil conditions, rapid dewatering can cause hydrostatic pressures on the underside of the canal walls that lead to wall failure. Most of the lined canals used in a tertiary irrigation unit or on large farms are of the smaller size. They have 1- to 2-ft bottom widths, 1:1 side slopes, and capacities below 35 $ft^3/s$.

Standard sizes and precalibrations are given in tables 8-2 and 8-3 so that the designer may select one of these structures to be built into an existing lined channel as shown on figure 8-5. The designer need only select a weir width with its corresponding sill height. Standard bottom ramp-flat crest combination flumes in typical slip-formed canals were selected for precalibrations.

Table 8-2 gives pre-computed flume selections for trapezoidal canals with bottom widths of 1, 2, and 3 ft. Canal sizes with bottom widths in excess of 3 ft are omitted in the pre-computed design tables on the assumption that larger sizes deserve special design consideration and should be computer designed and calibrated using accessible programs such as those provided in Clemmens et al. (1993).

Table 8-2 provides a number of pre-computed flumes that may be used for the various combinations of bottom widths and sidewall

slopes as given in the first two columns. The third column lists recommended values of maximum canal depth, $d$, for each side-slope and bottom-width combination.

The offering of many pre-computed sizes will aid in retrofitting older canal systems and yet not prevent the adoption of standard sized canals as proposed by other agencies and international bodies, such as the Natural Resources Conservation Service, U.S. Department of Agriculture (USDA), and the ICID.

For each combination of bottom and side slope, several standard crest sill heights can be used (column 8 in table 8-2). Columns 4 and 5 give the limits on discharge for each canal-flume combination. These limits on canal capacity originate from three sources:

(1) The Froude number, equation 2-25, in the approach channel, is limited to less than 0.5 to assure water surface stability.

(2) The canal freeboard, $F_b$, upstream from the structure, should be greater than 20 percent of the upstream sill-referenced head, $h_1$. In terms of canal depth, this limit is $d \geq (p_1 + 1.2h_{1\max})$.

(3) The sensitivity of the flume at maximum flow should be such that a 3/8-in change in the value of the sill-referenced head, $h_1$, causes less than a 10-percent change in discharge.

Also indicated in the last column of table 8-2 is a minimum head loss, $\Delta H$, that the structure must provide. Excessive downstream water levels may prevent this minimum head loss, which means that the structure exceeds its modular limit or submergence limit and no longer functions as an accurate measuring device.

When flumes are placed in irrigation canals, the downstream channel is similar to the upstream channel, and the modular limit range for a flume with no expansion section of 72 to 93 percent for low flow to high flow is appropriate. The tables presented herein for long-throated flumes and broad-crested weirs are based on this assumption, except that the upper limit is conservatively reduced to 90 percent.

Thus, the design head loss is either 0.1 $h_1$ or the listed value for $\Delta H$, whichever is greater. For these tables, it was assumed that the weir was placed in a continuous channel with a constant cross section. Technically, this limit of submergence is based on the total energy drop through the structure, but the velocity head component is usually of the same order of magnitude upstream and downstream so that $\Delta h$ may be satisfactorily substituted for $\Delta H$.

Table 8-2 is primarily intended for the selection among these structures. It is also useful for the selection of canal sizes. The Froude number in the canal is automatically limited to 0.5. Selecting the smallest canal for a given capacity will give a reasonably efficient section. For instance, if the design capacity of the canal is to be 35 $ft^3/s$, the smallest canal that can be incorporated with a measuring flume has $b_1$ = 2 ft, $z_1$ = 1.0, and $d$ = 3 ft.

Each standard flume can be used for a range of bottom widths because the change in flow area upstream from the structure causes only a small change in velocity of approach and a

corresponding small change in energy head. The width ranges have been selected so that the error in discharge caused by the change in flow area is less than 1 percent. This is a systematic error for any particular approach channel size, and the extent of this error varies with discharge. However, the width of the crest must match the table dimension value.

A flume suitable for several of the listed canal bottom widths is also suitable for any intermediate width. For example, in table 8-2, structure $E_e$ can be used in canals with bottom widths between 1 and 2 ft; for example, $b_1$ = 1.25 ft. The user will need to determine the sill height to match $b_c$, head loss, and maximum design discharge for these intermediate sizes.

The rating equation coefficients and constants for the flumes are given in table 8-3 and will reproduce the values presented in the original calibration tables produced by computer modeling (Bos et al., 1991) to within about $\pm$1 percent. The original tables were computed using the following criteria and the symbols on figure 8-5:

(1) Each flume has a constant bottom width, $b_c$, and a sill height, $p_1$, that varies with the canal dimensions.

(2) The ramp length can be chosen such that it is between 2 and 3 times the sill height. The 3:1 ramp slope is preferable.

(3) The gage is located a distance equal to at least maximum total head, $H_{1max}$, upstream from the toe of the ramp. In addition, the gage should be located a distance of roughly 2 to 3 times $H_{1max}$ from the entrance to the throat.

(4) The throat length should be at least 1.5 times the maximum expected sill referenced measured head, $h_{1max}$, but should be within the limits indicated in table 8-2.

(5) The canal depth must be greater than the sum of ($p_1 + h_{1max} + F_b$), where $F_b$ is the freeboard requirement, which is roughly 0.2 times the sill referenced maximum measured head, $h_{1\mathrm{max}}$.

Occasionally, a flume cannot be found from these design tables that will work satisfactorily. The user must then judge and select between several options; for example:

(1) Find a new site for the structure with more vertical space.

(2) Add to the canal wall height upstream from the site so that more backwater effect can be created.

(3) Try one of the other shapes.

(4) Use the design tables to interpolate and get a rating for an intermediate width, probably with some sacrifice in accuracy.

(5) Produce a special design using the computer model.

**(b) Long-Throated Flumes for Unlined Channels**

Measurement flumes for earthen (unlined) channels require a structure that contains the following basic parts: entrance to approach channel, approach channel, converging transition, throat, diverging transition, stilling basin, and riprap protection. As illustrated on figure 8-6, the discharge measurement structure for an earthen channel is longer, and thus more expensive, than a structure in a concrete-lined canal (figure 8-5). In the latter, the approach channel and sides of the control section already exist, and the riprap is not needed.

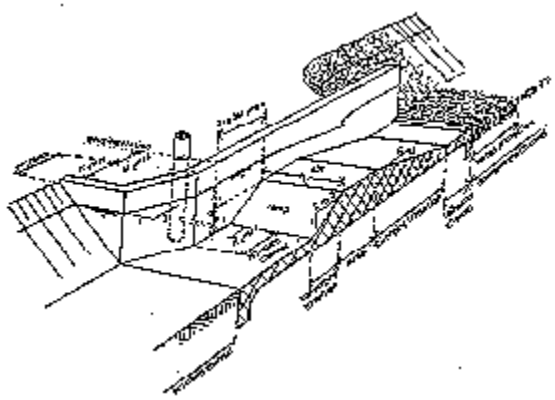


Figure 8-6 -- Flow measurement structure for earthen channel with a rectangular control section.

For earthen canals, the designer selects both structure flow width and a sill height and must be more aware of the other design considerations. For lined channel design, only the sill height must be selected.

If the upstream sill-referenced head is not measured in a rectangular approach canal of this same width, but instead is measured in the upstream earthen section, then these tables require correction to the discharge, *Q*, for the change in the approach velocity. The tables and equations can also be used to determine the rating for side-contracted rectangular flumes. Procedures needed to handle and correct for change of velocity of approach are given in Bos (1989), Bos et al. (1991), and Clemmens et al. (1993). Throat lengths for side contractions appear to work best if they exceed about 2 times the throat width.

The full-length structure of figure 8-6 can be simplified by deleting the diverging transition (downstream ramp) or the entire extended rectangular tailwater channel. These changes will increase the head loss across the structure and force energy dissipation to take place within the earthen canal section. The extended tailwater section of the structure may be deleted only if adequate riprap is provided and if the Froude number in the tailwater channel is less than 1.7 at maximum flow (Bos et al. 1991).

The approach canal of figure 8-6 provides a known flow area and velocity of approach. The coefficients and constants for rating equations for the rectangular flumes given in table 8-4 assume that the approach section is rectangular and has the same width as the throat.

The rectangular measurement flume discharges nearly equal quantities of water over equal widths. The major differences are associated with the friction along the walls. Thus, the flow is nearly two-dimensional along the crest, so rating tables can provide the unit flow rate, $q$, in cubic feet per second per foot width of crest for each value of $h_1$. This allows a wide variety of sizes for rectangular long-throated structures. For each width, $b_c$, of the structure, an accurate rating table can be developed by multiplying the design table discharges by $b_c$:

$$Q = b_c q \quad (8\text{-}1)$$

The equation, coefficients, and exponents for a series of rectangular flat-crested, long-throated flumes given in table 8-4 were developed from computer modeled tables given in Bos et al. (1991). The equation will reproduce those computer-derived table values to within $\pm$1.5 percent. The equation coefficients and exponents are given for sets of $p_1$ or crest heights. However, interpolation between crest heights gives reasonable results. Small groupings of structure widths were averaged to keep sidewall effect error to within 1 percent. Overall accuracy of rectangular long-throated flumes can be between 2 and $\pm$5 percent, depending on how accurately water levels are measured. Overall accuracy of $\pm$2 percent is possible but requires calibration by the computer program of Clemmens et al. (1993) and sensitive stilling well water level measurements.

If the approach area, $A_1$, is larger than that used to develop these rating design tables, either because of a higher sill or a wider approach channel, the ratings must be adjusted for $C_v$. To simplify this process, the discharge over the structure for a $C_v$ value of 1.0 is given in the far right column of each grouping. This column is labeled $p_1$ = *infinity* because that would cause the approach velocity of zero, and $C_v$ would be 1.0. This scenario approximates a structure at the outlet of a reservoir or lake. The complete correction procedure is given in Bos (1989), Bos et al. (1991), and Clemmens et al. (1993).

The design procedure for lined rectangular canals is relatively straightforward. It consists of selecting a table crest height, $p_1$, that causes modular flow throughout the discharge range and provides sufficient freeboard at the maximum discharge. An appropriate width must be chosen for unlined canals. Several widths will usually work. Extremely wide, shallow flows are subject to measurement errors because of low head detection sensitivity. Extremely narrow, deep flows require long structures and large head losses.

Because of the wide variety of shapes that can be encountered in earthen channels and in the range of discharges to be measured, determining the interrelated values of $h_{1max}$, $p_1$, and $b_c$ of the structure is complicated. Although this difficulty complicates the design process, it allows the designer greater flexibility and expands the applicability of the flumes. The following criteria should be considered by the designer:

(1) The discharges to be measured (per foot of width) must be within the range of discharges shown in the table for the selected structure if the dimensions in the tables are to be used.

(2) The needed or selected allowable combined measurement error should be checked and not exceeded. The allowable error may vary for different flow ranges (Bos et al., 1991; Clemmens et al., 1993).

(3) ) Sufficient head loss should be available across the structure at all flow rates. If there is an abrupt expansion (no downstream ramp) into a rectangular channel the same width as the crest, the head loss should be the greater of $0.1H_1$ or the value shown in table 8-4. If the downstream channel is wider than the crest, the head loss should be at least $0.4H_1$.

(4) Placing a structure in the canal should not cause overtopping upstream.

(5) A uniform, straight, and unobstructed approach channel section of 10 times the channel width should precede the structure.

(6) The Froude number, as defined in chapter 3, should not exceed 0.5 for a distance of at least 30 times $h_1$ upstream from the structure.

Following these criteria will allow the designer to select a satisfactory structure that will operate as intended.

For a rectangular long-throated flume in an earthen canal, the rectangular section need not extend 10 times its width upstream from the structure if a gradual taper is used to guide the flow into the rectangular section. For the structures given here, it is recommended that the rectangular section extend upstream from the head measurement location (gaging station) as shown on figure 8-6. It is also recommended that well-designed protective riprap be placed downstream from the structure for a distance of four times the maximum downstream channel flow depth, $y_{2max}$ (figure 8-6). A step should be provided at the downstream end of the structure just before the riprap section to avoid local erosion from floor jets. Sizing of riprap and filters is discussed by Bos (1989) and Bos et al. (1991).

A freeboard criteria of 0.2 $h_{1max}$ has been used satisfactorily for lined channels. For unlined channels, it may be more appropriate to specify a maximum approach flow water depth, $y_{1max}$. The downstream water depth, $y_2$, needs to be checked and must not exceed the submergence or modular limit for both the minimum and maximum expected discharge.

If the channel is rectangular or the length of the rectangular-throated flume downstream from the crest end is as on figure 86, then 0.1 $H_1$ or the $\Delta H$ value given at the bottom of table 8-4 can be used as the lower value of minimum required total head loss, $\Delta H$. If a shorter length in an earthen channel is used and the tailwater channel is significantly larger than the stilling basin would be, then considerably more head loss will probably be required. The designer should use the head loss value for the discharge into a lake or pool, $\Delta H$, = 0.4 $H_1$. This value may represent a drastic difference in the value of head loss. The designer may decide to use the shortened structure and calculate the actual modular limit by use of the computer model (Bos et al., 1991). Another alternative is to build a prototype in the field and set the crest to the appropriate level by trial and error.

**(c) Measuring Flow in Circular Conduits Partly Full**

As previously mentioned, long-throated flumes for circular conduits are convenient for use as portable and permanent measurement structures. Bottom ramps followed by flat crests or sills

can be used in circular conduits. These flumes (figure 8-7) are usually placed in the conduit at a crest height from 0.2 to 0.5 times the pipe diameter in height. The open channel depth limit in the conduit is about 0.9 times the approach conduit diameter.

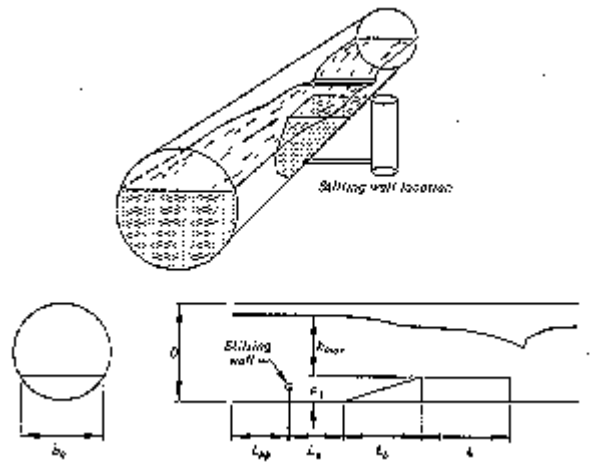


Figure 8-7 -- Long-throated flume in a partially filled circular conduit.

General methods of computing calibrations for long-throated flumes in circular conduits and selected construction configurations were developed using the computer model described in Clemmens et al. (1993).

The precalibrated selections given in table 8-5 are for average roughnesses of construction materials and are based on curve-fitted equations of computed discharge tables in English units for dimensions proportioned in terms of pipe diameter. Calibration equations for other pipe diameters can be approximated using Froude modeling relationships, which produce the following equation:

$$Q = (D)^{2.5}\, K_1(h_1 /D + K_2)^U \quad (8\text{-}2)$$

where:

$Q$ = discharge, $ft^3/s$
$D$ = diameter of pipe, ft
$K_1$ = constant from table 8-5
$K_2$ = constant from table 8-5
$h_1$ = head measured from sill top (bottom of contracted section), ft
$U$ = Exponent

Precalibrated flumes represented in table 8-5 are subject to Froude scaling. These and all the long-throated flume shapes can be similarly scaled without using the computer model as long as all dimensions remain proportional. Small differences from direct computer results are to be expected because roughness of construction materials is not usually scaled. Smooth concrete roughness was used to develop the values in table 85. The calibration equations, coefficients, constants, and exponents for the equation from table 8-5 will usually produce calibrations within $\pm$3 percent of discharge, not counting the error of head measurement, for scaling ratios between

1:5 and 5:1. Scaling expansion by 10 tends to overemphasize roughness and will underpredict discharge by 5 to 10 percent. Accuracy within $\pm 2$ percent requires individual computation of the constructed device using the constructed dimensions in the computer model of Clemmens et al. (1993).

As with the other broad-crested weirs and long-throated flumes, the width of the flat crest or sill surface, $b_c$, is one of the two most important dimensions in the flume. The other is the zero elevation of the head measuring device.

For portable measurements, it is recommended to translocate the water surface to a small stilling well overhanging the crest at the head reference location. Thus, the translocated head in the stilling well is conveniently referenced to the crest without the necessity of surveyor leveling of the structure (Bos et al., 1991). The measuring head and crest elevation can both be measured by the same point gage. The upstream gage should be used only if it is accurately leveled or is part of a permanently installed flume.

For example:

A circular concrete culvert 4 ft in diameter and 20 ft long is to be converted into a measuring structure. The outlet ends in an overfall so that a minimum sill height of 0.2*D* is useable. Develop the calibration equation using table 8-5, and sketch the installation dimensions.

Using equation 8-2 and table 8-5 gives:

$$Q = (D^{5/2})K_1(h_1/D + K_2)^U$$

or: $Q = (4)^{5/2}\ 4.13\ (h_1/4 + 0.004)^{1.736}$

or: $Q = 132.2(h_1/4 + 0.004)^{1.736}$

for an $h_1$ range of: $0.08\ D \leq h_1 \leq 0.65D$

or: $0.32 \leq h_1 \leq 2.6$

and a $Q$ range of: $0.056\ D^{5/2} \leq Q \leq 1.975D^{5/2}$

or: $1.792 \leq Q \leq 63.2$

The modular or submergence limits should be checked and should not exceed $0.8h_1$ if a vertical drop exists at the end of the downstream crest and should not exceed $0.9h_1$ if a 1:6 horizontal sloping ramp downstream is added such as shown on figure 8-6. These modular limits are equivalent to minimum required head loss to measure flow of $0.2h_1$. All flow rates to be measured should be checked for exceeding the modular limit.

A stilling well can be placed in the channel if it does not significantly obstruct flow or divert flow to a far bank and cause erosion. Placing the stilling well in the upstream channel often causes detrimental flow patterns that can affect the function of the flow measuring device, unless it is dug deep into the bank or placed a substantial distance upstream.

Represented on figure 8-8 is a static pressure tube consisting of several 1/8-in-diameter holes drilled into 1-in polyvinylchloride pipe used as a head measurement pickup. These holes are

located about 2 ft from the end of the capped pipe so that flow separation around the end of the pipe is neutralized by the time the flow passes the pressure sensing holes. The water level sensed here is transmitted to the stilling well where the depth can be observed by any of the several methods discussed in section 7 of this chapter.

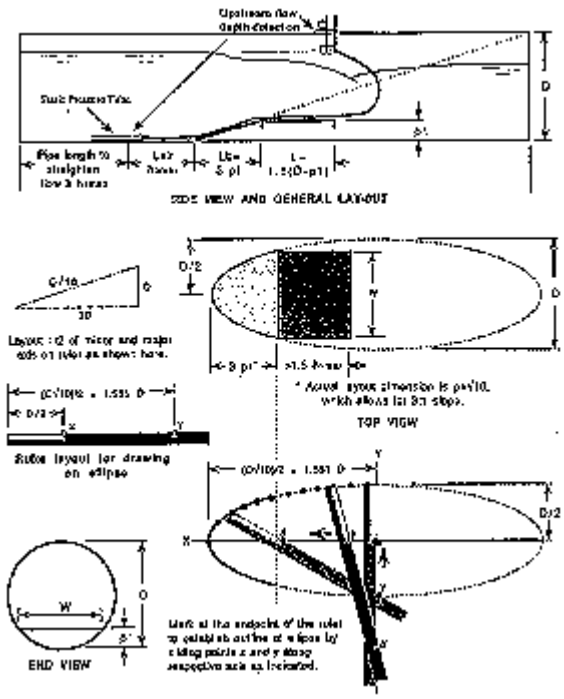



Figure 8-8 -- Layout scheme for portable long-throated measurement structures in partially full circular conduits.

Note that the sensing holes are well above the floor of the channel, which should reduce sediment plugging. Also, note that the sensing pipe is clamped tightly to the wall of the culvert so that debris trapping is minimized. The area obstruction of the pipe crossing the sill control area is small and can be ignored.

**(d) Constructing Portable Long-Throated Flumes for Circular and Semicircular Conduits**

A 0.2*D* sill height is commonly selected for semicircular conduits. For either semicircular or complete pipes, the sloping ramp can be fabricated from sheet materials such as galvanized steel, stainless steel, aluminum, or marine plywood. A suggested method for layout of the necessary portion of an ellipse is illustrated on figure 8-8.

## 10. Parshall Flumes

Although Parshall flumes are in extensive use in many western irrigation projects, they are no longer generally recommended because of the advantages of long-throated flumes previously cited and the disadvantages of Parshall flumes to be subsequently discussed. Some states specify the use of Parshall flumes by law for certain situations.

In the past, it was common to size and set flumes for 95-percent submergence to reduce approach flow depths 4 to 6 in. The 1976 second edition of this manual gives detailed examples of

selecting size and setting crest elevation for free flow and intended submergence. Although correction methods for determining submerged discharge exist, designing flumes for submerged flow measurement is no longer considered good design practice because it compromises accuracy. For example, imprecision of head measurement increases discharge error by 4 to 20 percent over the primary free-flow accuracy of 3 to 5 percent. In addition, a recent study (Peck, 1988) found a 12-percent discontinuity in the submergence correction function for a 1-ft flume depending upon whether downstream measuring head results from a falling or rising water surface.

Designing and setting Parshall flumes for submerged flow measurement is not usually recommended because less expensive, long-throated flumes can be designed that approach or exceed 90 percent submergence limits with a single upstream head measurement. Moreover, the absolute required drop in water surface is usually less for the long-throated flumes, particularly the modified broad-crested weir styles.

Because so many Parshall flumes are currently in use, the remaining part of this section is concerned mainly with structural dimensions for checking existing flumes, equations for computing discharges, free-flow discharge tables for each size flume, plots for submerged discharge measurement corrections, and head loss curves for assessing upstream depth changes caused by downstream delivery depth changes.

Care must be taken to construct Parshall flumes according to the structural dimensions given on figure 8-9. This factor becomes more important as size gets smaller. The portion of the flume downstream from the end of the converging section need not be constructed if the flume has been set for free flow where it is not expected to operate above submergence limit. This truncated version of the Parshall flume is sometimes referred to as the Montana flume.

Submergence corrections or discharge cannot be determined for Montana flumes or other modified Parshall flumes because they do not include the part of the full Parshall flume where the submergence head, $h_b$, was measured during calibration. Different size Parshall flumes are not geometrically proportional. For example, a dimension in the 12-ft flume cannot be assumed to be three times the corresponding dimension in the 4-ft flume. Each of the flumes on figure 8-9 is a standard device and has been calibrated for the range of discharges shown in the table. The flumes can reliably measure free-flow discharge to within "3 to "5 percent, plus head detection error, if standard dimensions are attained during construction, the flume is correctly set, and the flume is operated and maintained according to the recommended procedures.

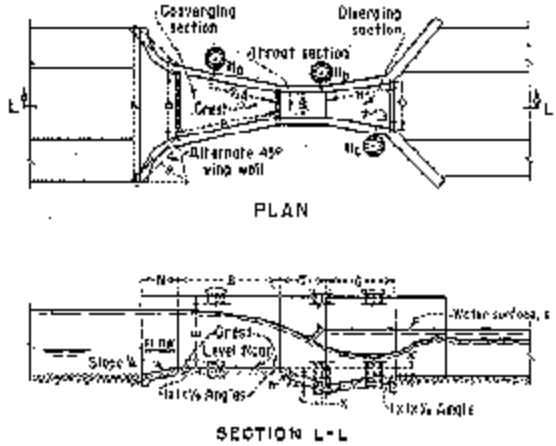



Figure 8-9 -- Parshall flume dimensions -- sheet 1 of 2
(courtesy of U.S. Natural Resources Conservation Services).

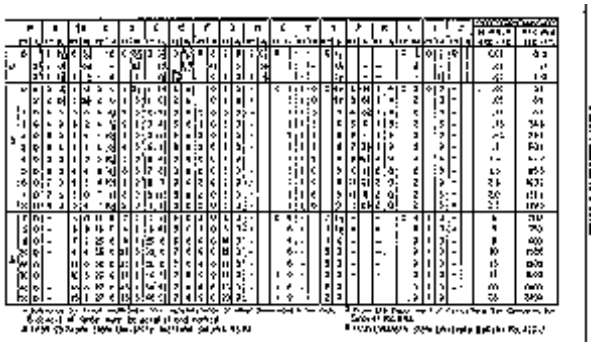


Figure 8-9 -- Parshall flume dimensions -- sheet 2 of 2
(courtesy of U.S. Natural Resources Conservation Services).

Parshall flume sizes are designated by the throat width, *W*, and dimensions are available for flumes from the 1-in size for free flow of 0.03 $ft^3/s$ at 0.2 ft of measuring head up to the 50-ft size with 3,000 $ft^3/s$ at a head of 5.7 ft. The free-flow discharge range and dimensions for Parshall flumes are given on figure 8-9. The minimum flows in this table up to the 1-ft-size flume are for a head of 0.2 ft because measuring at smaller heads results in imprecision of head measurement and surface tension effects. The remaining discharge limits are based on the range of the calibration data and practical size considerations.

### (a) Free-Flow Discharge Tables and Equations

Parshall flumes were calibrated empirically to generate the free-flow head versus discharge rating for the 1-in to 50-ft flumes. Some of the larger sizes were not directly calibrated but were scale modeled. The free-flow discharge equations for the standard Parshall flume sizes are of the form:

$$Q = Ch_a^n \quad (8\text{-}3)$$

where:

$h_a$ = measuring head (ft)  $Q$ = discharge ($ft^3/s$)  $C$ and $n$ for each size are given in table 8-6

Head versus discharge is given in tables A8-7 through A8-21 for all sizes (see appendix).

Table 8-6

Coefficients ($C$) and exponents ($n$) for Parshall flumes for equation 8-3

| Throat width | Coefficient ($C$) | Exponent ($n$) |
|---|---|---|
| 1 in | 0.338 | 1.55 |
| 2 in | 0.676 | 1.55 |
| 3 in | 0.992 | 1.55 |
| 6 in | 2.06 | 1.58 |
| 9 in | 3.07 | 1.53 |
| 1 ft | 3.95 | 1.55 |
| 2 ft | 8.00 | 1.55 |
| 3 ft | 12.00 | 1.57 |
| 4 ft | 16.00 | 1.58 |
| 5 ft | 20.00 | 1.59 |
| 6 ft | 24.00 | 1.59 |
| 7 ft | 28.00 | 1.60 |
| 8 ft | 32.00 | 1.61 |
| 10 ft | 39.38 | 1.60 |
| 12 ft | 46.75 | 1.60 |
| 15 ft | 57.81 | 1.60 |
| 20 ft | 76.25 | 1.60 |
| 25 ft | 94.69 | 1.60 |
| 30 ft | 113.13 | 1.60 |
| 40 ft | 150.00 | 1.60 |
| 50 ft | 186.88 | 1.60 |

**(b) Submerged Flow Determination**

Calibration tests show that the discharge at a given upstream measuring head is not reduced until the submergence ratio, $h_b/h_a$ (submergence head to measuring head) expressed in percent, exceeds the following values:

50 percent for flumes 1, 2, and 3 in wide

60 percent for flumes 6 and 9 in wide

70 percent for flumes 1 to 8 ft wide

80 percent for flumes 8 to 50 ft wide

These submergence limits are based on two measuring head locations shown in figure 8-9 within the structure and do not measure all the head loss caused by the flume. Thus, these limits do not represent the total required head loss needed to measure flow with one head measurement. The method of determining submerged flow discharge varies with different flume size groups. Examples are provided later.

**(1) Submerged Flow in 1- Through 3-Inch Flumes**

Submergence begins to reduce the discharge through the 1-, 2-, and 3-in flumes when it exceeds 50 percent. To determine discharges for submerged flows, the heads $h_a$ and $h_b$ are used with figures 8-10, 811, and 8-12. Users found they had difficulties in obtaining field readings of $h_a$ because of wave interference. To solve this problem, figure 8-13 was developed to relate $h_b$ to $h_c$, which is located at the downstream end of the flume divergence where the water surface is smoother.

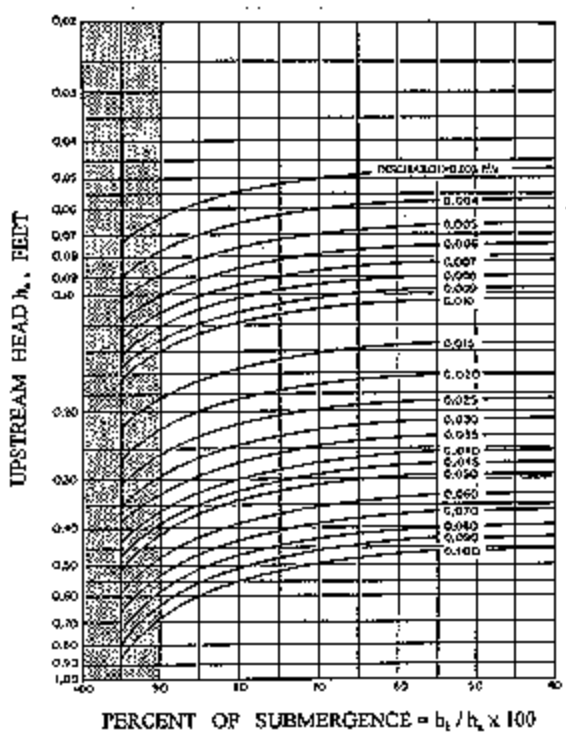



Figure 8-10 -- Rate of submerged flow through a 1-in Parshall flume (Robinson, 1957).

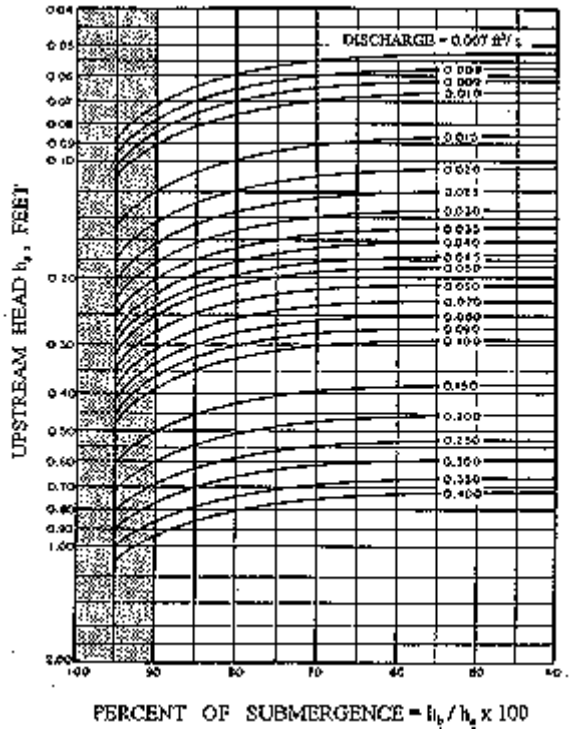



Figure 8-11 -- Rate of submerged flow through a 2-in Parshall flume (Robinson, 1957).

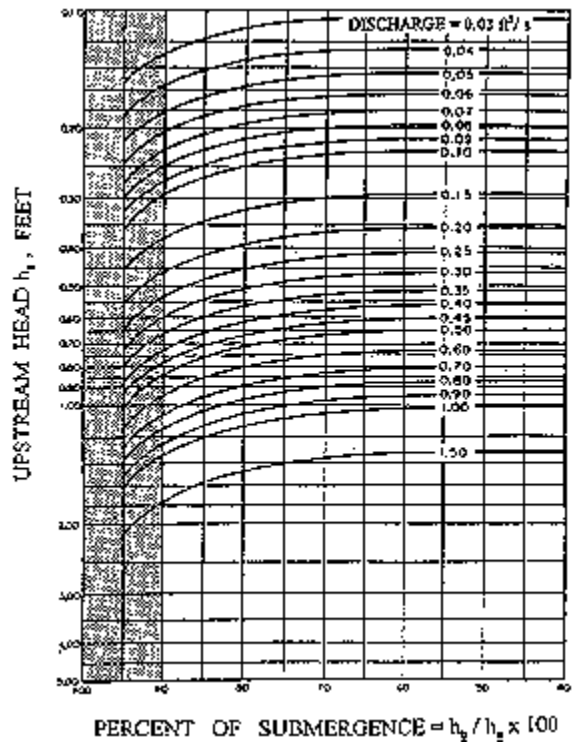



Figure 8-12 -- Rate of submerged flow through a 3-in Parshall flume (Robinson, 1957).

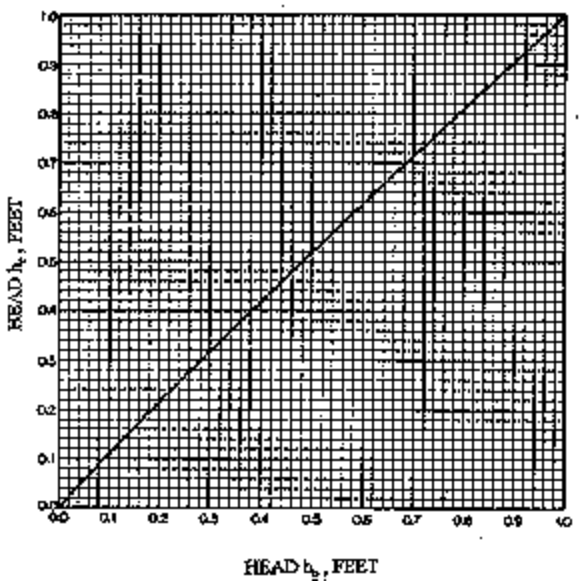



Figure 8-13 -- Relationship of $h_c$ and $h_b$ gages for 1-, 2-, and 3-in Parshall flumes for submergence greater than 50 percent (Robinson, 1957).

In a 3-in flume, assume $h_a$ of 0.20 ft and the downstream head measured at the $h_c$ gage is 0.19 ft. To determine the discharge, turn to the curve on figure 8-13, which shows the relationship of $h_c$ to $h_b$. For a value of $h_c$ equal to 0.19, $h_b$ is found to be 0.17. The submergence, $h_b/h_a$ = 0.17/0.20 = 0.85 or 85 percent.

Enter figure 8-12 with the value of the upstream head, $h_a$, of 0.20 and move horizontally to the right to the vertical line for $h_b/h_a$ of 85 percent. This intersection point lies about seven-tenths of the distance from the curved discharge line for 0.06 $ft^3/s$, toward the 0.07$ft^3/s$ line. The interpolated discharge value is 0.067 $ft^3/s$. This rate of flow for submerged conditions is considerably less than the free-flow discharge value of 0.082 $ft^3/s$ for $h_a$ of 0.20 ft. As mentioned previously in section 7 of this chapter, correcting for submergences greater than 90 percent does not provide reliable accuracy.

**(2) Submerged Flow Determination With 6- and 9-Inch Flumes**

When 6- and 9-in flumes are operating with submergences greater than 60 percent, the discharge is directly determined using figures 8-14 and 8-15, respectively. For example, determine the discharge through a 6-in flume when $h_a$ is 1.32 ft and $h_b$ is 1.20 ft. The submergence ratio, 1.20 divided by 1.32, is 0.91, or 91 percent. On figure 8-14, find 91 percent along the left-hand vertical scale and follow the 91-percent line horizontally to intersect the curved line for $h_a$, which is 1.32 (one-fifth the distance between the 1.3 and 1.4 lines). Then move vertically downward from this point to the scale at the base of the diagram and find that the submerged rate of flow is 2.02 $ft^3/s$. As mentioned previously in section 7 of this chapter, correcting for submergences greater than 90 percent does not provide reliable accuracy.

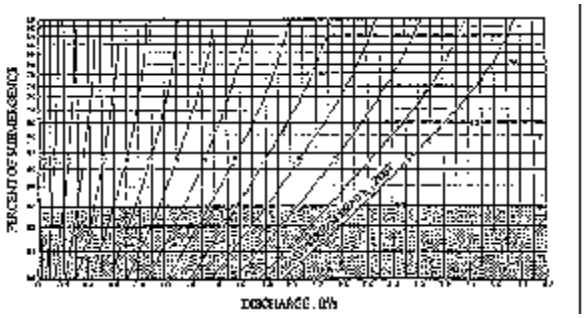


Figure 8-14 -- Diagram of determining rate of submerged flow for a 6-in Parshall flume (courtesy of U.S. Natural Resources Conservation Service).

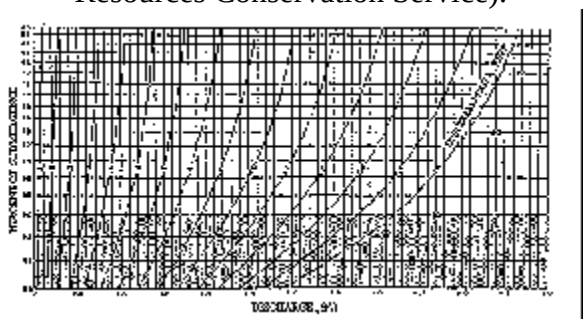


Figure 8-15 -- Diagram for determining rate of submerged flow for a 9-in Parshall flume (courtesy of U.S. Natural Resources Conservation Service).

**(3) Submergence Correction for 1- to 8-Foot Flumes**

The submergence corrections that must be subtracted from the free-flow values in table A8-12 to obtain submerged flow values in a 1-ft flume are shown on figure 8-16. For example, in a 1-ft flume with $h_a$ of 1.00 ft, the discharge from table A8-12 is 4.00 $ft^3/s$. If $h_b$ is measured to be 0.8, the submergence, $h_b/h_a$, is equal to 80 percent. If figure 812 for $h_a$ is 1.00 and submergence is 80 percent, the correction is 0.35 $ft^3/s$. Therefore, submergence would result in a reduction in discharge of 0.35 $ft^3/s$ or an actual discharge of 3.65 $ft^3/s$, compared to a free-flow discharge of 4.00 $ft^3/s$.

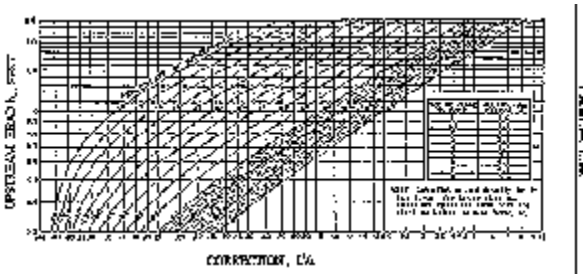


Figure 8-16 -- Diagram for determining correction to be subtracted from free discharge to obtain rate of submerged flow for 1- through 8-ft Parshall flumes.

Submergence correction values for 1- to 8-ft flumes are obtained from figure 8-16, but the procedures contained in the note in the figure must be followed.

These procedures state that values read from the curve are multiplied by the *M* values listed in the table on figure 8-16 for each size to obtain the product or correction to subtract from the free discharge values.

For example, assume that submerged flow occurs in a 3-ft flume where $h_a$ is 2.10 ft and $h_b$ is 1.89 ft. The submergence ratio, 1.89 divided by 2.10, is 0.90, or 90-percent submergence. The free-flow discharge for a 3-ft flume with $h_a$ of 2.10 is found from table A8-12 to be 38.4 $ft^3/s$. On figure 8-16, $h_a$ is 2.10 and submergence is 90 percent: a correction of 3.5 $ft^3/s$. However, this correction is only for a 1-ft flume. For a 3-ft flume, the correction must be multiplied by 2.4 (from tabulation on figure 8-16) to get the total correction of 8.4 $ft^3/s$. The corrected submerged discharge is, therefore, 38.4 minus 8.4, or 30.0 $ft^3/s$. As mentioned previously in section 7 of this chapter, correcting for submergences greater than 90 percent does not provide reliable accuracy.

**(4) Submergence Correction for 10- to 50-Foot Flumes**

The submergence ratio, $h_b/h_a$, expressed in percent, and the $h_a$ value are used on figure 8-17 to obtain the correction to be subtracted from the free-flow discharge determined from tables A8-12 through A8-20.

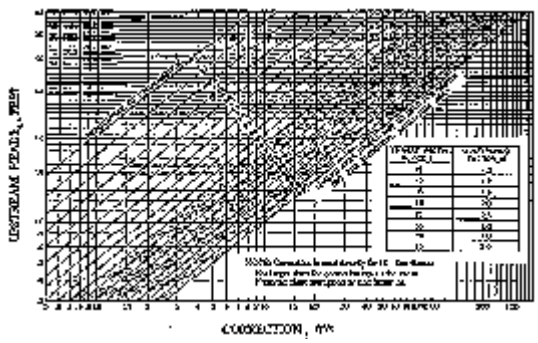


Figure 8-17 -- Diagram for determining correction to be subtracted from free discharge flow to obtain submerged flow discharges through 10- to 50-ft Parshall flumes (Parshall 1953).

The correction values, indicated along the base of the diagram on figure 817, give the number of cubic feet per second to be subtracted for each 10 ft of crest width, *W*. To aid in determining the multi plying factor, a tabulation has been incorporated on figure 8-17.

Thus, to determine the discharge for submerged flow through a 20ft flume when $h_a$ is 3.25 ft and $h_b$ is 3.06 ft, first determine the submergence ratio:

$$\frac{h_b}{h_a} = 0.941 = 94.1\%$$

Enter at the left side of the diagram of figure 8-17, and at $h_a$ equals 3.25, project a horizontal line to intersect the 94-percent line, then continue on to one-tenth of the distance between the 94- and 95per-cent lines. Vertically below this point on the horizontal scale is the correction value, 56 $ft^3/s$. For a 20-ft flume, the multiplying factor is 2.0 (from tabulation on figure 8-17), and the total correction is:

$$2.0 \times 56 = 112 \text{ ft}^3/\text{s}$$

The free discharge value from table A8-16 for $h_a$ of 3.25 is about 503 $ft^3/s$. Therefore, the submerged flow is 503 minus 112, or 391 $ft^3/s$. As mentioned previously in section 7 of this chapter, correcting for submergences greater than 90 percent does not provide reliable accuracy.

**(c) Head Loss Determination**

Flumes are obstructions that produce backwater that extends upstream from the flume and raises the water surface in the approach channel. This difference in elevation of the flow upstream from the structure with and without the flume in place is the head loss caused by the flume. The difference in measuring heads is not the head loss of Parshall flumes.

Downstream channel depth-discharge relationships often change with changes of downstream flow resistance, which frequently varies with sediment deposits, debris, canal checking operations, and aging. Downstream changes in flow resistance plus head loss can cause overtopping of upstream approach channel banks. Thus, irrigation system managers that have Parshall flumes need to determine head losses.

**(1) Head Loss for 10- to 50-Foot Throats**

The increase in depth upstream from the structure or the head loss for the 10- to 50-ft flume is determined using figure 8-18. For example, assume a 20-ft flume is set 1.4 ft above the bottom of the channel, is discharging 950 $ft^3/s$, and is at 90-percent submergence. The head loss from figure 8-18 is obtained by following the vertical 90-percent submergence line up to the curved discharge line for 950 $ft^3/s$, projecting a horizontal line to the sloping 20-ft throat line, and coming vertically down to the head loss scale reading of 0.9 ft.

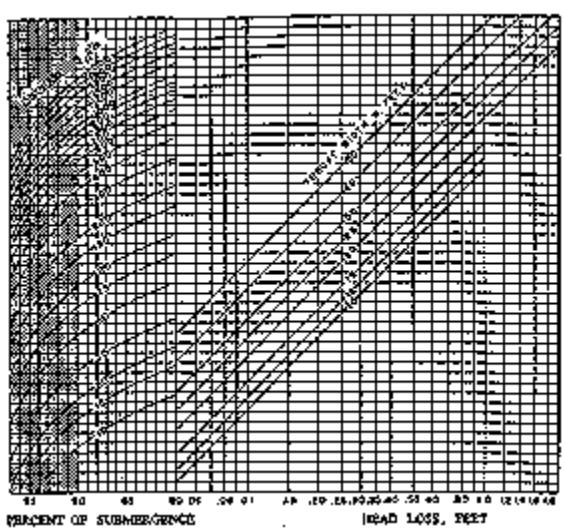



Figure 8-18 -- Head loss through 10- to 50-ft Parshall flumes (Parshall 1953).

**(2) Head Loss for 1- to 8-Foot Throats**

The head loss values for flumes 1 to 8 ft wide can be determined from figure 8-19. For example, assume a 4-ft flume which has a 70-percent submergence with 20 $ft^3/s$, and determine the head loss. Using figure 8-19, find the intersection of the vertical 70-percent line with the slanting 20-$ft^3/s$ discharge line in the left side of the figure. Then, from this intersection, project a horizontal line to the intersection with the slanting line for the 4-ft throat width in the right side of the figure. From this point, project vertically down to read head loss on the bottom scale, which reads 0.43 ft.

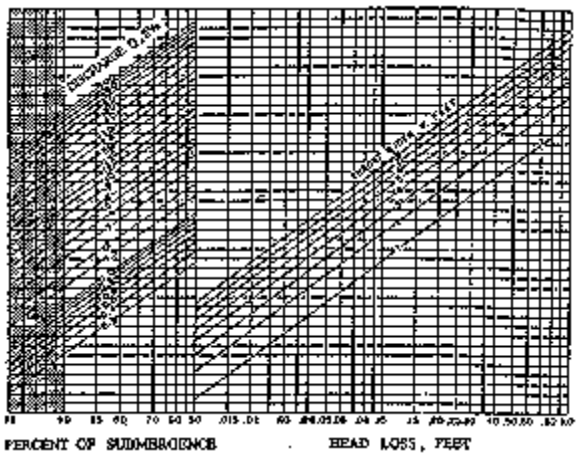



Figure 8-19 -- Head loss through 1- to 8-ft Parshall flumes
(courtesy of U.S. Natural Resources Conservation Service.

**(3) Head Loss for 9-Inch Throats and Smaller**

Losses for 9in flumes and smaller are usually less critical, and the elevation of the upstream water surface is determined in the manner used for the

1-, 2-, and 3-in flumes. The difference between $h_a$ and $h_b$ is considered an adequate estimate of head loss.

## Additional information for *Parshall Flumes*

The listings here should not be construed as an endorsement or recommendation of a service or product by the Bureau of Reclamation, Agricultural Research Service, Natural Resource Conservation Service, or other participants of these web pages. These are provided only as a convenience to our web clients. The listing below were selected based on a manufacture statement that they can provide a device related to this chapter or section.

# Computing the Submerged-Flow Correction for Parshall Flumes

## Tony L. Wahl

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**Preface:** The information provided below is intended for use with *existing* Parshall flumes operating in the submerged-flow correction zone. *If you are contemplating construction of a new Parshall flume, you are strongly urged to consider a long-throated flume. Information about long-throated flumes is available at* www.usbr.gov/wrrl/winflume

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Figures 8-16 and 8-17 in the Water Measurement Manual, 3rd Edition (Chapter 8, Section 10), provide a means for correcting free-flow discharges through Parshall flumes to account for the effect of submergence. Figure 8-16 is for flumes of 1-ft width, and includes multiplying factors for use with flumes of 2- to 8-ft width. Figure 8-17 is for flumes of 10-ft width, again with multiplying factors for larger flumes up to 50-ft width, and can be easily converted to a single equation:

$$DQ = \frac{h_a^{\,2}W}{10}\,[\mathbf{3.364 + 20.19}S^2\,\mathbf{ln}\,S]^2$$

where $DQ$ is the discharge reduction in $ft^3/s$, $h_a$ is the upstream head in feet, $W$ is the flume width in feet, and $S$ is the submergence ratio, $h_b/h_a$.

Figure 8-16 is more difficult to convert to an equation form, due to its non-linear nature (in log-log space) at low upstream heads and low submergences. Hilaire Peck ("Submerged Flow in Parshall Flumes", in *Hydraulic Engineering*, Proceedings of the 1988 National Conference on Hydraulic Engineering, American Society of Civil Engineers, Colorado Springs, CO, August 8-12, 1988) tested 1-ft Parshall flumes and developed an equation to compute discharge reductions due to submergence:

$$DQ = \mathbf{0.000132}h_a^{2.123}e^{9.284S}$$

where $e$ is the base of natural logarithms, 2.7183. This equation yields smaller discharge reductions and does not have the non-linear character of Parshall's nomograph (Fig. 8-16).

Converting Figure 8-16 to a tractable equation would be a tedious exercise. Also, Peck's more detailed experiments on 1-ft flumes indicate less discharge reduction due to submergence than do Parshall's limited data, making the value of such an effort questionable. More detailed physical testing is needed to extend Peck's data for use on 2- to 8-ft wide flumes.

However, in the interim, it is reasonable to use Peck's equation for 1-ft wide flumes and the multiplying factors shown on Figure 8-16 to obtain discharge corrections for 2- to 8-ft wide flumes, with one caveat. Peck's equation is only valid for flow conditions on the right side of the discontinuity that he observed in submerged flow rating curves (i.e., submergences less than about 85 to 90 percent). (Note: Peck has an equation applicable to the left side of the discontinuity, but procedures for defining the exact point of discontinuity are not well defined.)

Thus, for flumes of 1- to 8-ft width the discharge reduction in $ft^3/s$ can be computed using:

$$DQ = M(\mathbf{0.000132}\ h_a^{2.123} e^{9.284S})$$

where $M$ is a multiplying factor that varies as follows:

| Size of Flume, $W$ (feet) | Multiplying Factor, $M$ |
|---|---|
| 1 | 1.0 |
| 1.5 | 1.4 |
| 2 | 1.8 |
| 3 | 2.4 |
| 4 | 3.1 |
| 5 | 3.7 |
| 6 | 4.3 |
| 7 | 4.9 |
| 8 | 5.4 |

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# CHAPTER 9 - SUBMERGED ORIFICES

## 1. Definition and Classification of Orifices

An orifice used as a measuring device is a well-defined, sharp-edged opening in a wall or bulkhead through which flow occurs. Orifices may be used to measure rates of flow when the size and shape of the orifices and the heads acting upon them are known. For irrigation use, orifices are commonly circular or rectangular in shape and are generally placed in vertical surfaces, perpendicular to the direction of channel flow.

A submerged orifice and the same orifice discharging freely have nearly the same coefficient of discharge. Submerging an orifice provides the capability to measure relatively large flows with a small drop in water surface, conserving delivery head compared with weirs. However, the submerged orifice requires head measurements upstream and downstream. The difference between the two heads is used in the orifice equation (equation 9-1). A free- flow measurement requires measurement of only one upstream head.

Using an orifice as a water measuring device demands attention to dimensions and craftsmanship, and the orifice must closely simulate conditions existing when it was calibrated. Equation coefficients depend on these details and can vary considerably. For full contraction, the orifice plate should be machined around the entire perimeter of the opening to a clean, straight, and sharp upstream edge and corner in the direction of the flow. Rounding of an upstream face corner can partially or fully suppress contraction. For example, 1-percent rounding of the upstream face corner of the opening perimeter in terms of minimum orifice opening dimension causes about a 3-percent increase of the contraction coefficient. A well-designed bellmouth will eliminate all contraction (Schuster, 1970).

Orifices may be partially contracted in two senses. One is the amount of curvature of the jet in the direction of flow and the other in the amount of orifice opening perimeter which produces no curvature of the jet passing through the opening. The latter is called suppression. An example of a partially suppressed orifice is a sluice gate, where the approach boundary on the sides and bottom continues past the sharp edge of the gate leaf above. This arrangement eliminates the jet contraction along part of the orifice opening perimeter, increasing the effective coefficient of discharge.

Coefficients are used in equations to account for: neglecting the approach velocity head, the approach velocity distribution, the decrease of jet velocity caused by friction, and the amount of jet contraction caused by the flow curving around the corner of the orifice perimeter.

The proximity of the upstream water surface to the top of the orifice opening affects the amount of contraction. For full contraction, the water surface upstream from the orifice must always be well above the top of the opening. Similar to weirs, if the bottom or the side walls of the approach channel are too close to the orifice edges, then the sides and bottom of the orifice jet are not fully contracted. If the upstream water surface drops below the top of the opening, the opening, in effect, becomes a weir.

## 2. Advantages and Disadvantages

Submerged orifices conserve head and are used where fall is insufficient for weirs. Submerged orifices can be used where cost, space limitations, or other site conditions do not justify a weir or flume. A disadvantage of the submerged orifice is that accumulations of submerged debris or sand and sediment upstream from the orifice may prevent accurate measurements. Severe blockage with trash could cause upstream bank overtopping. Where fall is not limited and space is available, a long-throated flume should ordinarily be chosen. Both weirs and flumes are less susceptible to interference from weeds and trash, and clogging is easily visible. Typically, sharp-crested weirs and some long-throated flumes are less expensive and more accurate.

## 3. Fully Contracted Submerged Orifice

The principal type of submerged orifice used for measuring irrigation water in an open channel is the vertical, sharp-edged, fully contracted, rectangular orifice. This orifice is accurate and is the principal type for which the discharge coefficient has been carefully determined. The longer dimension of the rectangle is horizontal to help meet the approach flow boundary conditions discussed in the next section of this chapter. Such an orifice is illustrated on figure 9-1 with recommended box dimensions on figure 9-1 given in table 9-1.

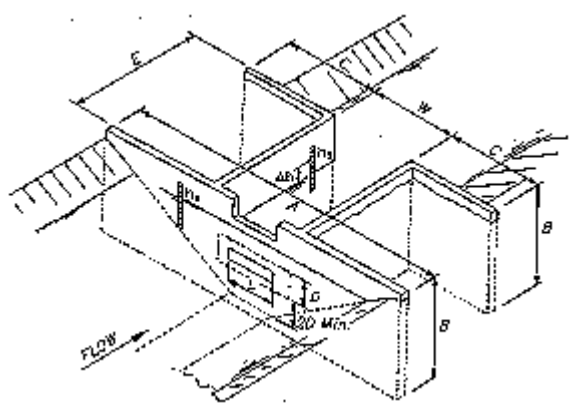


Figure 9-1 -- Submerged-orifice measurement structure viewed from upstream (refer to table 9-1 for dimensions).

| Table 9-1. Recommended box sizes and dimensions for a submerged orifice | | | | | | |
|---|---|---|---|---|---|---|
| Size of orifice | | Height of structure, *B* (ft) | Width of head wall, *A* (ft) | Length, *E* (ft) | Width, *W* (ft) | Length of downstream wing wall, *C* (ft) |
| *Height*, *D* (in) | Length, *L* (in) | | | | | |
| 3 | 12 | 4 | 10 | 3.0 | 2.5 | 2 |
| 3 | 24 | 4 | 12 | 3.0 | 3.5 | 2 |
| 6 | 12 | 5 | 12 | 3.5 | 2.5 | 3 |
| 6 | 18 | 5 | 14 | 3.5 | 3.0 | 3 |
| 6 | 24 | 5 | 14 | 3.5 | 3.5 | 3 |
| 9 | 16 | 6 | 14 | 3.5 | 3.0 | 3 |
| 9 | 24 | 6 | 16 | 3.5 | 3.5 | 3 |

## 4. Conditions for Accuracy of Fully Contracted Submerged Rectangular Orifices

The standard submerged rectangular orifice described on figure 9-1 and in table 9-1 has four sides, consisting of thin-edged plates, far enough removed from the sides, bottom, and top of the water prism in the approach channel that essentially full jet contraction occurs. The contraction which occurs is about equal to the maximum that could be obtained with the sides of the orifice at infinite distances from the water prism boundaries.

The following conditions are required to accurately replicate equation 9-1 coefficients and use table 9-1:

(1) The upstream edges of the orifice should be straight, sharp, and smooth.

(2) The upstream face of the orifice wall should be vertical.

(3) The top and bottom edges of the orifice opening should be level.

(4) The sides of the opening should be truly vertical.

(5) The inset orifice plates must be flush, and the upstream face of the supporting bulkhead with the fasteners must be countersunk on the upstream side.

(6) The distance from the opening edges to the boundary and the water surface, both on the upstream and downstream sides, should be greater than twice the least dimension of the orifice opening.

(7) The face of the plates must be free of grease and oil.

(8) Avoid orifice plate knife edges because they are a safety hazard and can damage easily; orifice opening plate perimeter should be between 0.03 and 0.08 inch (in) thick.

(9) If the plates are thicker than condition (8), the plate edges should be reduced to the required thickness by chamfering the downstream edge of the orifice plates to an angle of at least 45 degrees.

(10) Flow edges of plates require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasive cloth or paper.

(11) The edges of the supporting bulkhead wall cutout to receive the orifice opening plate should be located at least one wall thickness from the orifice opening edges.

(12) For submerged flow, the effective head on the orifice is the actual difference in elevation between the water surfaces upstream and downstream from the orifice wall. The differential head should be at least 0.2 foot (ft).

(13) For free flow, the effective head on the orifice is the difference in elevation between the upstream water surface and the center of the orifice opening.

(14) The cross-sectional area of the water prism 20 to 30 ft upstream from the orifice should be at least eight times the cross-sectional area of the orifice.

(15) The selected type of head measuring device must be compatible with required project accuracy and the amount of head loss that is acceptable.

If all these requirements are satisfied, then the effective discharge coefficient is good to +/-2 percent. However, the accuracy of discharge measurement depends strongly on the secondary head measurement system selected and the magnitude of $\Delta h$. Chapter 8 contains error values for different head measurement systems.

## 5. Discharge Through a Submerged Rectangular Orifice

The equation for computing the discharge of the standard submerged rectangular orifice is:

$$Q = C_c C_{vf} C_{va} A \sqrt{2g(h_1 - h_2)} \quad \text{(9-1b)}$$

where:

$Q$ = discharge ($ft^3/s$)
$C_c$ = coefficient of contraction
$C_{vf}$ = coefficient of velocity caused by friction loss
$C_{va}$ = coefficient to account for exclusion of approach velocity head from the equation
$A$ = the area of the orifice ($ft^2$)
$g$ = acceleration caused by gravity ($ft/s^{2)}$
$h_1$ = upstream head (ft)
$h_2$ = downstream head (ft)

The coefficient of contraction, $C_c$, accounts for the flow area reduction of the jet caused by the flow curving and springing from the orifice edges. The coefficient $C_{vf}$ accounts for the velocity distribution and friction loss. The product, $C_c C_{vf}$, is sometimes called the coefficient of discharge, $C_d$. The coefficient $C_{va}$ accounts for using the water head only and does not fully account for the velocity head of approach. This coefficient is near unity if all the requirements of section 4 are met. The effective discharge coefficient, $C_d$, is the product $C_c C_{vf} C_{va}$, which has been determined experimentally to be 0.61 for rectangular irrigation weirs. The coefficient of contraction has the most influence on the effective coefficient discharge. Because $C_c$ must approach unity as velocity approaches zero, its value will increase rapidly after reaching some low velocity. Thus, the equation should not be used for heads less than 0.2 ft even with very precise head measuring devices. The difference between upstream and downstream heads or water surface elevations is sometimes called the differential head, and equation 9-1a can be rewritten as:

$$Q = C_d A \sqrt{2g\Delta h} \quad \text{(9-1b)}$$

where:

$\Delta h = h_1 - h_2$, differential head
$C_d = 0.61$, as determined experimentally.

The discharge, when velocity of approach is negligible, may be computed using equation 9-1b. Table A9-2[1] was prepared for orifice areas from 0.25 to 2.0 $ft^2$.

[1] The prefix "A" denotes tables that are located in the appendix.

## 6. Dimensions for Fully Contracted Submerged Rectangular Orifices

The most suitable proportions for standard submerged rectangular orifices are those in which the height, *D*, is considerably less than the width, *L*. Usually, these proportions are preferred because of shallow flow depths in some canals and open laterals. Figure 9-1 and table 9-1 provide recommended dimensions for wood or concrete submerged-orifice structures.

The size of the orifice selected for a particular situation is governed by the quantity of water to be measured and the head available. The precision of the head measuring system relative to the minimum required differential needs to be considered when selecting size. For example, if staff gages are used which can only read head to within +/-0.005 ft, the uncertainty of the differential is +/-0.01 ft. This uncertainty in the head causes a discharge error of +/-2.5 percent at a differential head of 0.2 ft. Chapter 3 gives more detailed examples of error calculations at low heads for selection of head measuring devices. Chapter 8 contains head error information for different measurement systems

## 7. Construction and Setting of Standard Fully Contracted Submerged Orifices

Submerged-orifice structures should be substantially constructed of concrete or, under certain circumstances, of wood. The structure should extend several conduit widths downstream from the orifice wall to provide erosion protection in unlined channels. The floor and sides of the box conduit downstream from the orifice opening should be set outward from the opening a distance of at least twice the smallest orifice opening dimension. A flashboard may be placed at the downstream end of the orifice box conduit to assure submergence of the orifice; however, the flashboard should be sufficiently downstream to prevent disturbing the water issuing from the orifice. The orifice wall should be set truly vertical, and the top of the wall should reach only to the maximum expected water level, so the wall can act as an overflow weir in the event of operational difficulties. Wingwalls or cutoff walls should be provided at the upstream and downstream end of the orifice box conduit to prevent undermining the orifice structure and leakage around the structure. Figure 9-1 and table 91 provide recommended dimensions for a concrete or wood submerged-orifice structure.

## 8. Discharge Adjustment for Contraction Suppression in Submerged Orifices

Because effective discharge coefficients are not well defined where suppression exists, use of a standard fully contracted orifice is desirable wherever conditions permit. However, a bottom suppressed orifice allows the sediment to pass the structure.

To avoid accumulations of sediment on the upstream side of the orifice, the bottom contraction may need to be suppressed by placing the lower side of the orifice at canal grade. In occasional instances, use of orifices with both bottom and side contractions suppressed may be necessary.

For rectangular submerged orifices having partially suppressed perimeter contraction and negligible velocity of approach assured by providing an approach area at least 8 times larger than the orifice opening, the approximate discharge may be computed by:

$$Q_s = 0.61(1 + 0.15r)\, A\sqrt{2g\Delta h}$$

where:

$Q_s$ = discharge of the suppressed orifice in $ft^3/s$, velocity of approach neglected
$r$ = ratio of the suppressed portion of the perimeter of the orifice to the total perimeter

The variables $\Delta h$, $A$, and $g$ have the same significance as in equation 9-1b. The term in the parentheses can be thought of as a factor that adjusts the fully contracted effective coefficient of discharge used in equation 9-1b in terms of amount of perimeter with suppressed contraction. This method is expected to produce a coefficient correct to within about +/-3.0 percent.

As a temporary estimating procedure, this method can be used to estimate discharge when sediment deposits are present in the approach to an orifice that was meant to be fully contracted. If the deposits were similar in effect to a smooth invert at the bottom of the orifice, the correction would be good. However, the accuracy of the estimated correction is usually in doubt because of the shape, depth, and location of the deposits. Best practice would require removing the sediment immediately rather than making the discharge adjustment.

Equation 9-2 can be used for sluice gates when they are in effect bottom and/or side suppressed rectangular orifices with variable opening area. Table A9-3 gives discharge versus head for orifices that are both bottom and side suppressed for orifice areas of 2 $ft^2$ to 125 $ft^2$. Other more exact and complex approaches can be used for determining discharge with sluice gates. These approaches are discussed by Bos (1989), who states that equation 9-2 agrees closely to relationships developed by Henry (1950) and Franke (1968).

## 9. Requirements for Suppressed Submerged Rectangular Orifices

The requirements in section 4 related to distance from the sides and bottom do not apply. However, all the remaining requirements apply. Element (14) concerning approach area is especially important.

## 10. Excess Velocity of Approach

Submerged orifices should be installed, operated, and maintained in such a way as to make the velocity of approach negligible. To prevent excess velocity of approach, the size of the approach flow area should be greater than eight times the size of the orifice opening. Generally, the requirements of section 4 of this chapter will prevent excess velocity of approach. The original tables presented by Christiansen (1935) limit velocity of approach to about 0.5 foot per second (ft/s).

To account for excess velocity of approach, the approach velocity head is frequently added to the differential head under the radical assuming that the effective coefficient of discharge does not change. However, in equation 9-1b, this correction assumes that all the correction is accounted for by an approach velocity head term alone. However, this procedure only constitutes a partial correction. The factors that cause excess velocity of approach also cause changes in the contraction and head loss. Thus, the effective discharge coefficient changes by some undefined amount. It is better to find the cause of excess velocity, and if operation changes or maintenance cannot remedy the problem, then a replacement device may be required.

Orifices can be calibrated for velocity of approach effects by comparing against another device. This comparison would require measurements at given discharges at several upstream and downstream heads. The cost of these measurements most likely would exceed the cost of a replacement measuring device.

## 11. Constant-Head Orifice (CHO) Turnout

### (a) General Description

A water measuring device frequently used in irrigation is a combination regulating gate and measuring gate structure. This device uses an adjustable rectangular gate opening as a submerged orifice for discharge measurement and a less expensive circular gate downstream. This system is called the CHO turnout. For convenience, it is operated by setting and maintaining a constant head differential across the orifice. Discharges are set and varied by changing the gate opening. These structures may be used in place of meter gates or turnout gate-and-weir combinations to regulate and measure flows from canals and open laterals into smaller ditches. The turnouts are usually placed at right angles to the main canal or open lateral. Typical CHO turnouts are shown on figures 9-2 and 9-3.

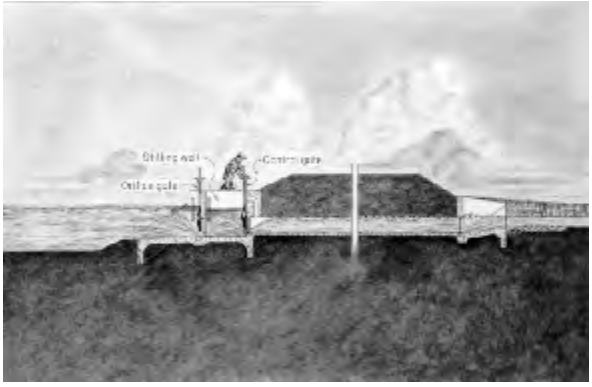

Figure 9-2 -- Schematic diagram of a CHO turnout.

Figure 9-3 -- A single-barrel CHO turnout.

The CHO turnout consists of a short entrance channel leading to a headwall containing one or more gate-controlled openings, a head measurement stilling basin section, and a downstream headwall with one or more gate-controlled barrels that release the flow into the delivery channel (figure 9-4). The rate of flow is measured by using the principle that a submerged orifice of a given size operating under a specific differential head will always pass the same known quantity of water. The upstream gate or gates serve as orifices. The orifice area can be increased or decreased by adjusting the upstream gate or gates. Usually, the head differential is maintained at a constant value, usually 0.20 ft ($\Delta h$ on figure 9-4) measured by staff gages or stilling wells located upstream and downstream from the orifice gate headwall.

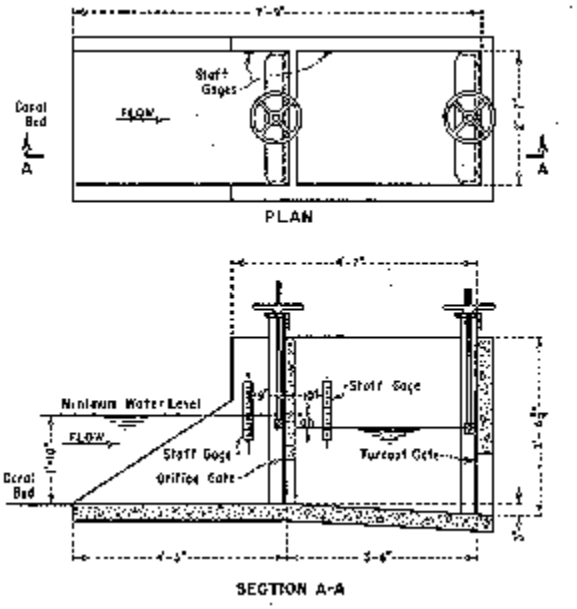


Figure 9-4 -- Schematic view of a single-barrel CHO turnout with a horizontal inlet channel.

To set a given flow, the opening of the orifice for the desired discharge is obtained from discharge tables (tables A9-4 and A9-5 for the older 20- and 10-$ft^3$/s sizes). With the upstream gates set at this opening, the downstream gates are adjusted until the differential head across the orifice as measured by the staff gages or stilling wells is at the required constant head (usually 0.20 ft). The discharge will then be at the desired value.

Two sizes of orifice gates, 24 by 18 in and 30 by 24 in, have been used extensively in the past. Both sizes are provided in single-barrel and double-barrel designs. The capacity of the single-barrel 24- by 18-in turnout is 5.0 $ft^3$/s. The capacity of the single-barrel 30 by 24-in turnout is 10 $ft^3$/s. Double-barrel installations have twice the capacity of the single-barrel ones. Newer designs (Aisenbrey et al., 1978) provide standard CHO turnouts for discharges of 2-,4-, 6-, 9-, 12-, 15-, 18-, 24-, and 30-$ft^3$/s with corresponding opening widths of 1.5, 1.5, 2.0, 2.5, 2.5, 3.0, 3.5, 4.0, 4.0 ft. The gate sizes for these turnouts vary from 18 to 48 in.

Table A9-6 gives discharge versus gate opening for these turnout sizes with a differential head of 0.2 ft.

**(b) Discharge Calibrations**

Calibration tests for the original design sizes were conducted in the Bureau of Reclamation (Reclamation) laboratories in Denver, Colorado, on one-half-scale models of 24- by 18-in CHO turnouts (Blackwell, 1946). The effective coefficient of discharge varied from 0.68 to 0.72 as gate opening increased from 0.2 to 1.5 ft. These tests covered ratios of approach head to gate opening of from 6 to 2, respectively. To produce tables A9-4 and A9-5, the effective coefficient of 0.70 at the ratio of 4 was used in tables for both single-barrel and double-barrel structures with a standard set head differential of 0.2 ft. Thus, the table values are good to +/-3.0 percent.

Discharge tables for the newer CHO sizes (Aisenbrey et al., 1978) are also based upon a coefficient of 0.70. Discharge for standard head differential of 0.2 ft is provided on standard drawings and in table A9-6. For the 2-$ft^3$/s CHO turnout, with minimum canal water surface elevation and maximum recommended orifice gate opening, the submergence ratio (approach depth to opening) is about 4. As the turnout size increases, the minimum approach submergence ratio decreases to become about 2 for 15-$ft^3$/s and larger sizes.

Differential heads other than 0.2 ft can be used, but equation 9-1b and an effective coefficient of 0.70 must be used to compute discharges or to generate new tables.

To provide CHO calibrations and structural designs for sizes not actually calibrated using a discharge coefficient of 0.70 and to attain "3 percent equation accuracy, Aisenbrey et al. (1978) give the following design criteria for smaller and larger CHO turnouts with capacities up to 30 $ft^3$/s:

- For maximum capacities of 10 $ft^3$/s and less, the length of gate basin should be at least 2.25 times the maximum gate opening or 1.75 times the gate support wall opening, whichever is greater. However, no basin length should be less than 3.5 ft.
- For capacities between 10 $ft^3$/s and 30 $ft^3$/s, the gate basin length should be at least 2.75 times the maximum gate opening. The bottom of the gate basin should be level.
- The gate opening should be less than or equal to 0.8 times the wall gate support wall opening.

- The distance from the gate lip to the top of the gate support wall opening should be at least equal to the wall thickness.
- The approach flow submergence above the top of the opening should be 1.78 times the velocity head plus 0.25 ft.
- The set head differential should be at least 0.2 ft.

An important detail of the Reclamation orifice gate design is a 1-1/2- by 1-1/2-in angle iron brace projecting upstream on the face. The projecting leg of angle iron is located 1-3/4 in from the gate lip. Some of the smaller gates were built without this brace and were field calibrated with weirs. They were found to have an effective coefficient of 0.65. When this bracing is missing, equation 9-1b and this lower coefficient must be used to calculate discharges or tables.

Colorado State University (CSU) tests (Kruse, 1965) determined that the effective discharge coefficient is about 0.65 for the normal operation where the depth upstream from the turnout is 2.5 or more times the maximum gate opening. This coefficient is the same value that Reclamation determined for no angle iron bracing at the bottom of the upstream gate face.

CSU also investigated the effects of changes in upstream and downstream water levels, sediment deposits, plugging of the orifice gate with weeds and debris, and approach flow conditions.

For discharges larger than about 30 $ft^3/s$, special structures involving multiple gates and barrels are designed for the particular site and flow requirements.

**(c) Effects of Upstream Water Depth**

When the depth of water upstream from the orifice gate is four or more times the height of the opening of the orifice, the coefficient of discharge, *C*, remains essentially constant at 0.65 (Kruse, 1965). When the depth of water upstream is less than four times the orifice opening, the coefficient increases. The rate of increase is moderate at submergence ratios between 4 and 2.5, but rapid at submergence ratios below 2.5.

Attempting to predict the coefficients for different installations having low submergence ratios is impractical and inaccurate, and doing so is not recommended. Structures should be installed so the minimum water depth in front of the orifice gate will be at least 2.5 times, but preferably 4 or more times, the maximum expected gate opening. In some cases, to place the structure low enough, the inlet channel may need to be sloped downward as shown on figure 9-5. An alternative design in which the inlet floor is abruptly stepped downward is also used.

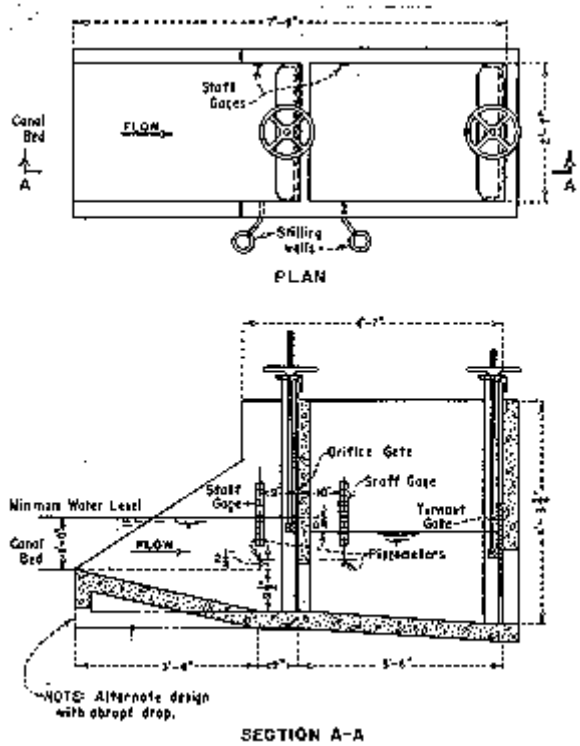


Figure 9-5 -- Schematic view of a CHO turnout with a sloping inlet channel and with piezometers and stilling wells.

**(d) Effects of Upstream and Downstream Water Depth**

Because of its name, the CHO is often mistakenly thought to maintain the constant head differential after setting when the water surface changes in the supply canal. However, the CHO cannot maintain this constant differential because the orifice gate coefficient varies with upstream submergence and differs from the downstream control gate coefficient.

A change in tailwater depth or downstream submergence on the control gate after a discharge has been set also can cause a significant change in the flow rate. The set differential changes because the two gates have different coefficient characteristics relative to their shape and response to amount of submergence. If considerable drop exists in the channel downstream from the turnout, tailwater will have no effect on flow measurement. However, if the CHO turnout is placed at about the same grade as the ditch it is supplying, the discharge may be affected as the water level changes.

Therefore, whenever tailwater or downstream delivery depth can affect the rate of flow, the ditchrider must make the necessary and frequent adjustments until flow conditions in the ditch become stable.

**(e) Effects of Sediment and Weeds**

In common irrigation use, sediment is usually swept through the orifice and the downstream gates during normal operation (Blackwell, 1946). The small sediment accumulations that occur in the stilling basin between the gates have little or no effect upon performance. Thus, sediment is usually not a problem in CHO turnouts.

Choking caused by weeds that become lodged within the measuring orifice can be serious. Moreover, choking can be difficult to detect when silty water is flowing because the orifice cannot be seen. The principal cause of choking is the presence of waterlogged weeds that catch in the gate opening. These weeds may trap other particles and eventually plug the turnout. The measuring accuracy of CHO turnouts is greatly reduced by the presence of even a few weeds. Care must be taken to ensure that the orifice and the area upstream from the orifice are kept completely clear of weeds and other debris. Trashscreens or trashracks are sometimes placed at the inlet to the CHO turnout.

**(f) Effects of Approach Flow Condition**

The turnouts are usually placed at 90 degrees to the canal centerline (figure 9-3). As a result, when the flow in the canal moves past the turnout, an eddy and related flow disturbances occur at the turnout entrance. This eddy and the other flow disturbances affect the flow into the turnout. The intensity of the disturbances depends largely upon the velocity of the passing supply canal flow. For small gate openings, the discharge coefficient, $C$, for the turnout increases from a value of 0.64 for a canal flow velocity of 1 ft/s to a value of 0.69 for a canal flow velocity of about 3 ft/s (Blackwell, 1946). On the other hand, with large gate openings, increasing the canal flow velocity near the turnout decreases the coefficient from high values of about 0.74 for canal flow velocities of 1.0 ft/s to low values of about 0.63 for canal flow velocities of 3.0 ft/s. This appreciable, but inconsistent, effect upon the measuring accuracy of CHO turnouts must be recognized. This error is greatest at the larger orifice openings. Whenever possible, installations should be designed so that relatively low flow velocities prevail at the turnout, especially if larger openings are to be used. Fortunately, the normal flow velocity distribution in canals provides relatively low velocities near the banks.

**(g) Head Measurements**

In the standard CHO turnout, the head differential across the orifice, or upstream gate, is determined by reading staff gages just upstream and downstream from the headwall on which the upstream gate is mounted (figure 9-4). Rough water surfaces at these gages can easily result in large head reading errors. These errors are particularly bad during large flows when the water surface in the stilling basin downstream from the orifice opening may be quite unsteady or tilted. Head reading errors can cause significant errors in flow measuring accuracy, and every reasonable effort should be made to avoid them. Chapters 6 and 8 show other ways of stilling the water surface to make head measurement more accurate.

Stilling devices to reduce water surface fluctuations at the staff gages can reduce head measurement errors. External stilling wells connected to piezometers upstream and downstream from the orifice gate greatly increase the potential accuracy of head readings and of the discharge measurements (figure 9-5). Additional information regarding stilling wells can be found in chapters 6 and 8. For existing structures, small wooden or metal shelf-type stilling devices installed within the flow area across the inlet and across the stilling basin near the staff gages will help reduce reading errors caused by vortices and waves (figure 9-6).

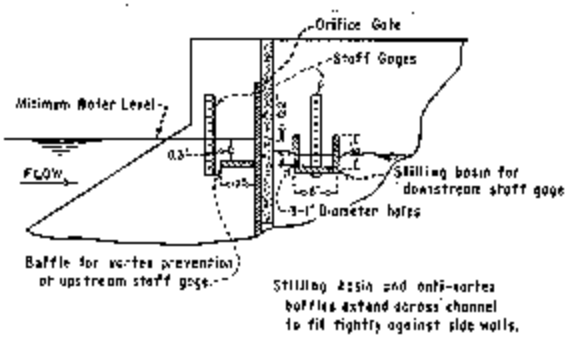


Figure 9-6 -- Baffles to reduce water surface fluctuations at staff gages in CHO turnouts.

## 12. Orifice Check Structures

Occasionally, at a given site, the canal water surface level should be checked up to a specified elevation while simultaneously measuring the rate of flow. The combined checking and measuring functions can be provided by orifice check structures which are built into the canals as in-line structures (figure 9-7). One or more orifice openings of the necessary size are constructed in the lower portion of a wall that extends across the canal at the upstream end of the check-type structure. These orifices are used to measure the discharge. A second wall with one or more gated openings is constructed at the downstream end of the structure. This downstream control is used to check the canal water surface to the desired elevation. Two stilling wells are located outside of the structure. One is connected to a piezometer in the canal upstream from the orifice wall, and the other is connected to a piezometer in the basin between the upstream and downstream walls. In small orifice check structures, staff gages are used in place of piezometer and stilling wells. In either case, the differential head acting across the orifice can be determined, and with knowledge of the orifice dimensions and characteristics, the rate of flow can be determined.

Figure 9-7 -- Gated orifice check structure used to maintain upstream water surface levels and to measure rates of flow in the Courtland Canal, Nebraska.

The coefficients of discharge that should be used to compute the rate of flow are difficult to determine analytically because of different degrees of suppression at the bottom and sides and between the orifice openings.

Computed discharge tables are ordinarily provided for each structure, but usually a statement is included that a field rating is necessary to ensure accurate results. In general, the recommended practice is that field ratings be made by current meter data and that discharge curves be prepared. For maximum potential accuracy, care must be exercised to prevent either excessively small gate openings or small differential head readings that cause large errors of precision of head or gate opening effects on discharge measurement.

## 13. Radial Gate Checks Used for Measuring Device

Radial gates are widely used in canal check structures to control canal flows and water levels. By measuring upstream water level, downstream water level, and gate position, radial gate checks can also be used to compute flow. Computing flow at check structures prevents the additional cost and head loss from flow measurement devices such as flumes, weirs, or flow meters.

Radial gate flow is a type of variable-area orifice flow, which may be either free or submerged. However, accurate computation of radial gate flow requires complex analysis. Discharge under a radial gate is influenced by numerous parameters and structure dimensions. Figure 9-8 shows a typical radial gate with some of the variables that affect gate flow. The angle $\theta$ of the gate's bottom edge (gate lip) varies with the gate opening, $G_o$, the pinion height, $PH$, and the gate's radius, $r$. Flow contraction is sensitive to the angle $\theta$, the type of gate lip seal, and water levels.

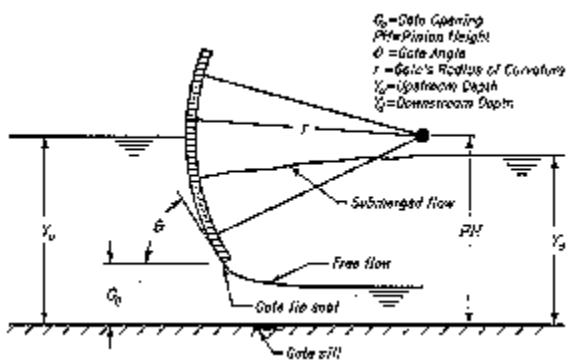


Figure 9-8 -- Diagram of radial gate showing calibration variables.

The general equation for flow through an undershot gate can be derived from the Bernoulli equation and expressed as:

$$Q = C_d G_o B \sqrt{2gH} \qquad (9\text{-}3)$$

where:

$Q$ = discharge (gate flow)
$C_d$ = coefficient of discharge
$G_o$ = vertical gate opening
$B$ = gate width

$g$ = gravitational constant
$H$ = a head term

The head term, $H$, in the above equation can be either the upstream depth, $Y_u$, or the differential head across the gate, $Y_u$ - $Y_d$ (see figure 98). When differential head is used, equation 9-3 becomes the well-known "orifice" equation. The development of the coefficient of discharge, $C_d$, depends on the definition of the head term as well as the various other parameters that affect gate flow. $C_d$ has been predicted using a number of different methods, but most of these methods have limited application and accuracy.

In 1983, a research program at Reclamation's Hydraulics Laboratory developed gate flow algorithms that represent the complete discharge characteristics for canal radial gate check structures.

These algorithms are a complex set of equations that cover the range of water levels and gate geometry normally encountered at canal check structures. When applied correctly, they can be as accurate as any canal flow measurement device or procedure. The main disadvantages to using these algorithms are their complexity and the requirement to accurately measure two water levels, $Y_u$ and $Y_d$, and the gate position, $G_o$. Additionally, sedimentation or check structure subsidence can change gate flow characteristics at existing structures and require recalibration over time.

A computer program has been developed to solve the radial gate flow algorithms. Program RADGAT executes on a personal computer to calculate either flow or gate position at a canal radial gate check structure. The user enters structure dimensions such as gate width, pinion height, gate radius, pier width (between gates), invert elevations, canal bottom widths and side slopes, and head loss coefficients for open transitions and siphons. These physical proper-ties are saved in a data file so they need not be reentered for successive program execution. Then, the user enters upstream and downstream water depths and has the option either to compute discharge for a given gate opening or compute gate opening for a given discharge. RADGAT can also produce rating tables of flow versus gate opening for a range of upstream and downstream depths.

Buyalski (1983) contains detailed results from the research program and explanation of the discharge algorithms. It also contains the original version of program RADGAT developed for main-frame computer application. The personal computer version of RADGAT may be obtained through Reclamation's Water Resources Research Laboratory in Denver, Colorado.

## 14. Meter Gates

In the past, meter gates have been used for controlling and measuring irrigation flows (figure 9-9) (Schuster, 1970; Ball, 1961). These gates are basically modified, submerged, variable area orifices (slide gates) at the upstream end of a length of smooth or corrugated pipe. The gate leaf has either a round or square bottom over the entrance. Wells provide a means of measuring the head upstream and downstream from the gate, designated $h_1$ and $h_2$, respectively. The upstream head, $h_1$, is measured in the well connected to the headwall located a certain distance to the side of the gate opening. The downstream head, $h_2$, is measured in the other well, which is connected to the pipe a short distance downstream from the gate. The difference in head in the two wells is the effective operating head across the gate. The discharge is then determined by the proper equation or a table provided by the manufacturers.

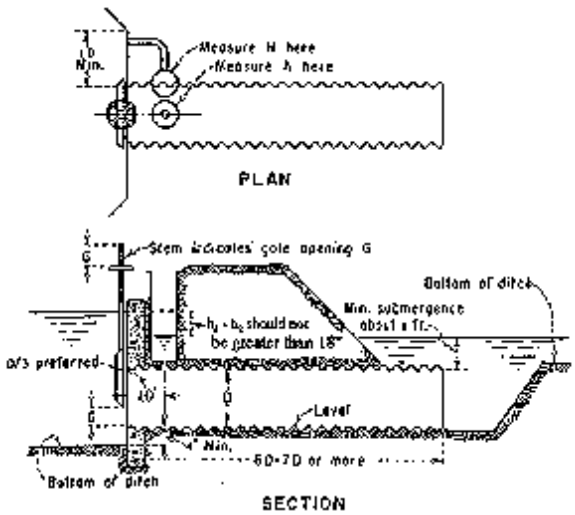

Figure 9-9 -- Typical meter gate installation.

Meter gates are usually purchased from commercial suppliers who furnish discharge tables for their product. Generally, the tables are reasonably accurate. In some instances, errors of 18 percent or more have been found. A number of characteristics of meter gates influence their performance, particularly when they are operated at openings larger than 50 percent or the upstream submergence above the crown of the pipe is less than the inside pipe diameter.

The discharge table being used should be checked to ensure that it applies to the brand and type of gate being used. Tables for round-bottom gates must not be used for square-bottom gates and vice versa. Gate settings must be made and read accurately, which requires that the gate position indicators be in good condition and show the true openings. The stilling wells should be periodically flushed to make sure they are operating properly and are free of obstructions and silt. Staff gages or scales should also be checked to be sure they have been secured in the proper zero position.

Weeds, trash, and sediment must be removed from the approach to the gates because they can cause flow disturbances that result in erroneous head differential readings. This requirement is particularly important along the wing walls because these walls have more effect upon the flow than does the alignment of the bottom. The approach effects are particularly important at gate openings greater than 50 percent.

Low head wall submergence over the meter gate entrance can also result in discharge errors, particularly at gate openings greater than 75 percent. Considerable error results when the head is less than one pipe diameter above the top of the pipe. Sufficient submergence must also occur at the downstream end of the conduit to ensure that the conduit flows full and that a readable water surface is present in the downstream stilling well, which will usually require at least 1 ft of water depth above the pipe crown. This amount of submergence will normally prevent scour damage downstream in earthen ditches.

Large errors in discharge determination can be introduced if the differential head (difference in water surface elevation between the two stilling wells) is small. For example, in reading the two water surface elevations in the stilling wells, an error of 0.01 ft could be made in each reading, giving a possible value of 0.10 ft for a true differential head of 0.08 ft. For a true discharge of 1.10 $ft^3/s$ through an 18-in meter gate open 5 in, the difference in the indicated discharge would be about 0.12 $ft^3/s$, an error of about 11 percent. If the gate opening was reduced to 2 in, and the upstream pool could be allowed to rise to pass the same discharge, the differential head would be 0.40 ft, and the same head-reading error of 0.02 ft would indicate a change of only 0.03 $ft^3/s$. The error in discharge determination would be reduced from about 11 percent to less than 3 percent.

The head in the downstream measuring well can vary widely depending upon the longitudinal and lateral location of the pressure tap in the pipe. Placing the pressure tap of the downstream measuring well 12 in from the gate is a special case requiring special calibration for each size gate unless the maximum gate opening is limited. A better location for the downstream piezometer would be at a distance *D/3*, measured from the downstream face of the gate. The pressure gradeline here is lower and flatter. Minor variations in piezometer locations would not result in major measuring errors, and the measured head differential would be greater. However, if the piezometer is moved to this point, the meter must be recalibrated because the manufacturer's published tables will not apply.

Laboratory tests have been conducted on square-bottom, flat-leaf meter gates to determine the coefficient of discharge, $C_d$, for a pressure tap located at a distance *D/3* downstream from the gate (Ball, 1961). This curve, shown on figure 9-10, is valid for all sizes of square-bottom, flat-leaf meter gates under the following standard conditions:

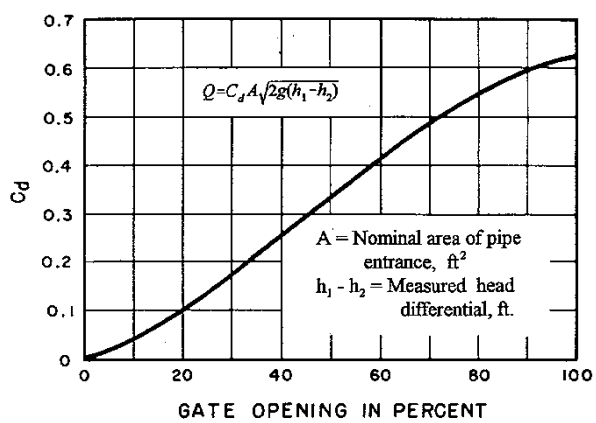


Figure 9-10 -- Coefficient of discharge curve for meter gates with downstream pressure tap at *D/3*.

(1) An approach channel floor sloping upward, 2 to 1, toward the gate, with the downstream end of the floor a distance 0.17*D* below the pipe entrance invert.

(2) Flaring entrance walls, 8 to 1, starting a distance *D/4* from the edges of the gate frame.

(3) Zero gate openings set when the bottom of the leaf is at the invert of the entrance.

(4) Upstream submergence greater than *D*.

(5) The downstream end of the pipe submerged to make the pipe flow full.

It should be noted that the coefficient $C_d$ is used with *A*, which is the area of the pipe and not the gate opening. Discharges may be computed from this equation with an accuracy of +/-2.5 percent. The degree of downstream submergence does not affect the accuracy of the meter if water rises sufficiently in the downstream well to obtain an accurate reading and the pipe runs full at the outlet.

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# CHAPTER 10 - CURRENT METERS

## 1. Introduction

Current meters are velocity measuring devices that sample at a point. Each point velocity measurement is then assigned to a meaningful part of the entire cross section passing flow. The velocity-area principal is used to compute discharge from current-meter data. Total discharge is determined by summation of partial discharges. Data are usually determined over a useful range of total discharges. These discharges are related to measured water surface elevations related to a fixed head measuring device to provide a rating curve. After full confidence in the rating is attained, the calibrated head measurement device and cross section may be used as a gaging station.

## 2. Classes of Current Meters

Several classes of current meters are used in water measurement.

- Anemometer and propeller velocity meter
- Electromagnetic velocity meters
- Doppler velocity meters
- Optical strobe velocity meters

Most of these will be discussed briefly here. The class that is more commonly used for irrigation and watershed measurements is the anemometer and propeller type; however, the use of electromagnetic velocity meters is very popular among water districts. The discussion in the following sections will mainly describe this class and its use.

### (a) Anemometer and Propeller Current Meters

Anemometer and propeller current meters are the most common type used for irrigation and watershed measurements. These meters use anemometer cup wheels or propellers to sense velocity. The Price current meter and the smaller pygmy meter modification are the most common current meters in use. These meters are rated by dragging them through tanks of still water at known speeds. The reliability and accuracy of measurement with these meters are easily assessed by checking mechanical parts for damage and using spin-time tests for excess change of bearing friction. This type current meter does not sense direction of velocity, which may cause problems in complicated flow where backflow might not be readily apparent. For irrigation needs, this problem can be avoided by proper gage station or single measurement site selection.

### (b) Electromagnetic Current Meters

Electromagnetic current meters produce voltage proportional to the velocity. The working principle of these meters is the same as the pipeline electromagnetic flowmeter, which is more fully described in chapter 14. One advantage of these current meters is direct analog reading of velocity; counting of revolutions is not necessary. These current meters can also measure crossflow and are directional. Electromagnetic current meters, while still not as reliable as the anemometer type, have improved greatly in recent years. Their use near metallic objects is still a limitation.

### (c) Doppler Type Current Meters

Doppler type current meters determine velocity by measuring the change of source light or sound frequency from the frequency of reflections from moving particles such as small sediment and air bubbles. Laser light is used with laser Doppler velocimeters (LDV), and sound is used with acoustic doppler velocimeters (ADV). The working principles for ADV type flowmeters are more fully described in chapter 11. Acoustic Doppler current profilers (ADCP) have also been developed. These instruments measure average velocities of cells of selected size in a vertical series. Thus, they measure vertical current profiles. ADCP measurements are becoming more frequent for deep flow in reservoirs, oceans, and large rivers. Most of the meters in this class are multidimensional or can simultaneously measure more than a single directional component of velocity at a time.

### (d) Optical Strobe Velocity Meters

Optical strobe velocity meters developed by the U.S. Geological Survey (USGS) and the California Department of Water Resources use optical methods to determine surface velocities of streams (USGS, 1965). This meter uses the strobe effect. Mirrors are mounted around a polygon drum that can be rotated at precisely controlled speeds. Light coming from the water surface is reflected by the mirrors into a lens system and an eyepiece. The rate of rotation of the mirror drum is varied while viewing the reflected images in the eyepiece. At the proper rotational speed, images become steady and appear as if the surface of the water is still. By reading the rate of rotation of the drum and knowing the distance from the mirrors to the water surface, the velocity of the surface can be determined. The discharge rate of the stream may be estimated by applying the proper coefficient to this surface velocity and multiplying by the cross-sectional area of the flow section.

The meter has several advantages. No parts are immersed in the flowing stream. Moreover, it can be used for high-velocity flows and for flows carrying debris and heavy sediment. The meter can measure large flood flows from bridges. However, the meter measures only the water surface velocity and is very dependent upon the selection of the proper coefficient.

## 3. Use of Current-Meter Gaging Stations

Current-meter gaging stations are permanent or semi-permanent stations located along a watercourse where flow conditions permit the establishment of a discharge rating curve based upon multiple current-meter measurements. After the rating curve has been established, the rate of flow is determined from the curve based on the measured depth of flow at the station. If measurements become necessary in existing streams or canals, current-meter gaging stations can be set up with relatively little effort and usually without modification to the channel.

Current-meter gaging stations are often preferred over other means of water measurement when large flows are to be measured and head loss is costly, or when freeboard is not available. They may also be desirable for sediment-laden flows even when discharges are not large. However, excess sediment and seasonal growths of weeds can change head versus discharge relationships, requiring frequent preparation of new rating curves. The frequent rating shifts can become labor intensive, and flumes may be the better choice.

Where flow depths are too small for current meters and only small heads are possible, flumes are probably the best alternative measuring method.

The discussion of current meters, gaging stations, and operational procedures presented in this chapter is brief and is intended mainly to stress the more typical irrigation water measurements that may be made by this method. For more detailed information, refer to USGS Water Supply Paper No. 888 (USGS, 1965), Buchanan and Somers (1969), the National Handbook of Water-Data Acquisition (USGS, 1980), and Wahl et al. (1995).

## 4. Location of Current-Meter Stations

Whenever possible, current-meter gaging stations should be located in straight, uniform stretches of channel having smooth banks and beds of permanent nature. The station should be located far from flow disturbances caused by turnouts and power stations. These flow disturbances will variably affect the relationship of discharge to gage height. In many channels, these conditions are difficult to find, and unusual care must be taken to obtain a satisfactory location.

The changing nature of some rivers and canals may require frequent current-meter measurements. Sand shifts may occur frequently, often daily, and aquatic weeds may continue to grow and increase in area. To obtain the gage-discharge relationship at stations on such streams, current-meter measurements may be necessary two or three times weekly or perhaps daily if the importance of equitable water distribution justifies such action. A rating section consisting of a short-lined section in a straight stretch of channel will ensure a meter station of unvarying dimensions if the sediment problem is not serious. Such a section in a canal is shown on figure 10-1.

Figure 10-1 -- Current-meter station on a canal, viewed from upstream. Current-meter measurements are taken from the bridge, and the sheltered stilling well houses an automatic water-stage recorder.

A gaging station located upstream from any permanent single control section, such as a drop, will usually have a simple relationship between the gage height and discharge. A gaging station located in a river may have successively changing control points downstream as discharge increases or decreases, resulting in more complicated gage height versus discharge relationships. The last two types are not commonly used in irrigation practice and will not be discussed.

## 5. Types of Current-Meter Measurements

Current-meter discharge measurements are classified according to the type of equipment used and the nature of the station:

- Wading measurement (figure 10-2).
- Cable supported measurement (figure 10-3).
- Bridge measurement (figure 10-4).
- Boat measurement (figure 10-5).
- Measurement through ice cover.

Figure 10-2 -- Equipment for making wading measurements with a current meter. Note tag line for marking stations.

Figure 10-3 -- Current-meter gaging station with cable car, corrugated steel shelter house, and stilling well.

Figure 10-4 -- Type A crane and current-meter assembly in position on bridge.

Figure 10-5 -- Making a current-meter measurement from a boat.

## 6. Current-Meter Stations and Handling Equipment

The essential components of a current-meter station are a water-level gage (stage recorder), a bench mark, fixed measuring points in the channel cross section, and a stay line to hold the meter in the measuring plane or cross section under high velocity and deep water. Water stages or elevations can be obtained by non-recording gages or water-stage recorders. The gage types most commonly used in irrigation water measurement are the graduated, enameled, vertical staff, hook, and float. A commonly used staff gage is shown on figure 8-4 in chapter 8. Float gages are often connected to water stage recorders that produce charts of the water surface variations against time. The benchmark should be conveniently and permanently located, with the elevation of the gage datum carefully referenced to the benchmark.

Velocity measurement points should be located in a cross-section plane which is oriented perpendicular to the channel flow. Where the channel is shallow enough to permit wading measurements or where cable-supported measurements are taken, a tagged wire should be used to establish the measuring points. When measurements are made from a bridge, permanent measuring points should be established upon the bridge. The measuring points should be permanently marked at equal intervals of from 2 to 10 feet (ft), depending upon the width of the stream or canal. If the stream velocity is high or if the structure from which the measurements are being made is far above the water, a stay-line can be used to pull the current meter back into the plane of the measurement cross section. A cable supporting a traveling pulley can be stretched across the canal upstream from and parallel to the measuring cross section. The traveling pulley is fitted with a swiveling stay-line pulley. The stay-line runs from the meter hanger, through the swiveling pulley, and back to the operator at the measuring station. The support cable is placed perpendicular to the flow velocity and far enough upstream so when the current meter is pulled back into the vertical plane at the measurement station, the slope of the stay-line relative to the water surface is flatter than 30 degrees.

Streamlined weights with large tail fins, commonly called Columbus or C-type weights, are used to carry the meter down into the flow and help hold it in the desired position when measurements are being made from a bridge or a cable. Weights are available in 15-, 30-, 50-, 75-, 100-, 150, 200-, 300-, and 500-pound (lb) sizes. Usually, weights of 75 lb or less are adequate for canal and small stream measurements. To handle the relatively heavy current-meter and weight assembly, the type A portable crane shown on figure 10-4 is used. This crane is mounted on three wheels designed to hold the current meter and weight in a balanced position while moving between measuring points.

For stream measurement, the crane is tilted to lean against the bridge rail so the boom supports the meter and weight clear of the bridge. The meter is raised and lowered by a crank and cable reel on the frame. The crane may be folded into a compact unit for ease in transportation.

A cable device used extensively to position current meters across canals is shown on figure 10-6. The head tower with the operating mechanism for the cable and the tail tower on the opposite bank can be fixed installations, or vehicles may function as anchors on each side of the canal. A counter on the head tower reel determines the lateral position of the traveling block. Another counter on the reel raises and lowers the meter and determines meter depth. The entire installation is relatively inexpensive and permits stream gaging to be done safely and easily from the bank.

Figure 10-6 -- Cableway with traveling block to support the current meter and position it for readings. Counters are provided on the head tower and reel to determine the position of the meter in the channel.

A carriage and track system to handle current meters with heavy weights when working from bridges is shown on figure 10-7. The standard reel and counter assembly is mounted on a carriage supported by ball-bearing rollers that run on a 2- by 6-inch (in) timber track permanently mounted on the bridge rail. This equipment allows the operator freedom of movement with safety, facilitates obtaining accurate stream gaging data, and is easily portable from one station to another.

Figure 10-7 -- Carriage and track for handling current meter and weights from a bridge. A 2- by 6-in timber permanently attached to the bridge rail is the track for the portable, wheeled carriage that supports the reel, cable, and meter assembly.

## 7. Subclasses of Anemometer-Propeller Current Meters

These commonly used current meters convert velocity into counts of rotations. Conventional meters are of two general types - the propeller type with horizontal axis of rotation and the conical cup type with vertical axis. The relationship between the velocity of the water and number of revolutions per unit of time for various velocities is determined for each instrument by experiment. Individual meters of models that have had long and extensive use without structural or mechanical changes can use previous experimental calibrations with confidence. This procedure requires tight control during manufacture with close tolerances for mechanical part dimensions and verification with time-spin tests.

The manufacturer should provide the appropriate calibration equations, tables, or curves with each meter. A sample rating table is shown on figure 10-8 for a meter with the equations:

$$V = 2.14N + 0.03 \qquad \textit{for } N < 1.00 \qquad (10\text{-}1)$$

and

$$V = 2.19N + 0.01 \qquad \textit{for } N > 1.00 \qquad (10\text{-}2)$$

In these equations, $V$ is the velocity in feet per second (ft/s), and $N$ is the number of revolutions per second.

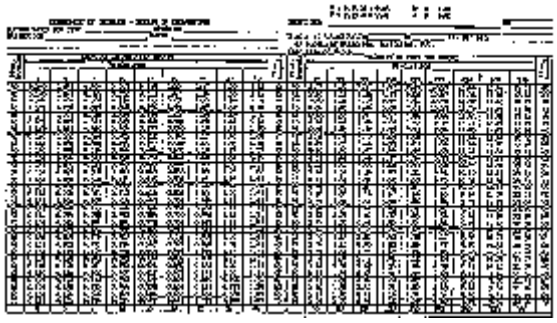


Figure 10-8 -- Typical current-meter rating table.

Each meter is calibrated for the types of suspensions with which it may be used (Smoot, 1968). The two principal types of suspensions are wading rod and cables (shown on figures 10-2 and 10-4, respectively).

Because accuracy is greatly affected by general condition, the instrument should be checked at least once a year. This check can be done by comparing the meter readings with a second meter by placing it in the same position in a non-changing flow. This procedure is done at low, middle, and high velocity to cover the meter measuring range. If significant difference exists between the two meter readings, or if another meter is not available for checking to begin with, then the meter should be sent to a laboratory for calibration.

### (a) Price-Type Meters (Vertical Axis)

The Price meter, a cup-type instrument with a vertical axis, was developed by USGS and is commonly used for irrigation water measurement.

This meter has the following general features: vanes to keep the front of the meter headed into the current, either a cable or a rod for handling the meter, weights for sinking the meter when it is suspended on a cable, an electric device for signaling and/or counting the number of revolutions, and connections from the current meter to a 12-volt battery-powered headphone (figure 10-9).

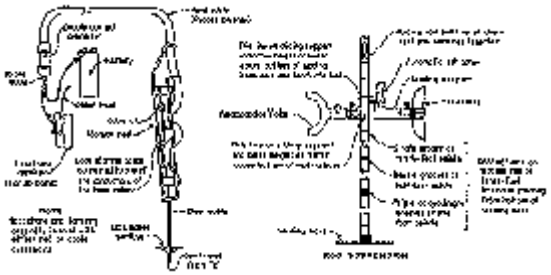


Figure 10-9 -- General assembly of Price type AA current meter (sheet 1 of 2).

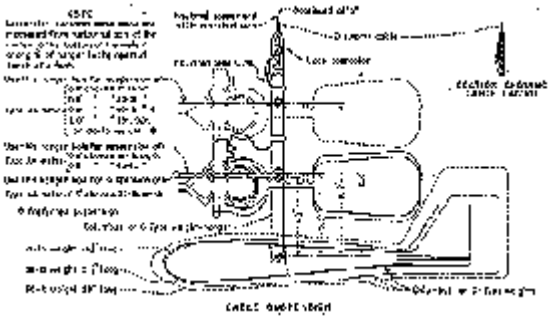


Figure 10-9 -- General assembly of Price type AA current meter (sheet 2 of 2).

The Bureau of Reclamation (Reclamation) commonly uses two standard Price-type meters: (1) the type AA meter with the Columbus-type weights or a wading rod, and (2) the type BTA meter

(figures 10-10 through 10-13). The pygmy meter, discussed in the following subsection, is also a modification of the standard Price meter. The BTA meter has the same pivot, hub assembly, and shaft as the type AA meter, which eliminates the need for two sets of spare parts. The parts for type AA and BTA meters are interchangeable, except for the yoke and the contact chamber. Two sets of revolution-indicating contacts are provided in the type AA and BTA meters; one set indicates every five revolutions. The electrical cable should be connected to the counter most appropriate for the anticipated bucket wheel speeds. A type AA meter on a wading rod is shown on figure 10-13.

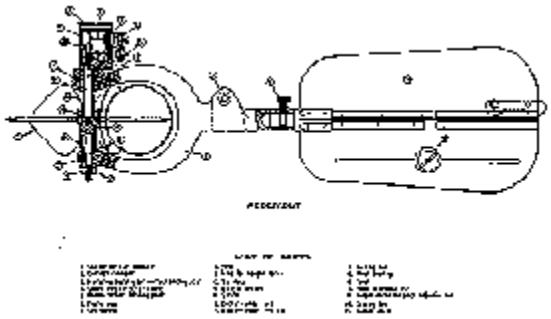


Figure 10-10 -- Assembly drawing of Price type AA current meter.

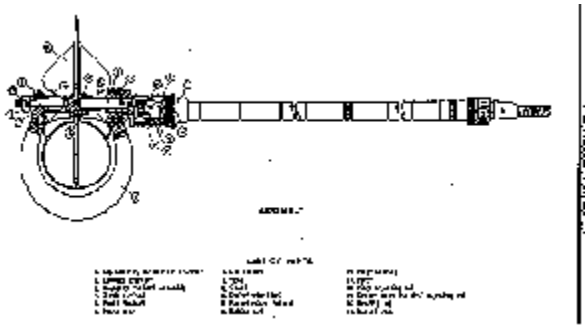


Figure 10-11 -- Assembly drawing of Price type BTA current meter.

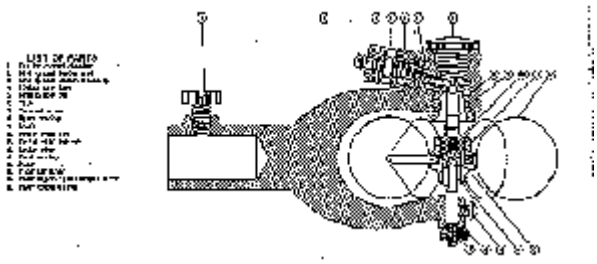


Figure 10-12 -- Assembly drawing of pygmy-type current meter.

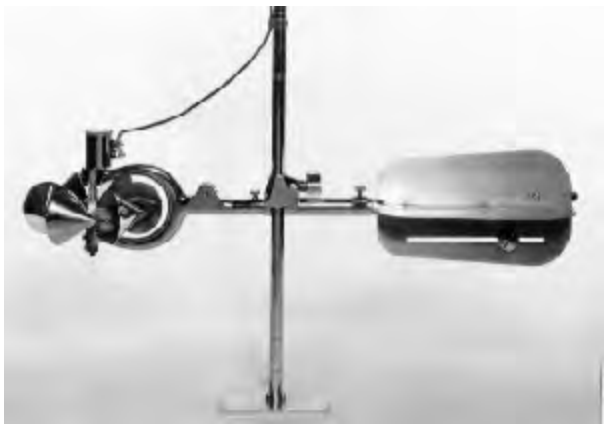


Figure 10-13 -- Price type AA current meter on a round wading rod.

An improved contact chamber has been developed by USGS to replace the wiper contact of the Price type AA meter (USGS, 1965). The new chamber contains a magnetic switch that is hermetically sealed in a hydrogen atmosphere within a glass enclosure. The switch assembly attaches rigidly to the top of the meter head just above the tip of the shaft. The switch is operated by a small permanent magnet fastened to and in balance with the shaft. The switch quickly closes when aligned with the magnet and promptly opens when the magnet moves away. One count per revolution is obtained.

The magnetic switch can be used on any type AA meter by replacing the shaft and the contact chamber. The change does not alter the rating of the meter. Headphones must not be used with the new switch because arcing can weld the switch contacts. Instead, an automatic counter should be used (USGS, 1965).

**(b) Pygmy Meters (Vertical Axis)**

Pygmy meters are similar to Price meters in that both contain a cup-type wheel mounted on a vertical shaft. The pygmy cup wheel is 2 in in diameter, compared with 5 in for conventional Price meters. Thus, the pygmy meter can measure velocities closer to flow boundaries. The contact chamber is an integral part of the yoke and contains a single-revolution contact only (figure 10-12). The meter has no tailpiece, and no provision is made for cable suspension. The rotational speed of the pygmy meter cup wheel is more than twice that of Price meters. Consequently, use of the pygmy meter is limited to velocities up to 3 or 4 ft/s. The pygmy meter was specially designed for use in small, shallow streams. The smaller meter was necessary because a standard

Price meter does not perform with sufficient accuracy when it occupies a good share of the available stream depth. The pygmy meter may also be used in large canals where the velocity of flow is low or near the edges of a canal to supplement data taken farther out in the channel with a Price meter.

**(c) Propeller Meters (Horizontal Axis)**

In special situations, Reclamation has used meters of the propeller type with horizontal axles. Hoff meters, Haskell meters, Ott meters, and Neyrpic "Dumas" meters are examples. A Dumas meter and electrical output cable attached to a support rod are shown on figure 10-14a. An assembly of eight Dumas meters with appropriate handling equipment is shown on figure 10-14b. In this case, the equipment was mounted on a flatbed truck for positioning. These meters have some advantages compared to the Price meters. They are less sensitive to velocity components not parallel to the meter axis, they are smaller, and they are more suited for mounting in multiple units.

Figure 10-14a -- "Dumas" current meter of the propeller type with horizontal axle. Hott and Ott meters are of the same type.

Figure 10-14b -- Truck-mounted assembly of eight propeller-type current meters and signal recording equipment used on Gateway Canal, Weber Basin Project, Utah.

## 8. Wading Rods

Two types of wading rods are available for supporting the current meters when working in shallow and moderate-depth streams: (1) the conventional round rod and (2) the more convenient top-setting rod. Both rods use a baseplate that rests on the bottom of the flow channel.

The round rod (figure 10-13) consists of several sections of 1-ft-long, 2-in-diameter, nickel-plated round brass tubing. The rod is graduated at intervals of 0.1 ft by shallow machined lines around the rod. A single groove is used at the 0.1-ft graduations, double grooves at the 2-ft intervals, and triple grooves at the foot marks. A nickel-plated sliding support machined from a bronze casting moves up or down on the rod and is held at any desired location by a spring-actuated lock which uses a lever for release. The current meter and the vanes, if used, attach to this sliding support.

The top-setting wading rod (figure 10-15) permits all settings to be made in the dry and has a main column of 2-in hexagonal stock and a meter positioning rod of d-in-diameter stock. The main rod attaches to the baseplate and is graduated in 0.1-ft intervals so depth of flow can be measured. Interval markings are the same as those used on common wading rods. The meter is secured to the lower end of the positioning rod and guided by means of a support that slides on the main rod. The position of the meter and sliding support is set by raising or lowering the positioning rod which extends through the handle at the top of the main rod. When the elevation of the meter is set to read the depth on the vernier, it will be at the 0.6 depth position. Doubling the vernier reading puts the meter at the 0.2 depth, and halving puts it at 0.8 depth. Once set, the positioning rod, and hence, the sliding support and meter, is secured by a locking device on the handle. Thus, all adjustments are made from above water so the operator's hands and the log can remain dry.

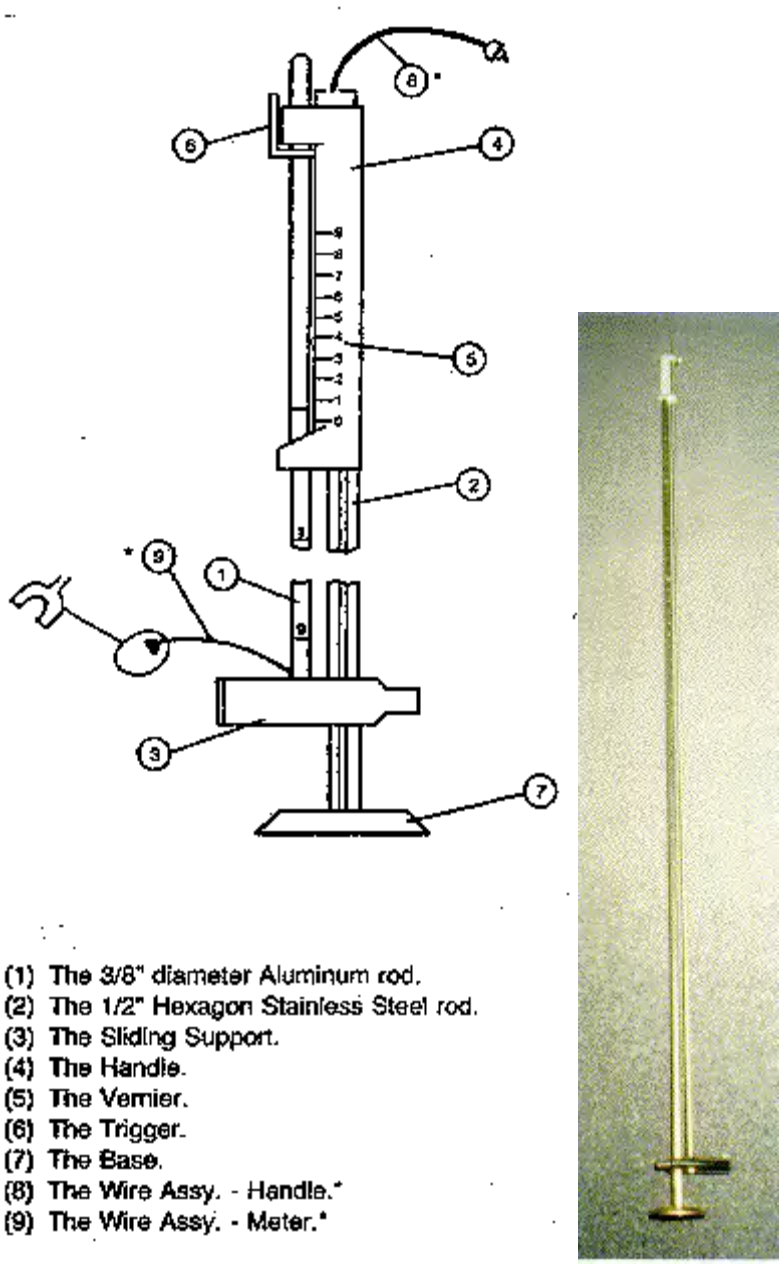



Figure 10-15 – Top setting wading rod.

## 9. Care of Propeller Meters

Current meters must receive the best care during transportation and use to ensure accurate velocity measurements. Particular care should be taken when working near bridge piers and abutments, floating debris or ice, and also when measurements are being taken at irregular or unknown sections and the meter is suspended on a measuring line. If the cups or blades become bent or damaged, the results obtained from the rating curve for the meter will be unreliable. After completing the measurements at a rating station, the meter should be carefully cleaned. After each day's use, it should be properly lubricated.

The Price-type meters have special cases for storage when the meter is not in use. For damage protection, the cup wheel should be supported firmly on the resting pin that replaces the needle bearing while the meter is stored or being transported. Meter damage has occurred because of improper packing and careless handling in transportation. The meter case should be substantial and rigid with properly fitted interior supports to prevent movement and damage to the delicate parts.

## 10. General Procedures and Precautions

Accuracy of measurement can be maintained by observing the following precautions for Price meters (including the pygmy meter modification of the Price meter):

- The meter should be spin tested before and after completing measurements to assure that the meter has no error-causing damage. With the shaft in a vertical position and the cups protected from air currents, the cups should be given a quick turn to start them spinning. If the meter is in proper adjustment and the bearings are free from foreign particles, the cups should come to rest in not less than 3 minutes. If the length of spin is only about 12 minutes, but the cup wheel comes to rest gradually, all flows except those of very low velocities may be measured. If the length of spin is only about 1 minute but the cup wheel comes to rest gradually, the meter may still be used to measure velocities above 1 ft/s. If the length of spin is less than 1 minute, the meter should be reconditioned. Under laboratory controlled conditions, rotation should continue for about 4 minutes. The manner in which rotation ceases will help indicate the condition of the meter and should be observed.
- The cross section of the stream should be divided vertically into 20 or more segments. Very small streams and sections with smooth, firm boundaries are exceptions, and a smaller number of stream cross-section segments would be sufficient. A single vertical reading is used if the distance between verticals is less than 1 ft. Horizontal divisions are generally selected so not more than 10 percent, and preferably not more than 5 percent, of the discharge will occur between any two adjacent verticals.
- The stopwatch should be checked frequently and kept in good condition.
- For low and irregular velocities, the period of observation should be lengthened to obtain a more accurate average count.
- The current meter should be withdrawn from the water between velocity readings to make sure that rotation is not being impeded by debris or any other cause.
- The meter should be allowed at least 10 to 20 seconds to attain rotation speed before counting commences.

- The total operation of the meter at each elevation of a vertical should consist of at least two consecutive periods of at least 40 seconds. If significant differences are apparent in each period, more readings should be taken.
- Measurements while wading should be done facing the bank, standing just downstream from the tag line, and at least 18 in to the side of the meter.

## 11. Method of Measurement

Depth sounding, either with a meter and rod assembly or with a special sounding line and weight, should first be made at each of the permanent measuring points. These depths should be properly recorded. Next, the mean velocity at each of the measuring points should be determined with the current meter by one of the methods listed in the following section. Velocity measurements should be properly recorded.

Errors of velocity measurement will arise if the current meter:

- Is placed closer to the boundary than 1-2 rotor diameters
- Is used to measure velocities less than 0.5 ft/s or out of the range of calibration. Overdriving the rotor can damage bearings
- Is not held steady in one position during the time measurement
- Is used in significant waves, such as those caused by wind
- Is used in flow which is not parallel to the axis of the propeller meter or is oblique to the plane of the cup-type meter
- Is impeded by weeds or debris

## 12. Methods of Determining Mean Velocities

The following methods are used to determine mean velocities in a vertical line with a current meter:

- Two-point method
- Six-tenths-depth method
- Vertical velocity-curve method
- Subsurface method
- Depth integration method
- Two-tenths method
- Three-point method
- One-point continuous method

The two-point method consists of measuring the velocity at 0.2 and then at 0.8 of the depth from the water surface and using the average of the two measurements. High accuracy is obtainable with this method, and its use is recommended. However, the method should not be used where the depth is less than 2 ft.

The six-tenths-depth method consists of measuring the velocity at 0.6 of the depth from the water surface and is generally used for shallow flows where the two-point method is not applicable. The method gives satisfactory results.

The vertical velocity-curve method consists of measuring the velocities at enough vertical positions so that the velocity profile is defined well enough to calculate a sufficiently accurate mean velocity. The method is very accurate, depending upon the number of data points measured for profile, but is time consuming and costly.

The subsurface method involves measuring the velocity near the water surface and then multiplying it by a coefficient ranging from 0.85 to 0.95, depending on the depth of water, the velocity, and the nature of the stream or canal bed. The difficulty of determining the exact coefficient limits the usefulness and accuracy of this method.

The depth or traveling integration method is performed by observing the velocity along a vertical line by slowly and uniformly lowering and raising the meter throughout the range of water depth two or more times. The method is not accurate and should be used only for comparisons or quick, rough checks.

The two-tenths, three-point, and one-point continuous methods are special procedures based on a relationship - previously established for the section - between the true discharge and the velocities observed by these methods. These methods are generally reliable for sections which undergo no serious changes because of erosion, sedimentation, or other deformation. They are discussed in detail in USGS (1965) and USGS (1980). Of the methods cited in this section, the two-point method and the six-tenths-depth method are most used in canal work.

## 13. Computing Discharge

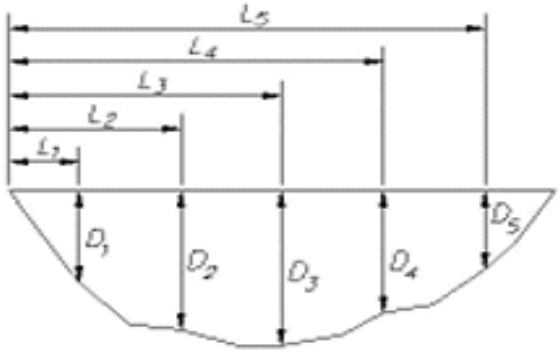
The velocity-area principle is used to compute discharge from current-meter data. Total discharge is determined by summation of partial discharges. A partial discharge is the product of an average point or vertical line velocity and its meaningfully associated partial area, expressed as:

$$q_n = \nabla_n a_n \quad (10\text{-}3)$$

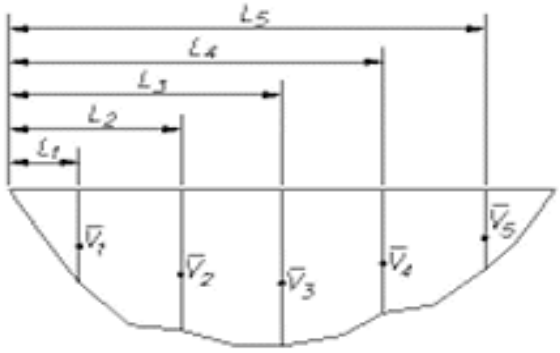
The total discharge is then:

$$Q = \sum_{1}^{n} (\nabla_n a_n)$$

The simple average, the midsection method, and Simpson's parabolic rule applied to both the depth and average vertical line velocity values will be discussed using figure 10-16. This figure shows: (a) where the boundary is broken up into inflecting straight line sections and (b) where the boundary is smoothly curved.

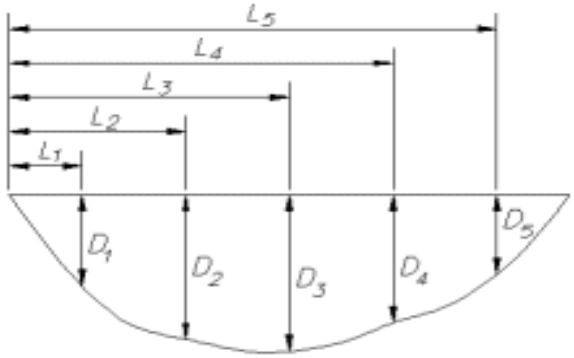



Typical Cross Section

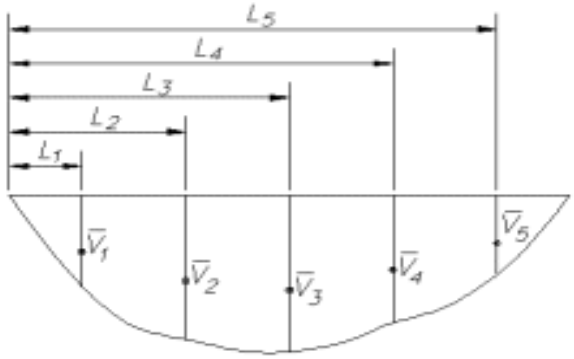



Horizontal Velocity Profile

Figure 10-16a -- Calculation of discharge using the midsection method.




Typical Cross Section




Horizontal Velocity Profile

Figure 10-16b -- Calculation of discharge using Simpson's parabolic rule method.

The measured and computed variables are as follows:

$q$ = the discharge in cubic feet per second ($ft^3/s$) for a partial area
$Q$ = total discharge
$\nabla$ = the mean velocity associated with the partial area
$a$ = partial area of total cross section
$L_1, L_2, \ldots L_n$= distance to vertical measurement locations in feet from an initial point to vertical station
$\Delta L$ = the distance in feet between consecutive vertical measurement stations
$\nabla_1, \nabla_1, \ldots \nabla_n$ = the respective mean velocities in feet per second at vertical measurement stations
$D_1, D_2, \ldots D_n$= the water depths in feet at verticals
$n$ = the number of verticals related to the partial area

## 14. Simple Average Method

Using the simple average of two successive vertical depths, their mean velocity, and the distance between them results in:

$$q_{3\text{-}4} = \left[\frac{\nabla_3 + \nabla_4}{2}\right]\left[\frac{D_3 + D_4}{2}\right](L_4 - L_3) \qquad (10\text{-}5)$$

The two hyphenated integers as a subscript denote that the partial discharge, $q$, is for the area between two consecutive vertical measurement points as numbered.

## 15. Midsection Method

In the midsection method, the depth and mean velocity are measured for each of a number of verticals along the cross section. The depth at a vertical is multiplied by the width, which extends halfway to the preceding vertical and halfway to the following vertical, to develop a cross-sectional area. The product of this area and the mean velocity at the vertical gives the discharge for the partial section between the two halfway points. A summation of the partial discharges gives the total discharge. The formula for computing the partial discharge using the midsection method is:

$$q_{n\pm} = \nabla_n \left[\frac{(L_n - L_{n-1}) + (L_{n+1} - L_n)}{2}\right] D_n \qquad (10\text{-}6)$$

The value, $n$, with plus and minus after it denotes that the partial discharge, $q$, is for the area between halfway back toward the previous vertical measurement and halfway toward the next forward vertical.

The mean velocities are determined by any one of the methods listed in section 12. For these two methods, the verticals do not need to be equally spaced, but the verticals should be chosen such that:

(1) The error of computing the area between the verticals does not exceed 3 percent when the bed is treated as straight lines between the verticals.

(2) Except at the banks, the difference between the mean velocities at the verticals does not exceed 20 percent relative to the lower velocity of a pair of verticals.

## 16. Simpson's Parabolic Rule

In this method, Simpson's parabolic rule is used twice to compute discharge using the area velocity method. First, the area is computed for three consecutive depths at velocity measuring stations using Simpson's rule. Second, average velocity for the same three verticals is computed by the rule. The discharge between the three verticals is the product of the average velocity and area. Using Simpson's rule assumes both the vertical depths and their corresponding average velocity vary parabolically (figure 10-16b). Natural riverbeds and older earth-lined canal bottoms follow curved shapes rather than the typical straight line geometry of hard-lined canal designs. Both vertical and horizontal velocity profiles tend to be parabolic in either case. Using Simpson's rule to obtain the area between three equally spaced consecutive verticals or two consecutive partial areas results in:

$$A_{n\pm} = \left(\frac{D_{n-1} + 4D_n + D_{n+1}}{3}\right) \Delta L \qquad (10\text{-}7)$$

where Δ is the distance between consecutive vertical velocity measuring stations which are equally spaced across the flow section.

Using Simpson's rule to obtain the mean velocity of three consecutive verticals or over two consecutive partial areas is expressed as:

$$<\nabla_{n\pm}> = \Delta L \left(\frac{\nabla_{n-1} + 4\nabla_n + \nabla_{n+1}}{3}\right)/2\Delta L \qquad (10\text{-}8)$$

The product of this velocity and the area from the previous equation results in the relationship for the discharge through the two consecutive partial areas, written as:

$$q_{n\pm} = \left(\Delta L\left(\frac{\nabla_{n-1} + 4\nabla_n + \nabla_{n+1}}{3}\right)/2\Delta L\right)\left(\frac{D_{n-1} + 4D_n + D_{n+1}}{3}\right)\Delta L \qquad (10\text{-}9)$$

Typical discharge computations obtained by the midsection method, equation 10-5, are illustrated on figure 10-17. Velocities were taken from the current-meter rating table on figure 10-8.

9-275C
(4/54)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DISCHARGE MEASUREMENT NOTES

Meas. No. 180
Comp. by DTS
Checked by WF

Snake River near Moran, Wyoming

Date July 6 1962. Party O. F. Sifolar
Width 214 Area 1,140 Vel. 3.70 G. H. 6.70 Disch. 4,220
Method 6-2-8 No. secs. 25 G. H. change 0 to in. Stag. 10.0
Method coef. 1.0 Hor. angle coef. 1.0 Sup. coef. 1.005 Meter No. 21,7010

| GAGE READINGS | | | | |
|---|---|---|---|---|
| Time | | Recorder | Inside | Outside |
| 1700 | 6.72 | 6.70 | 6.70 | |
| 1705 | 6.72 | 6.70 | 6.70 | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| 1810 | 6.72 | 6.70 | 6.70 | |
| Weighted M. G. H. | | 6.70 | | |
| G. H. correction | | | | |
| Correct M. G. H. | | | | |

Date rated 5-31-62 Used rating
for rod ..... corp. Meter 2 ft.
above bottom of wt. Tags checked ✓
Sp'n before meas. OK after OK
Mean plots ..... % dif. from ..... rating
Wading, cable, ice, boat, upstr., downstr., side
bridge ..... feet, mile above, below
gage and .....
Check-bar, chain found .....
changed to ..... at .....
Current .....
Levels obtained .....

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following
condition: Cross section cobbles
Flow open Weather fair
Other ..... Air ..... °F@ .....
Gage OK Water 52 °F@ .....
..... Record reported ..... Intake dished 6.70
Observer .....
.....
Control clear
.....
Remarks .....
.....
.....
G. H. of zero flow ..... ft.

Figure 10-17 -- Typical current-meter notes and computations for the midsection method using equation 10-5 (sheet 1 of 3).

| Distance from bank (feet) | Width | Depth | Depth of meter | Revolutions | Time in seconds | Velocity at point | Velocity mean vertical | Adjustment factor for angle | Area | Discharge |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 5 | 0 | | 0 | 40 | | 0 | | 0 | 0 |
| 40 | 10 | 3.40 | .2 | 60 | 41 | 3.25 | 2.79 | | 34.0 | 95 |
| | | | .8 | 50 | 48 | 2.33 | | | | |
| 50 | 10 | 4.70 | .2 | 80 | 43 | 4.13 | 3.52 | | 47.0 | 165 |
| | | | .8 | 60 | 46 | 2.90 | | | | |
| 60 | 10 | 5.30 | .2 | 80 | 43 | 4.13 | 3.73 | | 53.0 | 198 |
| | | | .8 | 60 | 40 | 3.33 | | | | |
| 70 | 10 | 5.80 | .2 | 80 | 42 | 4.25 | 3.82 | | 58.0 | 222 |
| | | | .8 | 80 | 52 | 3.42 | | | | |
| 80 | 10 | 5.90 | .2 | 80 | 39 | 4.53 | 3.97 | | 59.0 | 234 |
| | | | .8 | 60 | 39 | 3.42 | | | | |
| 90 | 10 | 5.90 | .2 | 80 | 39 | 4.53 | 3.89 | | 59.0 | 230 |
| | | | .8 | 60 | 41 | 3.25 | | | | |
| 100 | 10 | 5.90 | .2 | 80 | 30 | 4.93 | 4.04 | | 59.0 | 238 |
| | | | .8 | 80 | 50 | 3.55 | | | | |
| 110 | 10 | 6.00 | .2 | 100 | 43 | 4.62 | 4.09 | | 60.0 | 245 |
| | | | .8 | 80 | 50 | 3.55 | | | | |
| 120 | 10 | 6.20 | .2 | 100 | 48 | 4.62 | 3.98 | | 62.0 | 247 |
| | | | .8 | 60 | 40 | 3.33 | | | | |
| 130 | 10 | 6.25 | .2 | 100 | 47 | 4.78 | 4.02 | | 62.5 | 251 |
| | | | .8 | 60 | 40 | 3.33 | | | | |
| 140 | 10 | 6.30 | .2 | 100 | 48 | 4.62 | 3.96 | | 63.0 | 246 |
| | | | .8 | 60 | 48 | 3.18 | | | | |
| 150 | 10 | 6.70 | .2 | 80 | 39 | 4.53 | 3.82 | | 67.0 | 256 |
| | | | .8 | 60 | 43 | 3.10 | | | | |
| 160 | 10 | 6.90 | .2 | 80 | 42 | 4.25 | 3.81 | | 69.0 | 262 |
| | | | .8 | 60 | 48 | 2.79 | | | | |
| 170 | 10 | 6.30 | .2 | 80 | 42 | 4.25 | 3.66 | | 63.0 | 231 |
| | | | .8 | 60 | 43 | 3.10 | | | | |
| 180 | 10 | 6.10 | .2 | 80 | 41 | 4.33 | 3.87 | | 61.0 | 236 |
| | | | .8 | 60 | 39 | 3.41 | | | | |

Figure 10-17 -- Typical current-meter notes and computations for the midsection method using equation 10-5 (sheet 2 of 3).

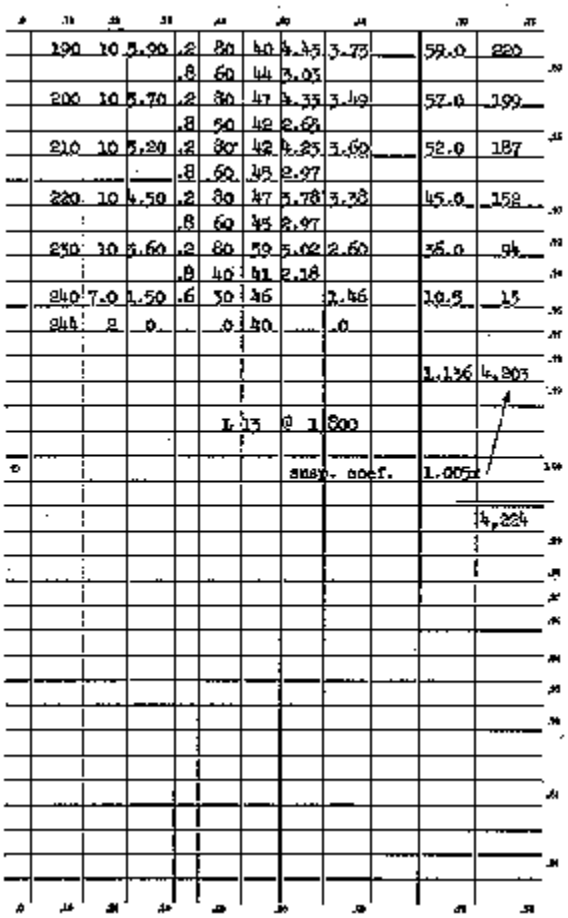


Figure 10-17 -- Typical current-meter notes and computations for the midsection method using equation 10-5 (sheet 3 of 3).

Simpson's parabolic rule method is particularly applicable to river channels and old canals that have cross sections conforming in a general way to the arc of a parabola or to a series of arcs of different parabolas. Simpson's method requires equally spaced verticals. The simple average and the midsection methods do not require equally spaced verticals. Thus, these two methods are well suited to computing discharges in canals that conform closely to their original trapezoidal rectangular shapes.

## 17. Canal Discharge Curves

To rate a flow section, discharge measurements at a current-meter station should be taken over a wide range of canal flows to ensure accuracy in preparing velocity, area, and discharge rating curves (section 1). Water is usually turned into the canals at gradually increasing rates as demand increases during the irrigation season. Thus, measurements for all flow stages in the canal often can be obtained during one season.

The canal bed at a well selected current-meter station is generally permanent in character, and a permanent rating curve could be made if not for sediment accumulations or for growths that occur in the canal during the irrigation season. The sediment and the growths both decrease the discharge capacity of the canal for all flow depths, and the effect is usually most pronounced during the latter part of the irrigation season.

This change in flow capacity of the canal for a given depth of flow must be taken into consideration when computing the quantity of water carried by the canal. If the canal is cleaned during the season, the relationship of discharge to gage height is again disturbed. The changing relationship of discharge to gage height in irrigation canals caused by changing boundary conditions is the chief source of error in flow measurements.

## 18. Gage Readings

To determine the quantity of water carried by a canal over a period of time, the gage must be read at least twice daily. More than one reading provides a means for checking the readings and also informs the canal attendant of any unexpected changes in canal stage. More frequent readings are needed when changes in stage are suspected or are made in the canal. The readings should be taken by the canal attendant on regular rounds. The gage should be read accurately, generally to the nearest hundredth of a foot. Automatic water-stage recorders eliminate the need for numerous readings and can increase the accuracy of the flow measurements.

## 19. Computations of Discharges

Current-meter measurements made at several specific flows can be used to obtain discharge, velocity, and area curves that apply to all inclusive gage heights by plotting the appropriate data on cross-section or graph paper (figure 10-18). Discharges, corresponding mean cross-sectional velocities, and cross-sectional areas are plotted on the horizontal axis. Corresponding gage heights are plotted on the vertical axis. Three separate curves are drawn through these data points.

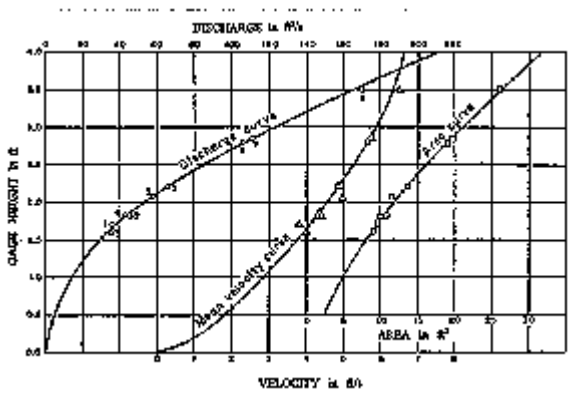



Figure 10-18 -- Typical discharge, mean velocity, and area curves for a canal.

The probable area curve is established first by drawing the most probable line through the data points. Using this curve, the accuracy of the area computations and of the flow depth measurements may be checked. Next, the computed mean cross-sectional velocities are plotted, and a curve is drawn through the points. This curve provides a check on the velocity computations and helps detect changes in velocity that may occur in the canal because of changing roughness or silting in the canal.

Finally, the discharge curve is drawn through the computed discharge points. If flow conditions in the channel did not change resistance significantly during the period needed for measurements over the full range of canal flows, the curve will generally be easy to draw.

If the relationship of discharge to gage height was affected by growths or sediment deposits, one or more additional discharge curves must be drawn. The number of rating curves required for a cross-section location depends upon the degree of the flow restrictions encountered and the rate at which the restrictions developed. These curves will generally be parallel to, but slightly displaced from, the curve for the clean canal. For the periods when the change is in progress, discharges may be estimated by proportioning between curves for the clean and restricted conditions on a time basis.

## 20. Rating Table

From the rating curve, a rating table may be prepared for each tenth or hundredth of a foot of gage height from zero to the maximum height of water in the canal or stream. For canals affected by growths or sediment, two or more such rating tables will be necessary, one for early in the season when the canal is clean, and the other for late in the season when growths or other restrictions are present. If the canal is cleaned during the irrigation season, operating personnel should be instructed to switch to the curves and tables for the clean canals.

## 21. Daily and Monthly Discharges

Discharges in acre-feet may be compiled from the daily gage heights and the rating tables. From these tables, the monthly discharges and the total amount of water delivered by the canal during the irrigation season may be obtained.

## 22. Measuring Discharges From Pipes With Current Meters

Propeller-type current meters have been used with limited success to measure rates of flow discharging from full pipelines (Rohwer, 1942). Measurements are made by traversing the pipe outlet with the meter to obtain an average velocity and then multiplying this velocity by the pipe cross-sectional area and by a correction coefficient. This coefficient has a value less than 1.0 because the meter traverses do not adequately measure flows close to the pipe walls and give a velocity measurement higher than the true average.

Accuracies within +/-5 percent can be obtained when the velocity of flow is enough to operate the meter but is less than 9 or 10 ft/s, provided the flow occurs without significant spiral flow, the discharge pipe is long enough to produce relatively uniform distributed flow, and the inside diameter of the pipe can be measured accurately. Velocities that are too high or too low, swirling flows, velocity concentrations, and pipelines not flowing full or carrying air reduce the accuracy obtainable. Also, the presence of the meter in the pipeline exit partially obstructs the flow. This obstruction reduces the rate of flow and increases the head in the pipeline. The effect is relatively small, but a correction factor is necessary to obtain best accuracies. In general, the method gives quick, comparative results but is not recommended where accurate flow measurements are needed. A simple, low, flat-crested, long-throated measurement structure (chapter 8) would be an accurate method to measure flow from a partially full pipe.

## 23. Bibliography

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# CHAPTER 11 - ACOUSTIC FLOW MEASUREMENT

## 1. Transit-Time Acoustic Flowmeters

Transit-time acoustic (ultrasonic) flowmeters are based on the principle that transit time of an acoustic signal along a known path is altered by the fluid velocity. A high frequency acoustic signal sent upstream travels slower than a signal sent downstream. By accurately measuring the transit times of signals sent in both directions along a diagonal path, the average path velocity can be calculated. Then, knowing the path angle with respect to the direction of flow, the average axial velocity can be computed (figure 11-1).

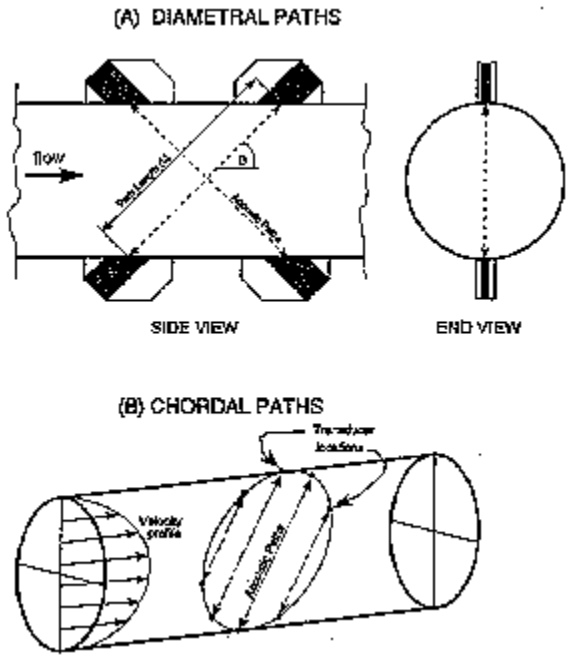


Figure 11-1 -- Transit-time acoustic flowmeters.

An acoustic flowmeter is a non-mechanical, non-intrusive device which is capable of measuring discharge in open channels or pipes. These flowmeters can provide continuous and reliable records of flow rates over a wide range of conditions including flow in both directions. Some typical applications include:

- Acceptance testing of hydraulic machinery (turbines and pumps).
- Flow measurement in conduits of large (360 inch [in]) and small (1/2 in) diameter.
- Hydroelectric powerplant management.
- Volumetric metering.
- Wastewater or water treatment plants.
- Laboratory and field calibration of other flow measurement devices.

Two common methods are used to calculate discharge using acoustic flowmeters:

**(a) Diametral-Path Flowmeter**

One or more pairs of acoustic transducers are mounted diametrically opposed in the measurement section (figure 11-1a). An average axial velocity is measured along each acoustic path, and volumetric flow rate is computed based on the known cross-sectional area of the conduit. This technique is based on an assumption that the velocity profile shape in the measurement section is very similar to a fully developed, turbulent velocity profile. As a result, flowmeter accuracy depends on how well the actual velocity profile compares to the assumed profile. A poor velocity profile will result in flow measurement errors.

A modification of the diametrically opposed, single-path flowmeter uses the opposite inside wall of the pipeline to reflect the acoustic signal to the receiving transducer. The transducers are tightly secured with straps on the same side of the pipeline. Transducer spacing depends on pipe diameter and wall thickness. Accuracy can be within +/-2 percent of actual under good conditions.

**(b) Chordal-Path Flowmeter**

This type of flowmeter uses four or more acoustic paths which are mounted on chordal paths across the measurement section (figure 11-1b). The average axial velocity component for each acoustic path is used to establish the velocity profile. The velocity profile is then numerically integrated over the conduit's cross-sectional area to determine the volumetric flow rate. As a result, flowmeter accuracy is relatively independent of the velocity profile. Furthermore, this type of flowmeter does not require calibration to reach the manufacturer's specified accuracy (usually between 0.5 to 2 percent of the flow rate).

The following advantages and disadvantages identified for acoustic flow measurement are discussed below.

**(c) *Advantages***

- High accuracy, which can be achieved independent of velocity profile, flow rate, and liquid temperature.
- Bidirectional flow measurement capability.
- Non-intrusive, incurring no head loss.
- Field calibrations are generally not required.
- System cost is almost independent of pipe size.
- No moving parts and easily serviceable.

**(d) *Disadvantages***

- Relatively high initial cost.
- Requires electronic technician to troubleshoot and service.
- Must be programmed for each pipeline material, diameter, and wall thickness.
- Entrained gases and/or suspended sediment affect the acoustic signal strength.

## 2. Theory

Acoustic flowmeters were developed based on the principles that the transit time of an acoustic signal is longer in the upstream than downstream direction, and that these transit times can be accurately measured using microcomputer technology.

Discharge measurements are based on determining the average axial velocity in a full-flowing pipe. Knowing this velocity and the cross-sectional area of the measurement section, a discharge can be calculated. The difference in transit times of acoustic signals traveling in opposite directions through the water can be related to velocity of flow (figure 11-1a). In the downstream direction, the velocity of the flowing water, $V_w$, adds to the speed of sound, $C$, to give the effective speed of the acoustic pulse, $C + V_w$. In the upstream direction, the velocity of flow delays the arrival of the pulse, resulting in an effective pulse speed of $C - V_w$. Taking the difference in these transit times eliminates $C$ from the calculations and results in $)t$. When $)t$ is known, the average axial velocity can be obtained from the formula:

$$V_{axial} = \frac{L}{2COS\theta}\left(\frac{1}{t_d} - \frac{1}{t_u}\right) = \left(V_{axial} = \frac{L}{2COS\theta}\ \frac{\Delta t}{t_u t_d}\right) \quad (11\text{-}1)$$

where:

$V_{axial}$ = average axial velocity of waterflow
$t_u$ = upstream travel time of the acoustic signal
$t_d$ = downstream travel time of the acoustic signal
$\Delta t$ = difference in upstream and downstream travel times
$\theta$ = angle between the acoustic path and the pipe's longitudinal axis
$L$= acoustic path length between the transducer faces

Another acoustic flow measurement technique uses a similar approach which employs the frequency difference between upstream and downstream acoustic signals. This method is similar to the transit-time method and will not be covered. For more information, see American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) standard MFC-5M-1985.

## 3. Available Technology

At this time (1996), many different types of acoustic flowmeters are available. As mentioned in previous sections, transit-time and frequency difference devices, as well as devices which use chordal (multipath) or diametral (single-path) paths to measure the average velocity in the pipe are available. Some systems use clamp-on transducers mounted to the outside of the pipe wall, and some use internal or wet-mount transducers. Likewise, some transducers are mounted in a spool, and others are installed in an existing section of pipe. All these options have their advantages and disadvantages, and they will be covered later.

All acoustic flowmeters consist of the following components.

**(a) Primary Device**

A spool piece with the transducers installed or an existing section of the pipe to which the transducers are mounted. Transducers can also be clamped to the outside of the pipe.

**(b) Measurement Section**

The pipe section in which the flow rate is being measured. This section is located between the upstream and downstream transducer locations and is usually a circular cross section, but acoustic flowmeters can be used in conduits of various shapes.

**(c) Transducers**

The transducers transmit and receive the acoustic signals. They may be factory or field mounted by clamping, threading, or gluing them to the pipe wall. Transducers can be wetted by the fluid or can be attached to the outside of the pipe. Wetted transducers may be flush mounted, protruding, or recessed. Some wetted transducers can be replaced without taking the pipeline out of service.

**(d) Acoustic Paths**

Single-path or multipath measurement sections can exist where each acoustic path consists of a pair of transducers. Common path configurations are diametral and chordal (figure 11-1) or diametrically reflective.

**(e) Secondary Device**

A secondary device contains the electronics necessary to operate the transducers, measure the transit times, process the data, and display and store the results. Most meters have several outputs available, including analog, digital, and/or alarms either as standard equipment or options. Likewise, several outputs can be stored or sent by telemetry to another location.

## 4. System Errors

Error sources for acoustic flowmeters are primarily related to the measurement of the average axial velocity. The main source of errors occurs in the determination of the acoustic path length, $L$, and the path angle, $\theta$. The error in the velocity measurement is directly proportional to the uncertainty of these two variables. Care must be taken to minimize errors in measuring path length and angles. This care is especially necessary for chordal path meters because the computational procedures require accurate positioning of the acoustic paths. Likewise, errors in the cross-sectional area of the measurement section cause an error in the discharge measurement. This error can be a result of out-of-roundness or shape irregularities caused by temperature, pressure, structural loading, or deposits on the pipe walls. In circular pipe, cross-section dimensional errors can be reduced by averaging diameter measurements made at upstream, midsection, and downstream ends of the measurement section.

Another source of error occurs in measuring the transit times of the acoustic signals and in detecting the acoustic signal in the presence of electrical noise.

Signal detection can also be hindered by signal modifications caused by changes in acoustical properties of the liquid which are caused by entrained air, suspended solids, and changes in temperature and pressure. Likewise, transducer fouling by algae or mineral deposits can reduce signal strength.

Secondary flows can create an error in the determination of $V_{axial}$ because the calculations are based on flow direction in the axial direction only. Secondary flow is caused by flow disturbances near the measurement section. These disturbances are typically caused by valves, elbows, or transitions. Secondary flow problems can be avoided by careful selection of the measurement section. For small pipes (diameters less than 36 in), 10 pipe diameters of straight pipe upstream and 3 to 5 diameters downstream from the measurement section should be sufficient. For pipe diameters greater than 36 in, 20 to 30 pipe diameters of straight pipe upstream and 3 to 5 diameters downstream may be required to obtain an acceptable velocity profile. If the measurement section must be placed near a bend, secondary flow errors can be reduced by orienting the acoustic paths perpendicular to the plane of the bend and locating the transducer as far downstream as possible. Likewise, another solution is the addition of another acoustic path which crosses the first path. Exact cancellations of secondary flow errors can be accomplished using a cross path configuration. The diametrically reflective path provides a cross path directly. Other variations in velocity profiles, due to Reynolds number effects and pipe wall roughness, can be corrected using a velocity profile correction factor. This correction factor corrects for the difference between the actual velocity profile and the profile assumed in the flowmeter's calculations. In general, deviations in velocity profiles are best accounted for by increasing the number of acoustic paths.

## 5. Installation Considerations

Many of the errors considered above can be eliminated or decreased by following the manufacturer's installation guidelines. Errors and their sources should be addressed prior to flowmeter installation. The following paragraphs cover areas which should be examined. More detailed descriptions are available in American Society for Testing and Materials (1984), American National Standards Institute (1985), and Laenen (1985).

### (a) Acoustic Path Length and Angle

Changes in acoustic path length and angle can be caused by significant changes in pressure or temperature, along with external loading on the meter section. The measurement section should be examined to determine if any of these conditions exist. In addition, path lengths and angles must be known with a high degree of accuracy.

### (b) Signal Detection

Entrained air, suspended solids, and transducer fouling may lower accuracy or prevent operation by weakening the acoustic signal. Electrical and acoustical noise caused by mechanical vibration, other electrical devices, or cavitation can also disrupt the flowmeter's operation.

### (c) Secondary Flows

Secondary flow or crossflow affects a meter's performance and should be evaluated in the system design. This design evaluation should include selecting a diametral path or chordal path meter and deciding whether a second crosspath is necessary. Path orientation should also be considered. Typically, the measurement section should be located as far downstream as practical from upstream bends, transitions, valves, and pumps.

### (d) Velocity Profile Integration

Chordal-path meters use numerical integration techniques to compute the flow rate. It is important that the chordal paths are positioned in accordance with the particular locations specified by the manufacturer.

### (e) Calibration

In general, acoustic flowmeters do not require a field calibration when manufacturer's suggested installation criteria have been met or exceeded. However, in some cases, unusual installation conditions or the need for a high degree of accuracy may require a calibration. Three methods exist for flowmeter calibration: (1) laboratory calibration, (2) field calibration, and (3) analytical techniques. For more information on calibration techniques, a good reference is the ANSI/ASME standard MFC-5M-1985 (American National Standards Institute, 1985).

## 6. Flowmeter Selection Guidelines

### (a) Single-Path Versus Multi-Path Flowmeters

Single-path meters are generally a lower cost alternative. They are also less complex which allows easier installation. Multi-path meters perform better under variable and/or non-ideal velocity profile distribution situations caused by upstream and downstream flow disturbances. Acoustic path orientation varies among meters; paths can be either crossed or parallel, or either chordal or diametral. The appropriate path configuration depends on site-specific constraints, economics, and the application.

### (b) External Mount Versus Through-Wall Transducers

External mount transducers are the easiest to install and require minimal surface preparation. As a result, installation is inexpensive when compared to through-wall transducers. External mounting transducers are non-intrusive, so they do not disturb the flow. They are also easily removed and replaced without taking the pipe out of service. It should be noted that errors in flow measurement caused by variable or changing wall and/or liner thickness can be significant.

Through-wall transducers are usually wetted or covered with a protective material. This type of transducer mount may provide increased acoustic signal strength because no signal attenuation occurs through the pipe wall. Through-wall transducers can be flush mounted, protruding, or recessed. Protruding or recessed transducer mounts can cause a local flow disturbance which may affect the flowmeter accuracy. Errors caused by a protruding or recessed transducer or the protective covering require a detailed analysis of the installation configuration.

The potential for transducer fouling from various waterborne contaminants (algae, minerals, etc.) also exists.

Theoretical equations used for acoustic flow measurement are based on the assumption that the transducers are in direct contact with the fluid. A protective covering or an external mount transducer will change the transit times and path angles. These changes are usually mathematically modeled by the manufacturer and corrected for by the secondary device.

## 7. Open Channel Acoustic Flowmeters

Open channel acoustic flowmeters are based on the same principles as pipeline flowmeters. However, open channel acoustic flowmeters are more complicated than pipeline flowmeters because the cross-sectional area varies with changing water level or stage. In general, these flowmeters are only economically practical for use where the following conditions exist:

- Channel widths are large.
- Head loss must be minimized.
- High accuracy is required.
- Section rating and stream gaging costs are high.
- Bidirectional flow (tidal) must be measured.
- Continuous measurements over a long time period are required.

This section will cover any additional considerations associated with open channel acoustic flowmeters not covered in the previous section on closed conduit acoustic flowmeters. Laenen (1985) and Laenen and Curtis (1989) contain more detailed information on open channel acoustic flowmeters.

Design of open channel meters is complicated by the potential errors introduced by a variable water surface and because the open channel environment can cause acoustic signal attenuation and refraction (bending). Another potential problem is signal deflection caused by density gradients or signal reflection from the channel bottom or water surface.

### (a) Single-Path Acoustic Velocity Meters

In general, single-path acoustic velocity meters (AVMs) are used as flowmeters by calibrating acoustic path velocities against mean channel velocities computed using standard stream gaging techniques. The discharge rating procedure for an AVM gaging site will involve developing ratings for both cross-sectional area and mean channel velocity. Necessary data required to develop these ratings are a stage-area relationship, acoustic path velocities, and the mean velocities through the discharge measurement cross section for a range of flows and stages. A data set should uniformly cover the expected range of stage and discharge. A velocity rating is developed using linear regression techniques to find the best-fit equation, with the instantaneous mean channel velocity as the dependent variable, and/or stage (acoustic path velocity) as the independent variables. After a calibration is established, discharge is computed by multiplying the instantaneous mean channel velocity, predicted from the best-fit equation, and the channel's cross-sectional area, which is determined using the stage-area rating. This method of flow measurement is only as accurate as the ratings developed during the calibration.

Therefore, care must be taken while measuring the discharge and in determining the channel's cross-sectional area for a range of stages. For installations where appreciable changes in stage occur, the transducers will have to be positioned to allow a full range of measurements.

**(b) Multipath Flowmeter**

This type of flowmeter uses several acoustic paths which are mounted at various elevations throughout the measurement section. The average velocity for each path is used to establish the velocity profile. The velocity profile is then numerically integrated over the channel's cross-sectional area to determine the volumetric flow rate. As a result, flowmeter accuracy is relatively independent of the velocity profile. However, integration errors are unavoidable because the velocities near the channel bottom and water surface cannot be measured because of acoustic interference caused by signal reflection.

**(c) Limitations**

Flowmeter accuracy and performance are limited by four factors:

1. Location of acoustic paths with respect to water surface and the channel bottom, which are reflective surfaces that can cause multipath interference at the receiving transducer(s).

2. Density gradients (usually caused by different water temperatures or salinities) cause the acoustic path to bend, which changes the acoustic path length.

3. Acoustic signal attenuation caused by varying concentrations of air bubbles, sediment, organic matter, and aquatic organisms.

4. Streamflow variability, which causes the angle between the acoustic path and the flow to change.

**(d) Availability**

Two types of equipment are available for use in measuring velocity: (1) a simple one- or two-path microprocessor based, preprogrammed system that will measure velocity only, and (2) a more complex, programmable, multipath minicomputer that can calculate discharge. At present (1997), open channel systems use 12 volts direct current or 110/220 volts alternating current.

**(e) Site Selection**

A thorough review of system limitations and equipment requirements is necessary prior to site selection (Laenen, 1985; Laenen and Curtis, 1989). A good measurement site has a reach where the velocity distribution is uniform and the channel is confined; areas with eddies or a high degree of turbulence should be avoided. It is recommended that the channel be relatively straight for 5 to 10 channel widths upstream and 1 to 2 channel widths downstream from the measurement section. The channel bottom should be stable or easily monitored for variations. A constant cross-sectional area and shape over the upstream and downstream extent of the measurement section is desirable.

If this condition cannot be met, an "effective" cross-section shape must be determined. The "effective" cross section is determined by taking the cross-sectional area along the acoustic path multiplied by the cosine of the path angle, $\theta$.

A concrete-lined section with a straight reach located upstream is ideal. During site selection, obtain cross-section survey information and note obstructions which may block the acoustic signal. Obtain temperature, total dissolved solids and sediment concentrations, and possible sources of air entrainment (overfalls, spillways, etc.). Variations in stage should be known in order to determine the number of acoustic paths required to assure the system accuracy.

**(f) Transducer Mounting Requirements**

When transducers are installed, their position and elevation must be measured and adjusted accurately for each transducer pair. Likewise, path lengths and path angles must be measured accurately. Transducer alignment is critical for establishing a strong acoustic signal and is usually performed by divers. Mountings should be designed so that transducer maintenance can be performed without using divers. Transducers are normally mounted near the banks, so mounting transducers on existing structures simplifies the installation process. Cabling options include submarine, overhead, or a responder link which eliminates the need for a cable crossing the channel. Cabling must be protected from damage from dredging, marine traffic, or vandalism.

**(g) Site Analysis**

The acoustic path(s) at each site should be checked for multipath interference caused by the water surface or channel bottom. In general, for every 100 feet (ft) of acoustic path length, about 1 ft of clearance is necessary to prevent multipath interference. The transducers should be located at least 20 in below the water surface to prevent signal bending caused by solar warming. Signal bending will affect the flowmeter accuracy. Therefore, avoid conditions where the acoustic signal is bent and is reflected off the water surface and/or channel bottom. Check the acoustic signal for potential attenuation. The normal sediment concentration that can be tolerated by most systems is about 2,000 milligrams per liter. However, tolerable concentrations are a function of transducer frequency, particle size, and acoustic path length.

**(h) Calibration**

Flowmeter calibration can be done using current meter measurements, other velocity-area methods, or using computations based on theoretical velocity profiles. The effort expended for calibration will depend upon factors such as number of acoustic paths, flow conditions at all stages, channel stability, and accuracy requirements. However, accuracy can be verified only within the limits of the calibration method used.

**(i) Accuracy**

For many streamflow conditions, a single-path flowmeter can measure flow within an accuracy of 3 to 5 percent. For multipath systems, accuracies of 2 percent or better can be achieved over a wide range of flow rates and channel conditions if the system design addresses the major sources of errors of acoustic flow measurement. Errors associated with open channel acoustic flowmeters are usually attributed to three sources:

1. Transit-time measurements, where timing errors can be on the order of 0.1 foot per second (ft/s) for systems which employ signal validation routines or 0.3 ft/s when signal validation techniques are not used.

2. Acoustic path angle variation. In general, for every one degree of uncertainty in path angle, about 1 percent uncertainty occurs in velocity measurement. Use of crossed acoustic paths will compensate for variations in streamflow direction.

3. Acoustic signal bending. For path lengths less than 1,000 ft, this error is usually less than 3 percent in velocity.

**(j) Operation and Maintenance**

Acoustic flowmeters are advanced electronic systems that require specialized maintenance. Properly trained technicians are needed to keep the flowmeter operating. An electronic technician and proper test equipment are needed to troubleshoot the equipment. This requirement is especially true during the initial phases of installation. Likewise, transducer mounts should be designed to allow access for transducer cleaning, alignment, and replacement without using divers.

## 8. Doppler-Type Acoustic Flowmeter

The Doppler flowmeter measures the velocity of particles moving with the flowing fluid (figure 11-2a). Acoustic signals of known frequency are transmitted, reflected from particles, and are picked up by a receiver. The received signals are analyzed for frequency shifts (changes), and the resulting mean value of the frequency shifts can be directly related to the mean velocity of the particles moving with the fluid. System electronics are used to reject stray signals and correct for frequency changes caused by the pipe wall or transducer protective material. Doppler flowmeter performance is highly dependent on physical properties such as the liquid's sonic conductivity, particle density, and flow profile. Likewise, non-uniformity of particle distribution in the pipe cross section results in a computed mean velocity that is incorrectly weighted. Therefore, the meter accuracy is sensitive to velocity profile variations and to distribution of acoustic reflectors in the measurement section. Unlike other acoustic flowmeters, Doppler meters are affected by changes in the liquid's sonic velocity. As a result, the meter is sensitive to changes in density and temperature. These problems make Doppler flowmeters unsuitable for highly accurate measurements.

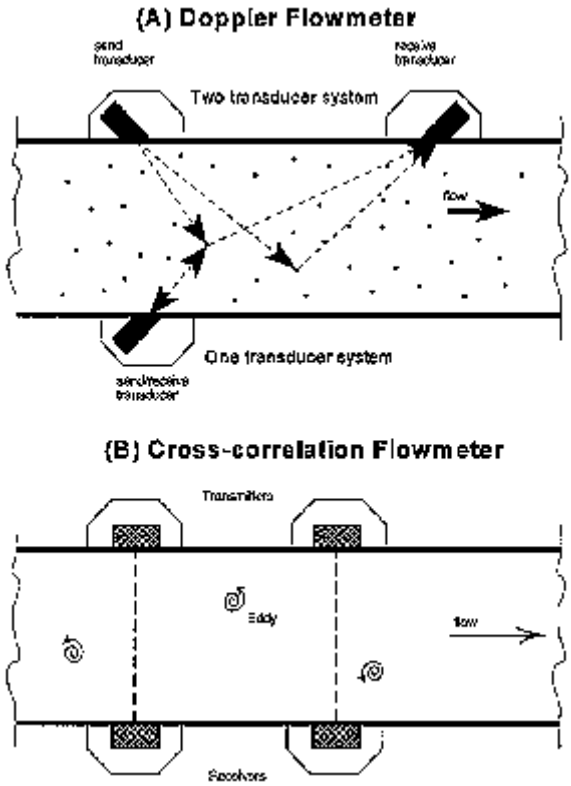


Figure 11-2 -- Doppler-type acoustic flowmeter and cross-correlation acoustic flowmeter.

## 9. Cross-Correlation Ultrasonic Meter

The cross-correlation meter employs two transverse acoustic signals separated by a short distance (figure 11-2b). Under no-flow or laminar-flow conditions, the two signals received are identical to those transmitted. When turbulent flow occurs, the movement of an eddy through a beam causes a change in the acoustic signal which has a unique signature. This particular eddy will cause an identical change in the second acoustic signal, and the eddy can be tracked as it moves down-stream. An electronic signal processor is used to compare the two received signals. When two identical signals are found, the time and distance (between the acoustic transmitters) information is used to compute velocity. In general, cross-correlation meters measure the average velocity of all the eddies crossing one pipe diameter. If no eddies are present in the flow, the meter can track sediment or bubbles. However, if the flowing fluid is homogenous and has no eddies (laminar flow), this type of meter will not work. Like the single-path transit-time meter, this meter measures an incorrectly weighted mean velocity. Therefore, the measurement is susceptible to an inaccuracy associated with variations in velocity profiles.

## Additional information for *Acoustic Flow Measurement*

The listings here should not be construed as an endorsement or recommendation of a service or product by the Bureau of Reclamation, Agricultural Research Service, Natural Resource Conservation Service, or other participants of these web pages. These are provided only as a convenience to our web clients. The listing below were selected based on a manufacture statement that they can provide a device related to this chapter or section.

## Web Resources

# The ADFM Velocity Profiler™ - A Report on Laboratory and Field Demonstrations Conducted for the Bureau of Reclamation

**Mike Metcalf - MGD Technologies Inc.; Tracy Vermeyen - Bureau of Reclamation, Water Resources Research Laboratory; Steve Melavic, John Fields - Bureau of Reclamation, Mid-Pacific Region**Mike Metcalf - MGD Technologies Inc.; Tracy Vermeyen - Bureau of Reclamation, Water Resources Research Laboratory; Steve Melavic, John Fields - Bureau of Reclamation, Mid-Pacific Region

## Introduction

A new type of flowmeter, the ADFM Velocity Profiler™ (Profiler) was demonstrated on March 3 and 4, 1997 at the Bureau of Reclamation's Water Resources Research Laboratory in Denver, Colorado. The demonstration was organized by Tracy Vermeyen of the Bureau of Reclamation and Mike Metcalf of MGD Technologies, the manufacturer of the Profiler. A subsequent field test of the instrument was conducted in the San Luis Drain near Los Banos, CA, on March 14, 1997. John Fields and Steve Melavic of the Bureau of Reclamation's Mid-Pacific Regional Office were responsible for organizing this test. This report documents the results of these tests.

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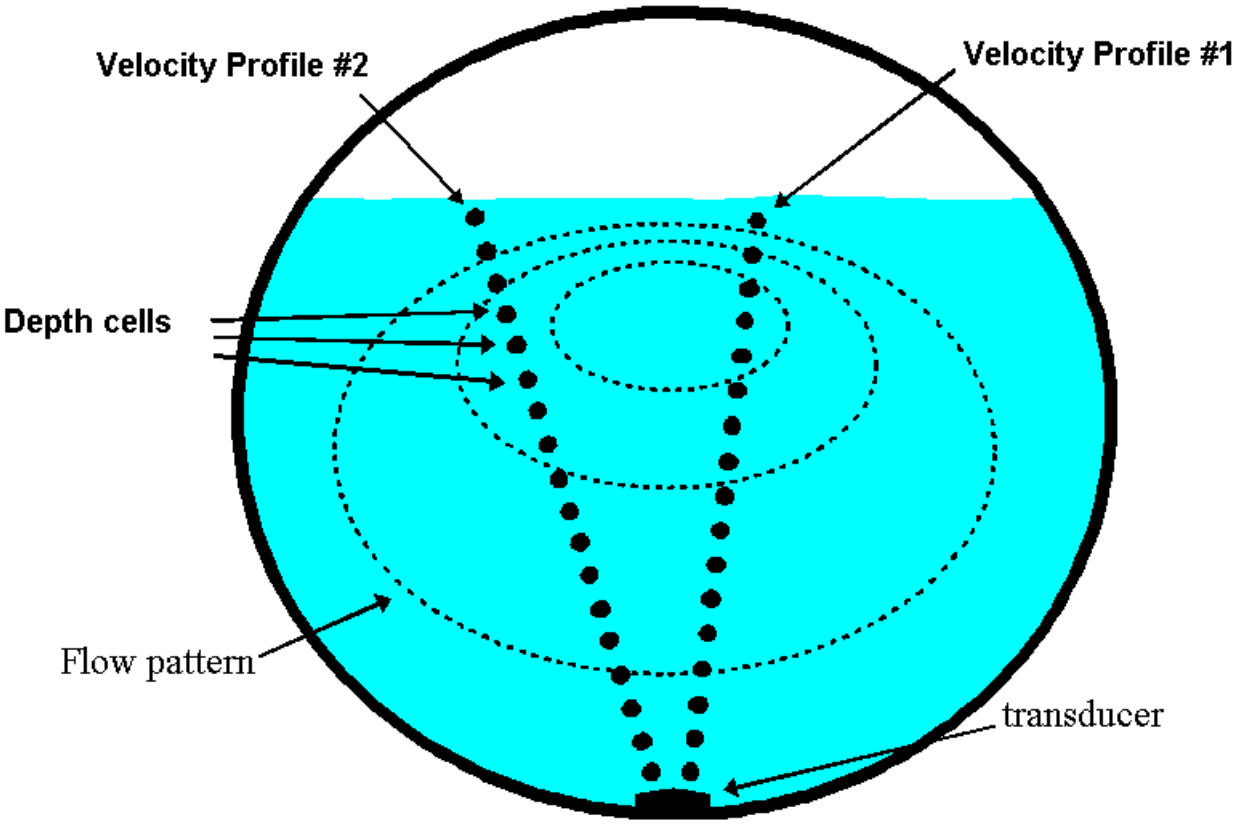


Figure 1. Cross section view of typical Profiler application. This figure shows the spatial relationship of the depth cells and the profiles relative to the transducer housing.

## The Instrument

Figure 1 shows a typical Profiler installation for measuring open channel flow in a pipe. A transducer assembly is mounted on the invert of a pipe or channel. Piezoelectric ceramics emit short pulses along narrow acoustic beams pointing in different directions. Echoes of these pulses are backscattered from material suspended in the flow. As this material has motion relative to the transducer, the echoes are Doppler shifted in frequency. Measurement of this frequency shift enables the calculation of the flow speed. A fifth transducer is mounted in the center of the transducer assembly and is used to measure the depth.

The Profiler divides the return signal into discrete regular intervals which correspond to different depths in the flow. Velocity is calculated from the frequency shift measured in each interval. The result is a profile, or linear distribution of velocities, along the direction of the beam. Each of the small black circles in Figure 1 represent an individual velocity measurement in a small volume known as a depth cell.

The directions of the velocity profiles in Figure 1 are based on the geometry of the Profiler's transducer assembly. Figure 2 shows a side view of the transducer assembly. The profiles shown in Figure 1 are generated from velocity data measured by an upstream and downstream beam pair. The data from one beam pair are averaged to generate Profile No. 1, and a beam pair on the opposite side of the transducer assembly generates Profile No. 2.

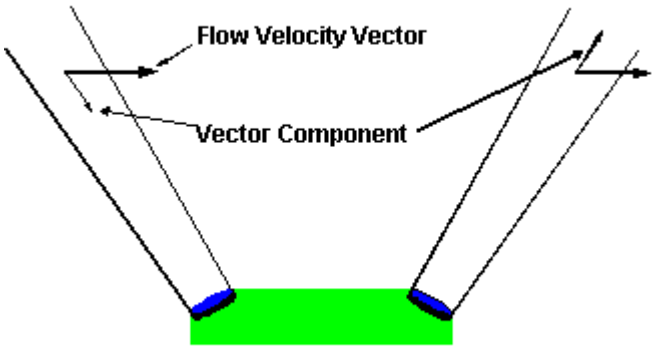


Figure 2. Side view of the Profiler transducer assembly and its beam geometry.

Since Doppler measurements are directional, only the component of velocity along the direction of the transmit and receive signal is measured, as illustrated in Figure 2. Narrow acoustic beams are required to accurately determine the horizontal velocity from the measured component. The narrow acoustic beams of the Profiler insure that this measurement is accurate. Also, the range-gate times are short and the depth cells occupy a small volume - cylinders approximately 5 cm (2 in.) long and 5 centimeters in diameter. These small sample volumes insures that the velocity

measurements are truly representative of that portion of the flow and potential bias in the return energy spectrum due to range dependent variables is avoided. The result is a very precise measurement of the vertical and transverse distribution of flow velocities.

The velocity data from the two profiles are entered into an algorithm to determine a mathematical description of the flow velocities throughout the entire cross-section of the flow. The algorithm fits the velocity data to the basis functions of a parametric model. The parametirc model is used to predict flow velocities at points throughout the flow. The resulting velocity distribution is integrated over the cross-sectional area to determine the discharge.

The key benefit to this approach is that the system will operate accurately under variable hydraulic conditions. As hydraulic conditions change, the change will manifest itself in the distribution of velocity throughout the depth of flow. As the Profiler is measuring the velocity distribution directly, it can adapt to changes in the hydraulics, and generate a flow pattern that is representative of the new hydraulic conditions, insuring an accurate estimate of flow rate.

**Test Procedure**

The Profiler was first tested in two sites at the Bureau of Reclamation's Water Resources Research Laboratory in Denver: a 4-ft-wide flume, and a 12-ft-wide rectangular channel. In both lab sites, the system was installed on the bottom of the flume, centered with the transducer's long axis aligned with the flume's axis (flow direction). No in-situ calibration or rating was performed.

**4 ft flume tests -** The test began with a flow depth of approximately 4 ft. The depth was increased after about one hour to around 7 ft. Profiler flow measurements were then compared with the venturi meter flows to check for accuracy and repeatability.

**12 ft channel tests -** The test began with a depth of flow of approximately 2 ft. The depth was decreased after about one hour to about 1.2 ft. Profiler flow measurements were then compared with the venturi meter flows to check for accuracy and repeatability.

The venturi meter flows were determined using a mercury manometer to measured the pressure differential across the venturi. This manometer was manually read several times during the tests. Once set up, the flow was held constant as it was controlled by an active feedback control system. The laboratory venturi meter was calibrated prior to the Profiler demonstration. A weigh tank facility was used to calibrate the venturi meter and the uncertainty in the venturi meter measurement was within $\pm$0.8 percent of the weigh tank flow rate.

Following the laboratory tests, the Profiler was placed in a "live" channel - the San Luis Drain located near Los Banos, CA. This channel is an irrigation drain for part of the San Joaquin Valley. The channel is trapezoidal in shape, with an 8 ft bottom width and 2:1 side slopes.

The Profiler was placed on an aluminum strap about 44 ft in length. Hinges were placed on the strap so that the 8 ft. center piece would lay flat on the channel bottom and the rest of the strap would conform to the side slopes of the channel. The channel was in normal operation during the installation with a flow depth of approximately 7.2 ft.

**Results**

Figure 3 shows the results from the 4 ft flume tests. The round symbols represent the Profiler data and the square symbols are the spot readings from the venturi meter. As shown in figure 3, the Profiler data agrees very well with the venturi meter readings.

At the beginning of the data record there is some scatter to the Profiler data, as the flow into the flume had just been set and the depth in the flume was still equilibrating. After the first few points, the flow rate readings and depth readings become steady. The Profiler measured an average flow rate of 6.86 $ft^3/s$ during the initial depth of flow of 4 ft (after depth equilibration), compared to 6.98 $ft^3/s$ for the venturi readings during the same time period; a difference of -1.72%. We also see a change in the Profiler flow rate measurement after the level was increased to 7 ft at around 10:00 a.m. The Profiler over predicts the flow because one pair of acoustic beams intersects the walls of the flume. Consequently, the average velocity is skewed higher because it is measured near the middle of the flume where velocities are larger than near the wall.

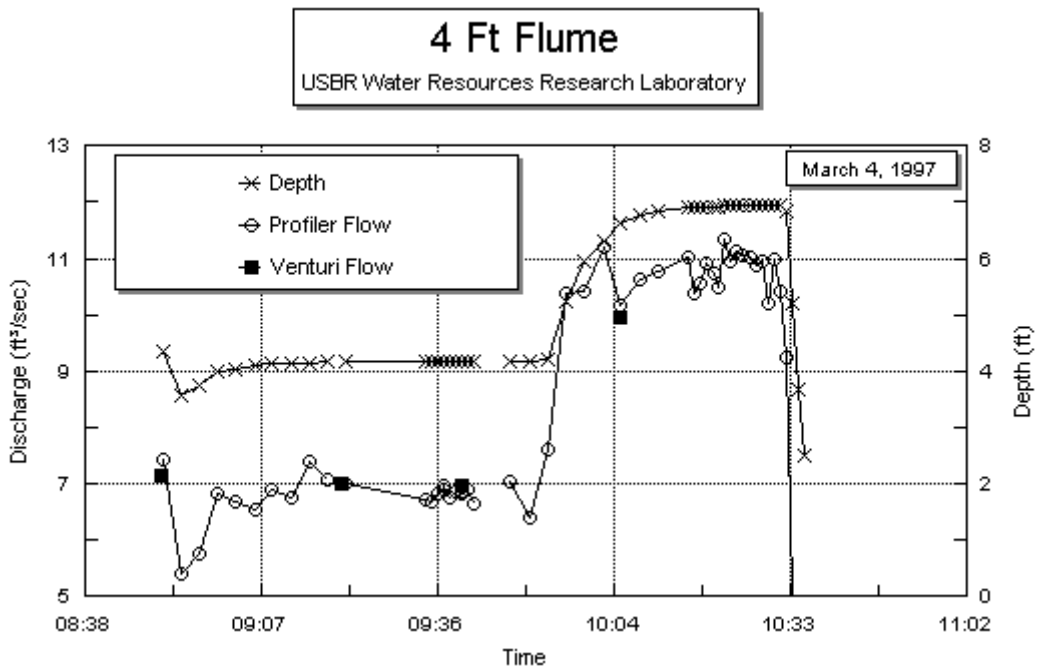


Figure 3. Profiler and venturi flow rates measured in the 4 ft flume are plotted as a function of time. The Profiler's depth reading is also plotted to illustrate the effect of fluctuating water surface level on the discharge measurement accuracy.

The spacing on the x-axis is irregular because several sampling schemes, in which parameters such as bin size and sampling interval, were varied. In most cases, changing these parameters did not affect the overall accuracy of the flow rate measurement.

Figure 4 shows the results from the 12 ft channel test. The round symbols are the Profiler data and the square symbols are the spot readings from the venturi meter. For this test, the Profiler data were averaged over a variety of time periods. Whereas Figure 3 is a plot of "raw" flow data, where each point corresponds to a individual measurement separated by an interval varying from one to five minutes. The first seven ADFM measurements were collected with an one minute averaging interval. The average of these seven measurements is 10.48 $ft^3$/sec. The venturi meter reading was 10.26 $ft^3$/sec, and this flow remained constant for the remainder of the test. The next five ADFM measurements were collected with an averaging interval of 5 minutes. The average of these five measurements is 10.29 $ft^3$/sec. The next six ADFM measurements were collected with an averaging interval of 2 minutes. The average of these seven measurements is 10.43 $ft^3$/sec. This test demonstrates how Profiler measurements becomes more precise as the number of measurements averaged together were increased. The ability to average hundreds of flow measurements over a short period results in a very precise flow measurement. This is illustrated by comparing the average of the all eighteen Profiler measurements with the two venturi meter readings. The Profiler average was +0.97% different from the venturi meter average. The last ADFM measurement was collected with an averaging interval of 2 minutes at a depth of 1.2 ft. The measured flow rate was 10.0 $ft^3$/sec. This measurement was made with a 10:1 width to depth ratio. This demonstrates the Profiler's unique capability to measure flows in wide, shallow channels.

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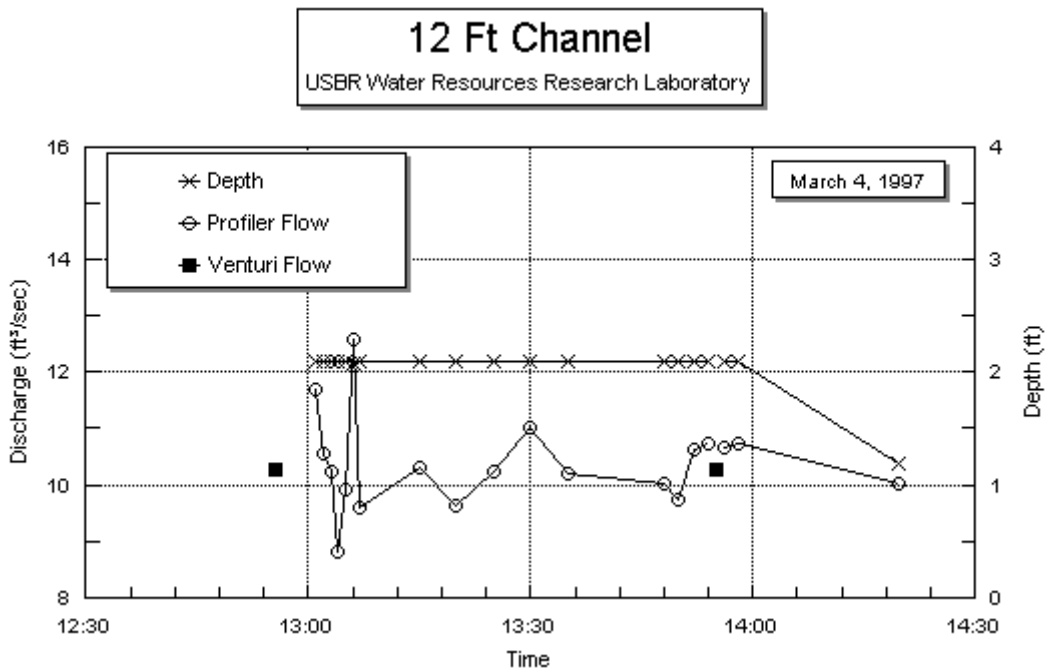


Figure 4. Profiler and venturi flow rates measured in the 12 ft channel are plotted as a function of time. The Profiler's depth reading is also plotted. Initially the Profiler's discharge measurements were variable, but with time the accuracy improved to within 1 percent of the venturi-measured discharge.

Figure 5 contains a plot of the flow rate, depth, and average velocity measured in the San Luis Drain near Los Banos, CA on March 14, 1997. All three measured parameters were steady over the test period. Variations in the flow rate correlate with variations in the average velocity, as the depth remains fairly constant. The average flow rate over the duration of the test was 91.1 $ft^3/s$. Flow rates of approximately 80 and 86 $ft^3/s$ were measured using traditional stream gaging methods. Stream gaging velocities were measured with a Marsh-McBirney Flo-Mate, which is an electromagnetic velocity meter.

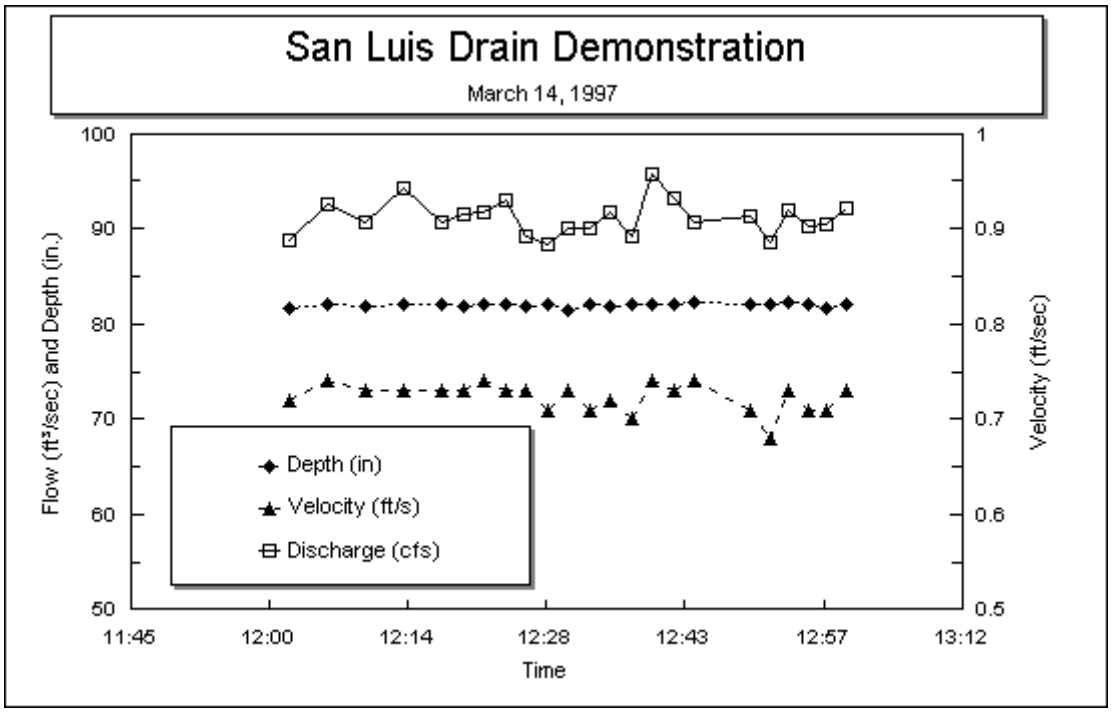


Figure 5. Flow rate, depth, and average velocity plotted as a function of time. The average flow rate measured in the San Luis Drain was 91.1 cfs with a standard deviation of 2.0 percent.

The first discharge measurement was obtained by manually measuring velocities at 0.2 and 0.8 of the depth measured from the water surface, at regular intervals across the channel. These velocities were used to compute an average velocity for a particular section of the channel. Multiplying this average velocity by the cross-sectional area of the individual section gives a flow rate for that section. The section flow rates are summed to determine the total flow rate for the channel.

The second discharge measurement was obtained by making a single velocity measurement at a height above the bottom of 0.6 of full depth, at regular intervals across the channel. This value was used as the average velocity in that section to compute a flow rate for that section. Again, section flow rates are summed to determine the total flow rate in the channel.

Note: This velocity measurement should have been measured at 0.6 of the depth measured from the *surface* not the bottom.

It should be mentioned that there was some concern over the accuracy of the manual velocity measurements. The relationship between the velocities measured at the various depths was not as expected. In particular, the velocity value measured at a height above the bottom of 0.8 of full depth, in some cases, was lower than anticipated.

**Conclusions**

- For laboratory tests, the Profiler measured flow rate with an accuracy of approximately 1.7% in the 4 ft. flume and 1.0% in the 12 ft. channel. The Profiler was able to accurately measure flow rate even with a width to depth aspect ratio of 10:1.
- This test demonstrated that the Profiler does not require an in situ calibration or rating Profiler to make an accurate flow measurement. Accurate flow measurements were attained without any special consideration to the installation, aside from placing the Profiler in the middle of the flow and aligning it with the direction of flow.
- The Profiler was successfully installed in a "live" channel, without interrupting the flow. Flow rates measured were repeatable and within roughly 10% of a traditional stream gaging measurement. However, there was some concern that the stream gaging measurement might not be accurate, as some velocities appeared lower than anticipated. This would lower the flow rate estimate generated by the stream gaging method.
- This demonstration was useful in showing the ability of the ADFM Velocity Profiler to measure flow rates in a variety of conditions with a minimal amount of time required to install and setup the instrument. This new technology has the potential to provide flow measurement in areas where traditional discharge measurement devices are impractical. It also could be a valuable tool for calibrations of existing flow measurement structures and for research studies that require velocity profile measurements.
- This instrument can accurately measure detailed velocity profiles in an open channel which can be used for engineering studies. For example, the ADFM can be used to measure velocity profiles which describe flow into and around structures such as fish screens or fish ladders.

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## Related links

MGD Technologies Inc. is a professional firm specializing in the assessment of the condition and performance of underground utility systems. The services are provided by highly trained individuals, experienced in the innovative application of integrated, advanced technologies. MGD's ADFM measures the flow velocity at discrete points throughout the depth of flow.
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San Diego CA 92131 USA
Tel. 619 695 9225
Fax 619 695 6890

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# CHAPTER 12 - DISCHARGE MEASUREMENTS USING TRACERS

## 1. General

Tracer methods can be used to determine discharge with accuracies that can vary considerably from about +/-1 percent to over 30 percent, depending on the equipment used and the care in applying the techniques. Closed conduit measurements are typically more accurate than open channel measurements because of better area measurements, better tracer dispersion and mixing control, and better measurement of tracer cloud travel times. However, injection of tracers against pressure in pipelines can be a challenge. Finding sufficient length of pipeline above ground for accurate time measurement may be difficult due to high velocities and pipeline fittings. In contrast, mixing can be a problem at low velocities, which often happens in open channels. Tracer methods are included in the American Society of Mechanical Engineers *Performance Test Codes* (1992) because of their high accuracy potential.

## 2. Kinds of Tracers Used

Basically, a tracer is considered anything that mixes with or travels with the flow and is detectable. A detectable tracer can be timed as it passes through a reach, or tracer concentration profiles can be measured in a reach.

Some tracers that have been used are:

- Dyes of various colors
- Other chemicals such as fertilizer, salt, and gases
- Radioisotopes
- Heat
- Traveling turbulent eddy pressure sequences
- Neutrally buoyant beads
- Floats

For irrigation measurements, salts and dyes are the most convenient and commonly used tracers. Salt tracers are sensed and quantified by measuring evaporated dry weight, chemical titration, or by measuring electrical conductivity. Dye concentrations are measured by fluorimetry or color comparison standards. Sometimes, visual observation of an exiting dye cloud is used, but considerable loss of accuracy occurs.

Fluorescein, Rhodamine B, Rhodamine WT, or Pontacyl Pink B dyes have been used because they are easily visible in very dilute solutions. Rhodamine B and Rhodamine WT have been cleared as nontoxic by the U.S. Food and Drug Administration. Rhodamine and Pontacyl Pink B are also quite stable with respect to fading by sunlight and to changes caused by waterborne chemicals. They do not tend to deposit on flow surfaces, sediments, or weeds. These dyes are usually available in powder form, and solutions are easily prepared. Before conducting a discharge measurement program, selected dyes should be tested with water samples or earth canal embankment material samples and exposed to check for possible adsorption, chemical reaction, and fading effects on dye stability.

Less frequently used methods involve measuring temperature upstream and downstream from a heat source and electronic cross correlations of trains of turbulent pulsations using acoustic methods discussed in chapter 11. The use of surface floats is discussed in chapter 13. Neutrally buoyant beads are usually used in laboratory work to track flow. Mixtures of beads with different specific gravities can also detect and measure fluid density profiles and stratification.

Radioisotopes are now rarely used because of their safety and pollution risks. In addition, isotope handlers must be licensed. However, use of any chemical or anything that can affect ecological characteristics of the water or conveyance boundaries may require clearance from several Federal and State authorities such as the U.S. Food and Drug Administration, the U.S. Environmental Protection Agency, and State fish and wildlife and natural resource departments. Government regulations and limits change with time and should be checked prior to a measurement program. However, even when operating within government regulations, public complaints related to taste and color and particles in the resulting water may occur.

## 3. General Methods of Application

Salt and dye tracers are used to determine discharge in two basic ways: (1) the velocity-area method, in which time of tracer travel through a known channel length and average cross-sectional area determine discharge and (2) the dilution method, in which discharge is determined by the downstream concentration of fully mixed tracer, which has been added upstream at a constant rate, and by accounting for the amount of tracer solids.

## 4. Discharge Equations for Tracer Methods

The following equations apply to both open channel and closed conduit flow.

### (a) Velocity-Area Tracer Discharge Equation

The discharge using velocity-area method is computed by:

where:

$$Q = \frac{AL}{T} \qquad (12\text{-}1)$$

$Q$ = discharge in cubic feet per second ($ft^3/s$)

$A$ = average cross-sectional area of reach length in square feet ($ft^2$)

$L$ = reach length between detection stations in feet (ft)

$T$ = recorded time required for the tracer solution to travel between the detection stations at each end of the measurement reach in seconds (s)

**(b) Tracer-Dilution Discharge Equation**

The dilution method equation for discharge is:

$$QC_0+qC_1= (Q+q)(C_2) \qquad (12\text{-}2a)$$

Solving for discharge in equation 12-2a results in:

$$Q = q\frac{C_1 - C_2}{C_2 - C_0} \qquad (12\text{-}2b)$$

where:

$C_0$ = the natural or background concentration of the tracer of the flow

$C_1$ = the concentration of the strong injected tracer solution

$C_2$ = the concentration of tracer after full mixing at the sampling station, including the background concentration of the stream

$Q$ = the discharge being measured

$q$ = the discharge of the strong solution injected into the flow

Equation 12-2 can be modified for use in terms of weight by substituting percent of dry weight of tracer for concentrations and weight of water per second for discharges.

The discharge of the channel flow, $Q$, is measured by determining $C_0$, $C_1$, $C_2$, and the injection rate, $q$. These required variables and equation 12-2 show that the dilution method does not need measurement of channel geometry or time measurement. Only the final plateau value or $C_2$, the downstream concentration, must be recorded rather than a complete record of the passing cloud that is needed with the salt-velocity-area method.

## 5. Common Sources of Errors

Tracers should be quite stable as previously mentioned. They should not deposit or react with chemicals in the water or with the pipe walls and their encrustations. Selected tracers should neither fade in sunlight nor be absorbed by open channel beds and their biological growths. These losses of tracer are a common source of discharge measurement error. In open channels, large backflow eddies can delay the dye and impede mixing. It is best to select a reach where large eddies or stagnant pools cannot significantly delay the tracers or affect mixing. The concentration of tracer solutions should be determined relative to needed visual observation or equipment detection sensitivity by careful analysis and verified by trial runs before a program of discharge measurements is undertaken.

Accuracy is also sensitive to how well the center of mass of the tracer clouds is determined with respect to time. First and last visual observations of a tracer cloud are difficult, and the mass center may not be located in the time center of the cloud.

With elaborate equipment such as multi-port pop valves, turbulators (turbulence-creating devices), complex electrodes, and fluorometers, accuracy can approach +/-1 percent. This degree of accuracy requires using the procedures included in American Society of Mechanical Engineers *Performance Test Codes* (1992).

For irrigation water, the strict code procedures, quality of procedures, equipment, and instrumentation can be relaxed to produce lower levels of accuracy. The selected accuracy target governs the complexity of needed injection equipment, detection equipment, and the quality of recorded data analysis.

The least accurate method would involve breaking a bottle of dye contained in wire mesh at an upstream station of a long reach at time zero and visually observing and estimating the time that the center of mass of the dye cloud passes the exit. Any simplified procedure must be evaluated for effect on mixing. Prior to a measurement program, equations 12-1 and 12-2 should be used for error analyses in terms of proposed equipment and procedures because they affect the equation variables. These analyses will determine if the simplified measurement procedures produce the selected accuracy target.

## 6. Tracer-Velocity-Area Methods

Either salt or dye may be conveniently used in tracer-velocity-area discharge measurements with equal potential accuracy. The only difference is that different detection equipment is needed. Dyes have an added advantage in that they can be detected visually, allowing simpler measurements of less accuracy that may be sufficient for irrigation needs. However, when using any simpler method, the error checks and mixing problems of section 5 in chapter 12 should be considered.

### (a) Salt-Velocity-Area Measurements

The salt-velocity-area method takes advantage of the fact that salt in solution increases the electrical conductivity of water. This method has been successfully used in open channels and pressure conduits of constant cross section.

Because of its high potential accuracy, the salt-velocity-area method is one of several methods accepted for turbine testing in American Society of Mechanical Engineers (1992). The equipment described in Thomas and Dexter (1955), consisting of injection system and the sensing electrodes (figures 12-1 and 12-2), are rather complex. Also, a turbulator is sometimes used to ensure adequate mixing of the injected salt tracer solution and the flow by the time they reach the first electrode station. Full details regarding the equipment required for techniques found satisfactory under field conditions are contained in Thomas and Dexter (1955).

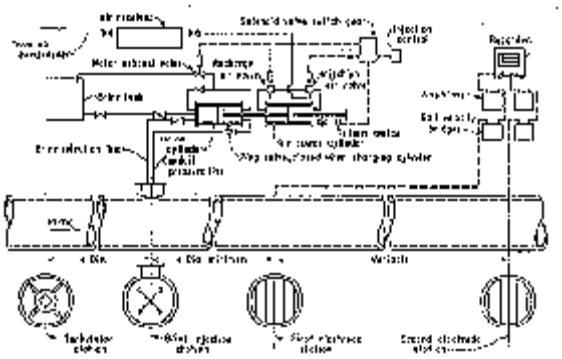

Figure 12-1 -- General arrangement of salt-velocity equipment for pressure conduits.

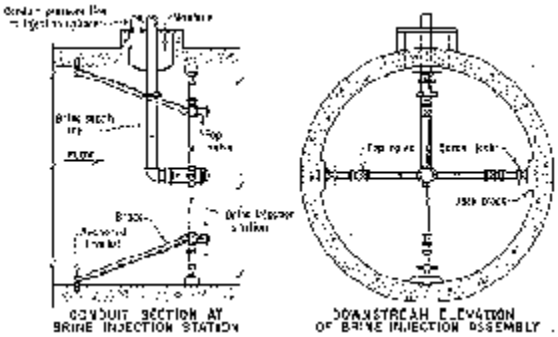


Figure 12-2 -- Brine injection equipment in conduit.

Commonly, sodium chloride (NaCl) is the selected salt used in the tracer injection solution. Finely ground salt should be purchased for ease in mixing the solution. Enough salt must be added to significantly increase the electrical conductivity of the water so that concentrations can be measured accurately. The required amount of salt can be estimated by analyzing the water for existing background quantity of salt in the measurement flow, estimating the amount of flow to be measured, and using chemical handbook data from conductivity-salinity tables. Trial runs may be needed to determine the optimum amounts, which may vary with discharge depending on the range to be measured.

For a measurement, a quantity of salt tracer solution is forced into the stream under pressure to provide better initial distribution and assure thorough mixing before arrival at the detection stations. The pop valve injector used by Thomas and Dexter (1955) (figure 12-2) will provide the faster and better mixing required to produce code accuracy.

To determine velocity for equation 12-1, a pair of electrodes is installed in the cross section at each end of a measured length of channel well downstream from the injection system. The distance between the pairs of electrodes should be sufficient to ensure accurate measurement of the time of travel between them. The electrodes are electrically energized and connected to a central instrument that records the electrical conductivity at each pair of electrodes with respect to time.

A sample of a strip chart recording showing conductivity change that occurs as a salt cloud passes the electrodes is shown on figure 12-3. The recording shows a conductivity rise that indicates the passing of the salt solution cloud past each electrode station.

In addition to their peaks, the cloud plots have a leading and a trailing edge of low conductivity approaching the baseline conductivity of the flowing water (figure 12-3). The time of cloud travel between electrodes is measured on the chart time scale between the centroids of the two plotted conductivity cloud areas above the background conductivity level. Digital recordings are more convenient than analog recordings for computer determination of area under the time-conductivity plots to determine the center of mass of salt clouds.

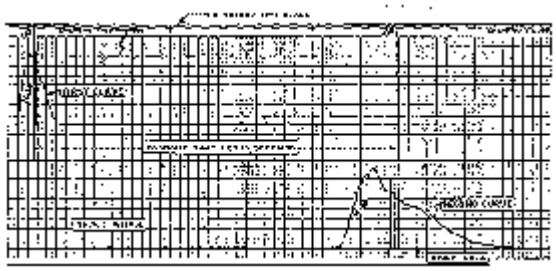

Figure 12-3 -- Sample records of a salt cloud passing upstream and downstream electrodes in the salt-velocity method of measuring flows in pipelines.

This method requires special equipment and experienced personnel and is relatively expensive. Care in selecting convenient reaches will help reduce time and expense in measuring length and determining an accurate average cross-sectional area.

**(b) Color-Velocity Measurements**

To achieve maximum accuracy using dye tracer solutions, the procedures similar to those described for the salt-velocity-area method must be followed. However, fluorometer detection or a set of visual color comparison standards must be used instead of equipment used for salt solution injections. Carefully following American Society of Mechanical Engineers *Performance Test Codes* (1992) will result in very accurate discharge measurements. Fluorometry combined with well designed multiple port injection and sampling port arrangements at two stations downstream from an injection station produces high accuracy.

The simpler but less accurate method using visual observation for tracer cloud detection in pipelines consists of determining the velocity of a dye tracer between two stations in the pipe. This velocity, used as the mean velocity of flow, is multiplied by the cross-sectional area of the pipe to give the discharge as shown in equation 12-1.

The simplified procedure ordinarily used in making the velocity measurements is described below. If possible, a small slug of concentrated dye solution is quickly injected or poured into the pipeline entrance where the pressure is relatively low. In pipes, a high-pressure system through fittings may be required to inject dye. Time observations are made at the instant the dye is injected and at its first and last appearance at the downstream station, usually at the pipe outlet. The mean velocity is computed from the mean time required for the dye to travel the known length of reach. Comparisons with other measurement methods show this simplified color velocity method is accurate enough for irrigation measurements when properly done in relatively long pipes.

Simplification similar to the pipe flow case is possible in open channel flow. However, the color-velocity-area method in open channels has more limitations and drawbacks. The air entrained by surface velocities and spray above the surface may hinder detection of the position of the center of mass of the colored water in high-velocity flows (Hall, 1943). Also, slow flows are more likely to cause mixing problems.

## 7. Tracer-Dilution Methods

The tracer-dilution method is capable of measuring both open channel and closed conduit flow. However, possible tracer losses may be more of a problem in open channel flow as discussed previously. Either salts or dyes may be used as tracers. The tracer-dilution method consists of adding a known, strong concentration of tracer solution, $C_1$ (equation 12-2) at a constant rate, to the flow (Schuster, 1970; Collins and Wright, 1964; and University of Newcastle on Tyne, 1964). Then, by chemical analysis, the downstream diluted uniformly mixed concentration, $C_2$, is measured. The solution must be added at a known constant discharge, $q$.

No measurements of flow section geometry or reach distance are required because the total flow is measured directly. The discharge of the channel flow, $Q$, is measured by determining $C_0$, $C_1$, $C_2$, and the injection rate, $q$. These required variables and equation 12-2 show that the dilution method does not need measurement of channel geometry or time measurement. Only the final plateau value or $C_2$, the downstream concentration, must be recorded rather than a complete record of the passing cloud that is needed with the salt-velocity-area method.

Because the concentrated tracer solution must be added to the flow at a constant known rate, positive displacement metering pumps are needed for injection. Also, this method requires a sufficient flow travel length with enough turbulence to thoroughly mix the dye. Required mixing lengths can perhaps be reduced by turbulators or injecting the dye simultaneously at a number of points across the stream, but the injection arrays may need prevalidation by analysis and preliminary measurement runs to assure complete mixing.

If salt solutions are used as tracers, then chemical or conductivity measurement methods are used for detection and concentration measurements. Finely ground salt should be purchased for ease in mixing the solution if selected as the tracer. If dyes are used, then visual color intensity comparison standards may be used. Modern fluorometers can measure dye amounts to one part of dye in a million parts of water and can detect one part in a billion. The human eye cannot detect these minute dilutions, but the dye is quite discernible to the instrument.

The color-dilution method may be used for measuring small, medium, or large flows because the cost of the dye is relatively low. The salt-dilution method is applicable to measuring discharges in turbulent streams of moderate or small size where other methods are impracticable. Excessive quantities of salt are required on large streams.

Tracer methods require special equipment and experienced personnel, and its use is relatively expensive. The injection equipment and electrodes or fluorometers for detecting and measuring the tracer concentration of the resulting downstream diluted flow make this method quite costly compared to other measuring methods.

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# CHAPTER 13 - SPECIAL MEASUREMENT METHODS IN OPEN CHANNELS

## 1. Introduction

Open channel flow measuring devices and methods described in chapters 6 through 10 are ones most commonly used for measuring irrigation water in the United States. Their relative simplicity makes them well suited for general use, and long experience has established their reliability. Tube-type flowmeters are installed in or at the end of pipes passing through embankments to laterals or ditches. Sometimes, these tubes are considered open channel measuring devices. Tube-type flowmeters are discussed in chapters 2, 11, and 14. Other specialized methods and devices for measuring water in open channels follow.

## 2. Open Flow Propeller Meters

Besides being used in closed conduit systems, propeller meters are frequently placed at the end of pipes delivering water to open channels (figure 14-6 in chapter 14). When used this way, they are often called open flowmeters. The requirements and maintenance problems inherent to these meters are discussed more thoroughly in chapter 14, which should be read along with the following information.

These meters should be installed in open channels that submerge the pipe exit or have small overflow check structures that assure submergence for the desired discharge range. Meters are available for pipe diameters from 2 to 72 inches (in). These meters need sufficient driving velocity and are likely to be inaccurate below 1.5 feet per second (ft/s). Spiral flow caused by poor entrance conditions from the canal to the supply pipe is a common source of error. Straightening vanes provided or specified by manufacturers should be installed. A poorly developed velocity distribution profile can also cause considerable errors in registration.

The accuracy of propeller meters is generally within +/-2 to +/-5 percent of the actual flow. However, careless setting of the meter in the turnout will cause sizable errors if the meter is not properly positioned (Schuster, 1970). For example, a meter with a 12-in-diameter propeller, suitable for measuring discharges up to 8 cubic feet per second ($ft^3/s$) in a 24-in-diameter pipe, when set with the hub center 1 in off the center of the pipe, showed an error of 1.2 percent. When the meter was rotated 11.5 degrees in a horizontal plane, equivalent to 1/4 in measured on the surface of the 22-in-diameter vertical meter shaft housing, the error was 4 percent, indicating that a small angular misalignment of the meter will cause a greater error than would be caused by a moderate eccentricity.

## 3. Deflection Meters

These meters are out of production for irrigation use. However, some are still in use. These meters have some advantages, and they may come back into production. Deflection meters consist of a shaped vane(s) that projects into the flowing water to sense velocity. A secondary device measures the deflection caused by the force of the flow. These meters can be installed permanently or may be easily moved from one location to another. In use, they hang into the flow and are supported on pivots.

Vanes can be shaped to match the flow section geometry to make them deflect the same amount for any given discharge regardless of the depth of flow in the flow section.

This attribute is a considerable advantage where the head-discharge characteristic of the channel is unstable. Flow sections with permanent pivots can be installed at various locations in an irrigation district, and the vanes can be transported from measuring station to measuring station.

Under ideal conditions, deflection meters have been found to be accurate within 2 percent. Generally, this accuracy will not be attained because field conditions are seldom ideal. For example, wind can produce errors up to 100 percent. However, a windbreak made from a piece of plywood will substantially reduce this kind of error.

## 4. Measuring Controls for Canals

Irrigation canal systems frequently include drops to adjust canal grades to the landscape. If the drop is great enough to make the flow pass through critical depth, a gage set in the canal a short distance upstream from the drop may be used to measure heads that, with calibration, can be related to discharge. Measured flow must pass through critical depth for the entire needed discharge measurement range. Chapter 2 has a section on critical depth. Discharge ratings are developed by current metering at various depths to produce tables and curves. In some channels where sufficient freeboard exists, side or bottom constrictions can be added, and a gage can be calibrated similarly. Measuring controls operate with the same principles as flumes and weirs but need special calibrations.

## 5. Calibration of Gates and Sluices

In many irrigation distribution systems, the flow of water is measured through gates and sluices. This measurement necessitates calibrating the gates and sluices.

In calibrating an individual gate, the discharge can be measured by any of the standard methods described in earlier chapters of this manual. A series of discharge measurements covering the range of openings is made, and the mean operating heads upstream and downstream from the gate are recorded for each measurement. For convenience when operating the gates in regular service, rating curves and tables may be compiled to provide the discharge in cubic feet per second ($ft^3/s$) for each opening and series of operating heads.

In calibrating sluices that meet the requirements of rating sections, the current-meter method is commonly used. It may also be practical to calibrate the sluice with a temporary weir, provided sufficient fall is available. The calibration consists of measuring the discharge for various depths of flow in the sluice at a rating station and plotting the discharges against depths. The channel should be of regular section and free from disturbance caused by upstream conditions such as bends, multiple gates operating at unbalanced openings, waves, and other distorting influences.

## 6. Slope-Area Method

The slope-area method consists of using the slope of the water surface in a uniform reach of channel and the average cross-sectional area of that reach to give a rate of discharge. The discharge may be computed from the Manning formula:

$$Q = \frac{1.486}{n} A R_h^{2/3} S^{1/2}$$

where:

$Q$ = discharge ($ft^3/s$)

$A$ = mean area of the channel cross section ($ft^2$)

$R_h$ = mean hydraulic radius of the channel (ft)

$S$ = energy slope of the flow

$n$ = a roughness factor depending on the character of the channel lining

A straight reach of the channel should be chosen at least 200 ft and preferably 1,000 ft in length. If the reach is free of rapids, abrupt falls, or sudden contractions or expansions, then the water surface slope is the same as the energy slope.

The slope, $S$, may be determined by dividing the difference in the water surface elevations at the two ends of the reach by the length of the reach. A gage point, carefully referenced to a common datum level, should be placed on each bank of the channel and in the center of the reach, in stilling wells if possible.

The hydraulic radius, $R_h$, is defined as the area of the cross section divided by its wetted perimeter. Where the channel or canal is of regular cross section, and the depths at the ends of the course are equal, the area and the wetted perimeter will be constant through-out the course. In irregular channels, the area and the wetted perimeter at several cross sections will be required, and a mean value will be used in computing the hydraulic radius. A static pressure tube, discussed in chapter 8, can be used to measure depth of flow.

The factor, $n$, depends on the character of the channel. It may vary from 0.010, where conditions approaching the ideal are maintained, to 0.060, where the channel is strewn with stones and debris or is about one-third full of vegetation.

Because the proper selection of the roughness factor, $n$, for many streams is difficult and is, at best, an estimate, the discharge determined by the slope-area method is only approximate. Care must be taken to determine the slope and areas simultaneously if the water levels are changing. Chapter 2 provides other flow equations, their friction factors that can be used with this method, and references with tables of friction factors.

## 7. The Pitot Tube

Pitot tubes are sometimes used to measure relatively fast velocities such as at drops, chutes, and overfall crests. Velocity traversing and discharge computations may be done in the same manner as with current metering (described in chapter 5). Pitot tubes are difficult to use in slow canal flow because they produce small differentials in slow flow. For example, the velocity needed to produce 0.1 ft velocity head is 2.6 ft/s.

Thus, pitot tubes have the problem of precision of head measurement relative to the size of head differential. Depending on needed accuracy, the secondary equipment could be costly and difficult to use in slow velocity. Pitot tubes and their use are more fully described in chapter 14.

## 8. Accounting of Inflow and Outflow From Reservoir Storage

When gain or loss in storage of a reservoir and the inflow to a reservoir are known, the outlet discharge may be computed. Conversely, when the storage, gain or loss, and the reservoir outlet discharge are known, the inlet flow may be computed.

In each of these computations, the gain or loss in storage during a given time period may be read from reservoir capacity charts and tables. These charts and tables generally give the reservoir volume in acre-feet for various gage heights of water. The change in reservoir volume for the time period is converted to cubic feet per second ($ft^3/s$). The change of reservoir discharge increased by the inflow or decreased by the outflow gives the average discharge or inflow, respectively.

Bank storage causes indeterminate deviation. Storage will tend to cause a slow drop in reservoir water surface when the net rate of outlet flow is low and will retard rise in water surface during a slow increase in storage. These changes usually are imperceptible to an observer. Adjustments for evaporation and wind effect on gage readings may be necessary in reservoirs of large areas.

## 9. Weir Sticks

Weir sticks are commercially calibrated stick or staff gage type devices which may be placed by hand upon the crest of a weir. In principle, the sticks show depth of flow plus velocity head or the runup of water above the water surface at the weir blade. This device gives an indication of the head that would have been measured at conventional weir measurement stations. Readings are taken at the top of the runup of water to indicate the rate of flow. Some sticks contain a piezometer and manometer to average the pulsations in the head reading. Turning the stick to an angle will not improve accuracy unless the stick has been calibrated in this position.

At best, the sticks can only approximate the potential accuracy of weirs when head is carefully measured in the normal manner. Weir sticks are designed to measure unit discharge along the crest of rectangular suppressed weirs. Thus, the gage indicates the discharge per unit length of weir. The design intent was to make weir measurements simpler without need for staff gage zero setting. Also, poor distribution of velocity of approach at the crest could be accounted for by multiple stick measurements and averaging along the crest because the weir stick measures the depth on the crest and the corresponding velocity head. Thus, they compensate for velocity of approach, such as caused by sediment deposits ahead of the weir blade.

## 10. Measurement by Floats

The approximate velocity of flow in a canal or stream and discharge may be determined by the use of floats (British Standards Institution, 1964). Because a number of other methods are usually easier and more accurate to use, this method should be used only when the other methods are impractical or impossible. A reach of canal, straight and uniform in cross section and grade and with a minimum of surface waves, should be chosen for this method.

Surface velocity measurements should only be attempted on windless days to avoid wind-caused deflection of the floats. Even under the best conditions, surface floats are often diverted from a direct course between measuring stations because of surface disturbances and crosscurrents. Surface floats are immersed one-fourth or less of the flow depth. Rod floats are submerged more than one-fourth of the depth but do not touch the bottom.

Cross sections are established along the straight reach of the channel at a beginning, midpoint, and end. The cross sections should be located far enough apart so the time interval required for the float to travel from one cross section to another can be accurately measured. The midpoint cross section provides a check on the velocity measurements made between the beginning and end sections. The channel width across the sections should be divided into at least three, and preferably at least five, segments of equal width. The average depth of each segment must then be determined. The float must be released far enough upstream from the first cross section to attain stream velocity before reaching the cross section. The times at which the float passes each section should be observed by stopwatch and recorded. The procedure is repeated with floats in each of the segments across the canal, and several measurements should be made in each segment.

For flows in canals and reasonably smooth streams, the measured surface float velocities should be multiplied by the coefficients as listed below:

Table 13-1. Coefficients to correct surface float velocities to mean channel velocities

| Average depth in reach (ft) | Coefficient |
|---|---|
| 1 | 0.66 |
| 2 | 0.68 |
| 3 | 0.70 |
| 4 | 0.72 |
| 5 | 0.74 |
| 6 | 0.76 |
| 9 | 0.77 |
| 12 | 0.78 |
| 15 | 0.79 |
| >20 | 0.80 |

The corrected velocities should then be multiplied by the cross-sectional area of the corresponding stream segments to obtain the segment discharges. The sum of the segment discharges will be the total discharge.

A method used extensively in India to determine velocities in open channels makes use of rod or tube floats. This device consists of a square or round wooden rod with a width or diameter of 1 to 2 in, depending on the length. The rod is designed with a weighted end so it will float in a vertical position with the length of the immersed portion about 0.9 times the depth of the water. This method is based on the reasonable assumption that the velocity of a rod float extending from the water surface to very near the bottom of a channel will closely represent the mean velocity of the water. Streams are divided into segments as described for the float method, except that velocities in areas near the banks of the channel are not measured by the rod method but are assumed to be two-thirds or three-quarters of the mean velocity of adjacent segments.

The rod float method may be used in canals with straight stretches that are regular and uniform in cross section and grade. Where these conditions exist and the flow is free of cross currents and eddies, discharge measurements may be made with a high degree of accuracy.

The accuracy of float methods are limited by many factors, including a lack of preciseness in the coefficients, too few stream segments being used, appreciable changes in stream depth along the test reach, oblique currents, wind forces, and experimental errors in measuring time and distances. Often, a number of people are required to perform this technique and make observations. The course of the floats is difficult to control, and they can be easily retarded by dragging on submerged debris and on the sides and bottom of the channel.

# CHAPTER 13 - SPECIAL MEASUREMENT METHODS IN OPEN CHANNELS

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# CHAPTER 14 - MEASUREMENTS IN PRESSURE CONDUITS

## 1. Introduction

Using pipelines instead of open channels has many advantages. Pipelines prevent loss of water by evaporation and seepage. Operation and maintenance costs are reduced because less land is waterlogged, and the need for canal weed prevention and removal is eliminated. Land that would be occupied by canals and embankments is available for crop production or other uses. Buried pipelines, compared to open canals, are safer for animals and people. In general, pipelines have a higher initial cost, but as the value of water, land, and labor increases, the use of pipelines becomes more economically feasible. Thus, accurate flow measurement in pipelines becomes increasingly important.

Pipeline flow can be measured in many ways. Selection of a particular installation depends upon specific local situations. The accuracy of flow measurements in pressure conduits can be very high. However, measuring devices and techniques must be properly selected, installed, used, and maintained.

## 2. General Comments on Pipeline Flowmeters

In-line flowmeters are usually classified by basic types of operation. Some of these basic types are:

- Differential head meters
- Positive volume displacement summing meters (generally municipal water)
- Calibrated velocity sensing meters
- Measured proportional or calibrated bypass meters
- Acoustic-type meters

Flowmeters can display or record total volume delivered or instantaneous discharge rates. Direct reading of totalized volume, rather than computing volume from instantaneous discharge readings, is especially convenient where water is sold on the volume basis. Many flowmeters are also equipped with auxiliary equipment to record and display the instantaneous flow discharge. This feature is of great advantage for irrigation when setting rates and controlling delivery.

Water measured in closed conduits with mechanical meters must be free of foreign matter. Meters should be inspected regularly (see chapter 5) to detect wear, corrosion, or other change that would tend to alter accuracy. Flowmeter use is limited by relatively high cost and short life in adverse operating environments.

## 3. Differential Head Flowmeters

This class of flowmeters includes venturi, nozzle, and orifice meters. When properly installed and used, these meters have a potential accuracy of "1 percent. These meters have no moving parts but use the principle of accelerating flow by some form of constriction. Heads are measured upstream where the meter is the size of the approach pipe and downstream where the area is reduced to a minimum.

The basic energy balance relationship is written as discussed in chapter 2. The velocity at one of these locations is solved for in terms of the difference of head between the two locations. Using the product of the upstream velocity and area results in discharge expressed as:

$$Q_a = CA_1A_2\sqrt{\frac{2g(h_1 - h_2)}{A_1^{\ 2} - A_2^{\ 2}}} \qquad (14\text{-}1)$$

where:

$Q_a$ = discharge
$A_1$ = upstream approach area
$A_2$ = area of the throat or orifice opening
$h_1$ = upstream head measurement
$h_2$ = downstream head
$g$ = gravity constant
$C$ = coefficient determined experimentally

The term, $h_1$ - $h_2$, often written in shorter form as $\Delta h$, is the differential head that gives the name to this class of meters.

The values of the effective discharge coefficient in both of the equation forms, for the same differential flowmeter, are the same. The coefficients are the same because the area divided by the square root of the denominator in each equation has the same value.

Equation 14-1 is valid for the venturi, nozzle, and orifice meters using proper respective effective coefficients. Each kind of flow meter has a different value of effective discharge coefficient. More details concerning what is accounted for by the effective discharge coefficient are covered in chapter 2.

With differential flowmeters, the pressure difference between the inlet tap and the throat or minimum pressure tap is related to discharge in tables or curves using the suitable coefficients with the proper equation. An example discharge curve is shown for an 8-inch (in) venturi meter on figure 14-1. Thus, the meters may serve as reliable flow measuring devices.

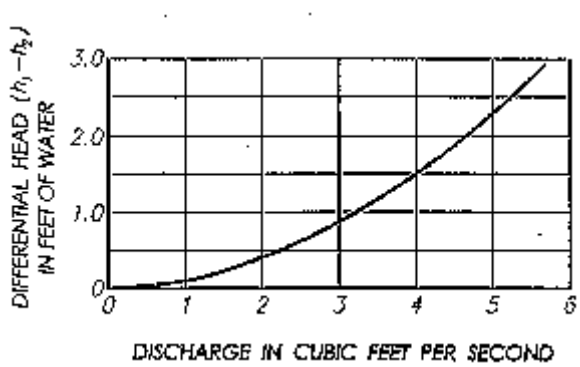



Figure 14-1 -- Typical calibration curve for an 8-in venturi meter - one kind of differential flowmeter.

**(a) Venturi Meters**

Venturi meters (figure 14-2) are one of the most accurate type of flow measuring device that can be used in a water supply system. They contain no moving parts, require very little maintenance, and cause very little head loss. Tables or diagrams of the head difference versus rate of flow may be prepared, and flow indicators or flow recorders may be used to display the differential or rate of flow. Venturi meters are often used in the laboratory to calibrate other closed conduit flow measuring devices.

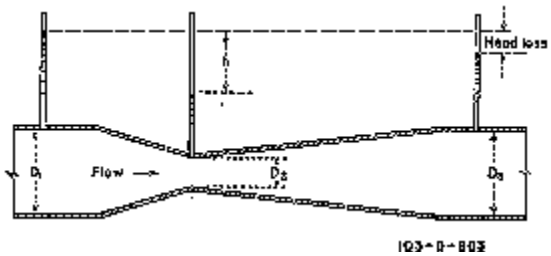



Figure 14-2 -- Sectional view of venturi meter.

The American Society of Mechanical Engineers (1983) and International Organization for Standardization (1991) contain details of pipeline meter theory, equations, coefficients, and tables with application instructions.

The effective discharge coefficient for venturi meters ranges from 0.9 to about unity (Streeter, 1951; American Society of Mechanical Engineers, 1983) with turbulent flow, and it varies with diameter ratio of throat to pipe.

The smaller commercial venturi meters are made of brass or bronze and are available for pipe sizes up to about 2 inches (in) diameter. Larger meters are usually made of cast iron with inner bronze linings. Some larger venturi meters have been constructed of concrete with the convergence and the throat made of finished metal. Large venturi meters have not been standardized for general irrigation practice, and the sizes, shapes, and coefficients are not well known. Accuracy and performance should be specified by purchase contract for large venturi meters. Some relatively simple and effective venturi meters have been made from precast concrete (Summers, 1952; 1953) and plastic (Replogle and Wahlin, 1994) pipe sections and fittings.

In the past, the expense of venturi meters and the fact that they must always operate with full pipelines have restricted their use on a broad scale in irrigation systems. The increasing demand for accurate flow measurements in pressure conduits will likely result in greater use of venturi meters in the future. Because venturi meters have smoothly varying flow boundaries, they have been used for measuring sewage and flow carrying other materials. Sometimes, this usage may require clean water backflushing for clearing manometer tubing. With trash-carrying flow that would require frequent flushing, small continuous purging flows have been used to keep material from plugging or entering the pressure taps between and during pressure head measurements. Many variations of the meter exist, each of which is tailored to meet the requirements of specific types of installations.

**(b) Nozzle Meters**

In effect, the flow nozzle is a venturi meter that has been simplified and shortened by eliminating the gradual downstream expansion (figure 14-3). The streamlined entrance of the nozzle causes a straight jet without contraction, so its effective discharge coefficient is nearly the same as the venturi meter. Flow nozzles allow the jet to expand of its own accord. This feature causes a greater amount of turbulent expansion head loss than the loss that occurs in venturi meters, which suppress exit turbulence with a gradually expanding tube boundary.

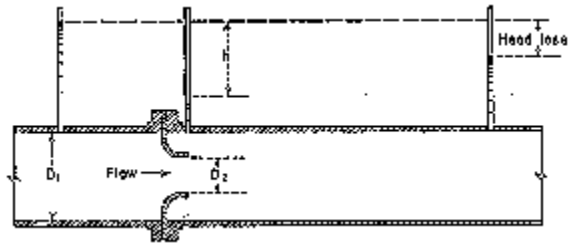



Figure 14-3 -- Sectional view of nozzle meter.

The effective coefficient of discharge for flow nozzles in pipelines varies from 0.96 to 1.2 for turbulent flow and increases as the throat-to-pipe-diameter ratio increases.

Frequently, the upstream pressure connection is made through a hole in the wall of the conduit at a distance of about one pipe diameter upstream from the starting point of the flare of the nozzle (ASME, 1983). Thus, the pressure is measured before it curves to enter the nozzle. The downstream pressure connection may be made through the pipe wall just above the end of the nozzle tube (ASME, 1983).

Flow nozzles have been made from precast concrete pipe and used in the field. Flow nozzles have not been used extensively for measuring irrigation water, probably because this application lacks standardization. Discharge tables provided by a manufacturer agreed closely with independent calibration tests and studies (Summers, 1952).

**(c) Orifice Meter**

The most common differential-pressure type flowmeter used in pipelines is the sharp-edged orifice plate (figure 14-4). These meters are frequently used in irrigation applications for measuring well discharges and agricultural chemicals that are injected into irrigation flows. The latter are usually small with details of installation and operation furnished by the manufacturers. Therefore, only larger diameter orifice plates in round pipes will be discussed here. Personal computers and the generalization of discharge coefficients renewed interest in the orifice as a primary device (Furness, 1987).

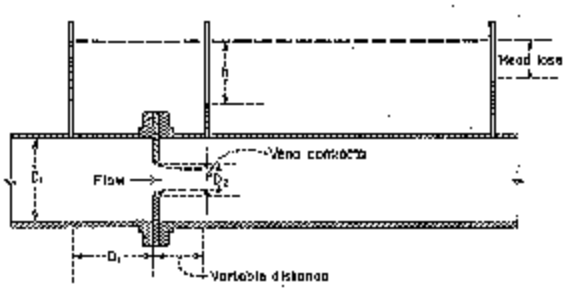


Figure 14-4 -- Sectional view of orifice meter.

Applications with proper water quality, careful attention to installation detail, and proper operation techniques (Hobbs, 1987) make these flowmeters capable of producing accuracy to within 1 percent. However, the usual maintenance and pipe conditions that generally occur in irrigation pipe systems limit field accuracies to within 3 to 5 percent of actual.

Advantages of the orifice plate are its simplicity and the ability to select a proper calibration on the basis of the measurements of the geometry (Dijstelbergen, 1982). Disadvantages of the orifice plate include the long, straight pipe length requirements and the limited practical discharge range ratio of about one to three for a single orifice hole size. However, the location of the range can be shifted by using sets of plates for changing orifice hole sizes. This shift, in effect, provides a range ratio increase. Calibrations based on tap locations relative to pipe diameter, rather than orifice diameter, make this feasible because the same tap locations can be used for different orifice plate hole sizes.

**(1) The Flow Rate Equation**

The equation now commonly used to calculate the flow rate from the pressure differential and other relevant parameters is:

$$Q = CC_v A\sqrt{2g\Delta h} \qquad (14\text{-}2a)$$

$$Q = C_d A \sqrt{2g\Delta h} \qquad (14\text{-}2b)$$

where:

$Q$ = the discharge
$C_d$ = the product $CC_v$
$C$ = a coefficient determined experimentally
$C_v$ = the velocity of approach factor
$A$ = the area of the orifice hole
$g$ = the acceleration of gravity
$\Delta h$ = the differential head

If differential pressure sensing equipment is used as the secondary measuring devices, then $2g\Delta h$ must be replaced with $2\Delta P/D$, where $\Delta P$ is differential pressure and $D$ is the density of the flowing water.

**(2) Standardization of Tap Locations**

Originally, the so-called vena-contracta tap (minimum contracted orifice jet diameter) was standardized. For those, the location of the downstream tap depended on the orifice hole size in the orifice plate. This diminished the possibility of altering the range by changing orifice plates because the tappings would also have to be relocated for each new plate size.

More recent orifice standards are based on extensive experimental data and can be applied with a fair degree of confidence. Studies carried out in Germany, the United States, France, and Britain resulted in the present ISO-5167 (1991) (adapted from British Standards-1042 [1943], and Dijstelbergen [1982]). The standards list the geometry of the devices, the installation conditions to be observed, and the equation relating flow and pressure differential. Three types (figure 14-5) of differential measuring taps as internationally standardized are:

- Corner taps
- Flange taps
- *D-D*/2 taps

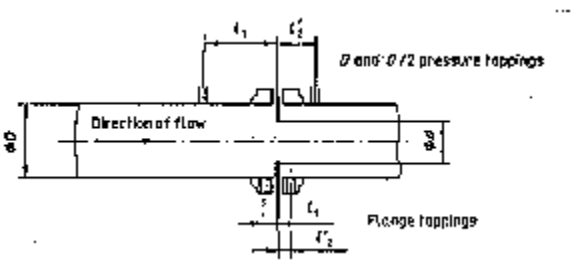



Figure 14-5 -- Flange and *D-D/2* pressure taps for orifice meter.

**(3) Orifice Plate and Hole Requirements**

Orifice plates require careful installation. The orifice plate coefficient is generally affected more by misalignment and disturbed velocity distributions than other differential-pressure meters because the abrupt pressure changes take place near the plate. Poor installation of an otherwise properly designed orifice plate can cause as much as a 20-percent error (Humphreys, 1987). The orifice plate should be mounted in such a way that it is possible to inspect at least the orifice plate and preferably the adjacent piping.

The orifice hole diameter should be at least 0.5 in, and its upstream edge should be free of visible dents, burrs, and rounding. The orifice hole must be bored perpendicular to the plate. The bore hole cylinder length must be between 0.005 and 0.02 times the pipe diameter (*D*). If the plate is thicker than 0.02*D*, the downstream orifice must be beveled at an angle between 30 to 60 degrees from horizontal. Centering of the plate orifice hole, as specified in the standard, is particularly difficult to meet for small pipes.

The plate shall be mounted perpendicular to the pipe axis. The orifice plate material should be thick enough so it will not bow under the differential pressure. The plate faces shall be flat and parallel. The plate thickness shall be less than 0.05 times the pipe diameter, and its upstream face shall be have a quality finish.

**(4) Meter Approach and Exit Requirements**

Downstream from pipe fittings, the required length of straight pipe approaching orifice meters varies with type, number, and orientation of fittings and increases in proportion to $\beta$ (ratio of orifice to pipe diameter). For example, a single 90degree bend requires from 6 to 18 diameters of straight approach pipe ahead of the upstream pressure tap for $\beta$ increasing from 0.2 to 0.75 (ISO, 1991). Two 90-degree bends in the same plane require 7 to 21 diameters for the same $\beta$ range. Two or more bends in different planes require 17 to 35 diameters. Globe valves require 9 to 18 diameters for $\beta$ increasing from 0.2 to 0.75. Gate valves require 6 to 15 approach diameters. An expander fitting requires 8 to 19 diameters. A reducer fitting requires 5 to 15 diameters of straight pipe upstream for $\beta$ ranging from 0.5 to 0.75, which differs from the previously mentioned values. Four to eight diameters of straight pipe are required downstream from the pressure taps.

**(5) Coefficient of Discharge**

Accurate values for $C_d$ have been developed for the standard tap locations. If the orifice-plate geometry and its installation conform to the orifice specifications of ISO 5167, a good estimate of performance can be developed by applying the Stolz equation appearing in those standards. This equation was developed by Stolz, who logically showed that the coefficients of the different taps normalized by pipe diameter are related. Thus, the value of the coefficient of discharge, $C_d$, depends on the particular tapping arrangement, the Reynolds number ($Re$) ($VD/v$), and the diameter ratio, $\beta$, as defined in equation 14-3. Originally, the older coefficients were separately determined for each tapping arrangement for specific orifice hole sizes.

In large pipe diameters, for example, the coefficient of the corner taps and flange taps should not differ. For small area ratios, all coefficients for different taps should be equal. Stolz statistically fitted the available data resulting in the unified equation given in ISO 5167 covering all tapping arrangements. This equation for $C_d$ is:

$$C_d = 0.5959 + 0.0312\,\beta^{2.1} - 0.1840\,\beta^{8} + 0.0029\,\beta^{2.5}(10^6/Re)^{0.75}$$

$$+ 0.0900(L_1/D)[\,\beta^4/(1 - \beta^4)] - 0.0337\,(L_2/D)\,\beta^3 \qquad (14\text{-}3)$$

where:

$C_d$ = coefficient of discharge
$L_1$ = the tap distance from the upstream face of the plate
$L_2$ = the tap distance from the downstream face of the of the orifice plate
$D$ = the pipeline diameter
$\beta$ = the ratio of orifice diameter to pipe diameter
$Re$ = the Reynolds number ($VD/v$)
$V$ = the pipeline velocity
$v$ = the kinematic viscosity of the water

The minimum allowable Reynolds number varies with diameter, tapping arrangement, and $\beta$. The Reynolds number ($VD/v$) for flange and ($D$-$D$/2) taps must be greater than 1,260 $\beta^2 D$. For corner taps Reynolds number must be greater than 10,000 for $\beta$ greater than 0.45. For $\beta$ less than 0.45, the Reynolds number must be greater than 5,000.

The first three terms of equation 14-3 give the corner tap coefficient when Reynolds number *(Re*) effect is insignificant. The fourth term introduces Reynolds number effect. The last term accounts for the distance of flange and *D*-*D*/2 taps from the upstream face of the orifice plate. Although the equation appears to give a coefficient value for all tapping locations, standardized or not, it was not developed with data for other than standard locations and, therefore, is not recommended for nonstandard tapping locations. The coefficients by this equation are substantially the same as found in older presentations. Differences come mainly from the data fitting method. Uncertainty of the coefficient is claimed to be less than ±1 percent, exceeding the usual requirements for irrigation use.

The equation which relates flow rate to head differential and other parameters may seem to be rather complicated but is a minor inconvenience with modern computer capabilities. For the usual irrigation practice that accepts meter accuracies within ±3 percent or more, the above precautions can be relaxed considerably.

## 4. Propeller Meters

Propeller meters are commercial flow measuring devices used at the ends of pipes and in conduits flowing full and under pressure (figure 14-6). The uses of propeller meters at the end of pipes (open flow propeller meters) are discussed in chapter 13. Propeller meters use multiple blades made of rubber, plastic, or metal. The propeller rotates on a horizontal axle geared to a totalizer that displays total volume that has passed the meter. The propellers are sometimes hung from a sealing plate with a gasket to seal around a saddle opening on the top of the pipeline. Others have propellers supported by spiders in short, permanent tubes for connection into pipeline flow. Some meters also display instantaneous discharge rate with indicator hands on dials.

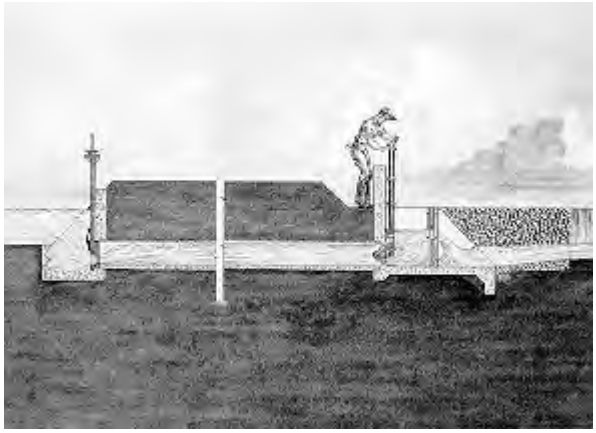


Figure 14-6 -- Typical propeller meter installation.

The meters are available for a range of pipe diameters from 2 to 72 in. They are normally designed for water flow velocities up to 17 feet per second (ft/s). The accuracy of most propeller meters varies from +/-2 to +/-5 percent of the actual flow. Greater accuracy is possible, and minimum driving velocities as low as 0.5 ft/s are sometimes claimed for certain meters. These claims may, at times, be justified; however, they are sometimes difficult to verify or reproduce, even in carefully controlled laboratory tests. Small changes of frictional resistance of bearings and other mechanical parts caused by wear can cause large deviations from calibration, especially at the low discharge end of measurement range.

With wear, error increases greatly for velocities below 1 to 1.5 ft/s. Propeller meters should be selected to operate near the middle of their design discharge range. This equipment can be a problem in existing irrigation systems with oversized pipes relative to delivery needs. Sections of the oversized pipe may need to be replaced with smaller pipes to provide enough velocity and approach pipeline length to allow development of velocity profiles.

Any condition that makes the approach flow different from calibration conditions affects the accuracy of the meter registration. Insufficient driving velocity relative to friction, unusual velocity distributions, or undeveloped velocity profiles and spiral flow can cause considerable errors.

If the propeller diameter measures less than half of the pipe diameter, the meter will be more sensitive to velocity profile differences. Changes in velocity distribution or velocity profile also influence registration. If the conduit from the canal to the meter is less than about six diameters long, typically, flow does not have sufficient time to develop a normal velocity distribution profile. This condition results in a blunt, evenly distributed velocity pattern (figure 14-7, case A). However, a conduit length of 20 to 30 diameters or longer will allow a typical, fully developed velocity profile (figure 14-7, case B).

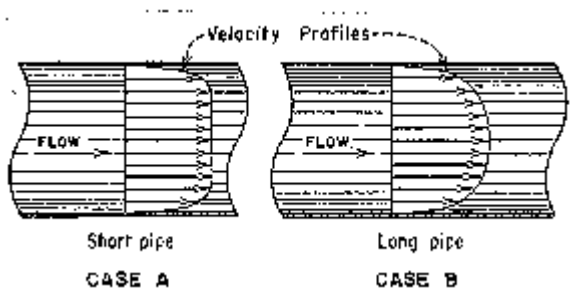


Figure 14-7 -- Velocity distributions in a pipeline.

With a fully developed velocity profile (case B), the velocity of flow near the center of the pipe is high, compared to the velocity near the walls. Thus, a meter with a propeller diameter of only half that of the pipe diameter would read 3 to 4 percent higher in this flow distribution than it would in the flat velocity profile (case A). Larger propellers up to 0.8 of the pipe diameter sample more of the flow velocity, producing greater potential accuracy. Laboratory tests show this statement to be true; and when the propeller diameter is 75 percent or more of the pipe diameter, the variation in registration caused by these velocity profile changes are minor.

Spiral flow is caused by poor entrance conditions and combinations of bends and fittings such as valves. Measurement errors caused by spiral flow can be large and, depending on spiral rotational direction of the flow, are either positive or negative.

Normally, the manufacturer provides detailed installation instructions which should be followed carefully. The same straight pipe approach and flow straightening vanes to prevent spiral flow that the manufacturer uses during calibration must be reproduced in field installations. Straightening vanes, at least several pipe diameters long, should be placed in the straight pipeline an appreciable distance upstream from the meter as specified by the manufacturer.

Propeller shafts are usually designed to rotate in one or more bearings. Bearings are contained in a hub, where they are protected from direct contact with objects in the flow. However, water often can and does enter the bearing. Some hubs trap sediment or other foreign particles. After these particles work into the bearing, a definite added resistance to turning becomes apparent. Some propellers are, therefore, designed for flow-through cleaning action so that particles do not permanently lodge and partially consolidate in the bearings. However, some of these bearing flushing systems have been plugged when the bearings have become fully packed with sediment. Newer propeller meters generally have sealed or ceramic bearings to minimize sediment wear problems.

Although propellers are designed to pass (to some degree) weeds, moss, and other debris, only a limited amount of foreign material that can be tolerated in the flow. Even moderate amounts of floating moss or weeds can foul a propeller unless it is protected by screens. With larger amounts or certain kinds of foreign material in the water, even screens may not solve the problem. Heavy objects in the water can damage propellers. Where rodents, such as muskrats, can get to plastic propellers, they have been known to cause chewing damage.

Propeller meters require continuous inspection and maintenance, which may amount to very little to very much, depending on local conditions and brands selected. Potential users should seek information from other local users before selection. In some cases of high maintenance costs and expensive water, these meters have paid for themselves in as little as 2 months on the basis of water conserved. However, in other areas where water is relatively plentiful, they have never repaid their original cost. Propeller bearing troubles are the most expensive and common problem and may be difficult to overcome except by means of a well-planned maintenance program. Maintenance costs can be excessive if meters are used for water with sediment. Propeller meters require a maintenance routine where bearings are replaced based on time of operation.

## 5. Bypass Meters

These meters measure part of the total flow which is allowed or forced through a small passageway by differential pressure across a fitting and returned to the main flow. Thus, these meters are sometimes called proportional, or shunt, flowmeters. The side flow drives an indicator or small water measuring device such as a propeller, vane, rotameter, or turbine meter. Indicators of the smaller flowmeter readings are related to total discharge by calibration. These reading devices display or indicate instantaneous rate of flow, totalized volume of flow, or both. Bypass meters are produced and sold commercially with calibrations and discharge tables.

## 6. Magnetic Flowmeters

The operation of magnetic flowmeters is based upon the principle that a voltage is induced in an electrical conductor moving through a magnetic field. In the case of magnetic flowmeters, the conductor is the flowing water being measured. For a given field strength, the magnitude of the induced voltage is proportional to the velocity of the conductor.

The meter consists of a nonmagnetic and non-electrical conducting tube or pipe through which the water flows. Two magnetic coils are used, one on each side of the pipe. Two electrodes in each side of the insulated pipe wall sense the flow-induced voltage.

The meter should be mounted so that the electrodes are horizontal to prevent air from breaking the voltage measuring circuit. The meter has electrical circuits to transform the induced voltage into a rate-of-flow indication on a meter dial (figure 14-8). The electrical sensing system and uniform flow-through passage allow the magnetic flowmeter to measure flow in both directions.

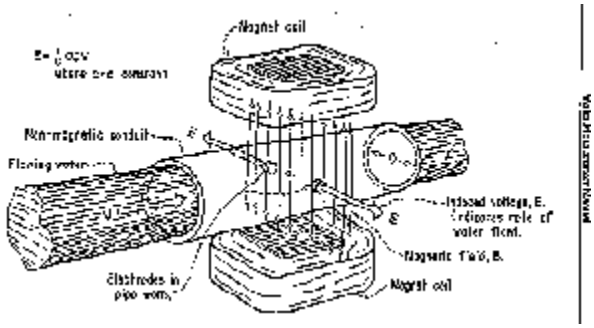



Figure 14-8 -- Schematic view of a magnetic flowmeter.

A source of electrical power is needed to activate the magnetic field, and a transmitter is used to record or send the rate-of-flow signals to desired stations. The water needs sufficient conductivity, but other properties such as temperature, viscosity, density, or solid particles do not change calibration. However, dissolved chemicals can deposit on the electrodes and cause accuracy errors. Some of these meters are provided with wipers or electrolytic or ultrasonic electrode cleaners.

Head losses through the meter are negligible, and accuracy of measurement in the upper half of the meter's rated capability is usually good. Later model electromagnetic meters can have good accuracy (+/-1.0%) for a range of minimum to maximum discharge.

## 7. Deflection Meters

A deflection meter consists of a vane or plate that projects into the flow and a sensing element that measures the deflection caused by the force of the flow against the vane. These meters are sometimes called drag or target meters. They are usually calibrated to indicate the rate of flow in some desired unit of measure. Head losses through the meter are low to moderate, depending upon design. These meters have no pressure taps to plug. The meters are available commercially and are relatively simple. Their accuracy ranges from moderate to good.

## 8. Variable-Area Meters

In variable-area meters, the water flows vertically upward in a conically tapered tube in which area increases with height. The rate of flow is indicated by the height at which a shaped weight attains stable support from the flow in the tapered tube. Smaller versions are commonly called rotameters because many of the weights are sometimes vaned to rotate for stability in the tapered tube. The weights appear to float freely in the tapered tube. Thus, they are often called floats. When the tube is transparent, the position of the float can be observed directly against graduations on the tube.

Larger meters sometimes have a stem attached to the float, which is linked mechanically or magnetically to an indicator. Auxiliary recording and transmitting of discharge and totalized volume are sometimes incorporated into these meters.

These meters generally have few moving parts to wear or otherwise cause trouble, and the accuracy of the meters can be high. The head losses may be large. These meters have to be installed in a vertical position, making pipe fitting more difficult.

## Web Resources

The listings here should not be construed as an endorsement or recommendation of a service or product by the Bureau of Reclamation, Agricultural Research Service, Natural Resource Conservation Service, or other participants of these web pages. These are provided only as a convenience to our web clients. The listing below were selected based on a manufacture statement that they can provide a device related to this chapter or section. To suggest new information for this page, go to the Suggest-A-Link web page.

ISA (Instrumentation Society of America, the international society for measurement and control)
RP16.4: Nomenclature and Terminology for Extension-Type Variable Area Meters (Rotameters)-1960

http://www.isa.org/?template=Ecommerce/ProductDisplay.cfm&ProductID=2507

## Manufactures

FLW Southeast, Inc.
1343 Canton Road Suite D-1
Marietta, GA 30066
Phone: (770) 424-1731
Fax: (770) 424-9733
E-mail: flwse@flwsoutheast.com
Related web page: www.flwsoutheast.com

## 9. Vortex Flowmeter

The vortex generating flowmeter is based on the principle that obstructions placed in flows generate vortex shedding trails in the flow (White and McMurtrie, 1971). A properly shaped obstruction will produce stable vortices that reinforce or interact with each other on each side of the obstruction.

The shedding vortex oscillations are sensed in different ways such as by thermistors, pressure cells, or magnetically picking up the oscillation of a shuttle ball in a chamber that has each end connected to each side of the obstruction. The proper shape of the obstruction also produces an oscillation frequency that is proportional to velocity over a large range of flow.

Manufacturers cite advantages such as the possibility of no moving parts, calibration by dimensional tolerance limits to $\pm 1$ percent, large discharge range, and adaptability to electronic digital counting. The meters can be made portable by installing the obstruction through the stuffing boxes.

## 10. Pitot Tube Velocity Measurements

The straight upstream tube shown on figure 14-9a, which is connected perpendicular and flush to the inside wall of the pipe so it does not sense any velocity force, is a called a ***piezometer***. Water rises in the piezometer to an elevation that only balances the pressure head in the conduit. A simple pitot tube is shown downstream on figure 14-9a. This open tube has a right-angle bend that is inserted into conduit flow with its horizontal leg pointed upstream and parallel to velocity. Water runs into the tube and rises into the vertical stem until its weight balances both the force of the pipeline pressure head, $h_p$, sometimes called ***static head***, and the force of approach velocity that has been converted to velocity head, $h_v$, by stagnation at the tip. In this form, the pitot tube is sometimes called a **total *head tube*** because the water rises above the tip a height equal to the sum, $H_t$, of pressure head in the conduit plus velocity head.

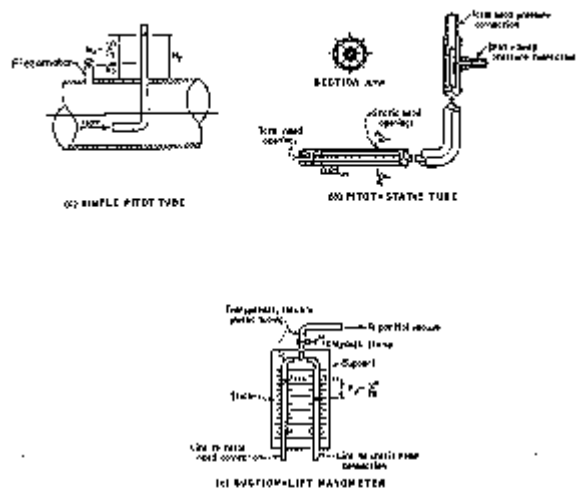


Figure 14-9.—Pitot tubes and manometer.

For a velocity measurement, the pressure head is subtracted from the total head, $H_t$, resulting in velocity head, $h_v$, or $V^2/2g$. Solving for the velocity of flow, $V$, results in:

$$V = C_t\sqrt{2gh_v} \qquad (14\text{-}4)$$

where:

$V$ = velocity
$g$ = gravity constant
$h_v$ = measured velocity head
$C$ = coefficient

Figure 14-9 -- Pitot tubes and manometer.

For a velocity measurement, the pressure head is subtracted from the total head, $H_t$, resulting in velocity head, $h_v$, or $V^2/2g$. Solving for the velocity of flow, $V$, results in:

$$V = C\sqrt{2gh_v} \qquad (14\text{-}4)$$

where:

$V$ = velocity
$g$ = gravity constant

$h_v$ = measured velocity head
$C$ = coefficient

For total head tubes that have reasonably long horizontal legs relative to tube diameter, the tube coefficient is commonly unity. However, pitot tubes with damaged tips, short tips, tube burrs, and short tips need calibration checks to determine correct tube coefficients that may deviate considerably from unity.

A more complex form of pitot tube is known as the ***pitot-static tube***, which consists of the total head tube threaded through the center of a larger tube. Static ports are drilled perpendicular to and around the circumference of the horizontal part of the outer tube. Typical pitot-static tubes have static ports that are placed a distance of at least three outer tube diameters from the tip and at least eight diameters from the vertical leg of the outer tube (figure 14-9b). These distances protect the static ports from stem and tip disturbances, which would cause tube coefficients to deviate from unity.

Properly constructed and undamaged standard pitot-static tubes have a coefficient very close to unity and can be used without corrections for tube interference effects (ASME, 1983). Some special instruments have coefficients that differ considerably from unity. Appropriate coefficients should be applied as specified by manufacturers.

Manometers are commonly used to measure heads separately or differentially in a U-tube. The suction lift manometer shown in figure 14-9c uses an inverted U-tube with partial vacuum to lift the water surfaces up to the scale for reading the pressures where pipeline total head is insufficient to do so itself. The velocity head is obtained by subtracting the pressure head from the total head. More conveniently, a differential pressure cell that senses velocity head directly can be used. A recording digital voltmeter attached to the pressure cells can provide continuous records of velocity.

The rate of flow in pipelines under pressure may be computed from the conduit cross-sectional area and velocity observations made by pitot tubes or by commercial adaptations of pitot tubes (ASME, 1983; 1992). Reinforced pitometers have been used successfully in pipes up to 5 feet (ft) in diameter with flow velocities of 5 to 20 ft/s. Even large pipes can be traversed by having access ports on both sides of the pipe and probing to or past the conduit centerline from each side. The principal disadvantage encountered is that relatively large forces push on the tube when flow velocities are high, making positioning and securing of the instrument difficult. Dynamic instability may also occur, causing the tube to vibrate and produce erroneous readings. The flow measurements can be very accurate at moderate flow velocities.

## 11. Point Velocity Area Methods

Computing discharge point velocities for open channel flow is discussed in chapter 10. In conduits, several point velocities can be obtained by traversing with a velocity measuring device such as a pitot tube. Arrays of several velocity measuring devices, such as axial current meters, are sometimes fixed on racks that span the conduit to measure several velocities simultaneously. Some flowmeters directly measure average velocity along lines through the flow.

The measurement of point velocities is relatively simple. However, partitioning the flow section relative to velocity points is complex, depending on the accuracy desired. The main problem in determining proper partial areas is that each point velocity represents or determines meaningful velocity weighting factors related to each point location. Many schemes can be used to locate measuring points on grids or diameters and assign weighting factors for each position. The procedures are further complicated when corrections are needed to account for the obstruction of rack support systems and the size of the instruments themselves. If accuracies better than +/-3 percent are needed, then procedures set by codes such as ISO (1977) and ASME (1992) should be consulted.

Some methods of averaging velocity are done by selecting equal areas related to the shape of the flow cross section and measuring velocity at specific points within these areas. For pitot measurements, the average of the square root of the velocity heads of the point measurements is multiplied by the flow section area.

The most common pressure conduit is the circular pipe. For a constant rate of flow, the velocity varies from point to point across the stream, gradually increasing from the walls toward the center of the pipe. The mean velocity is obtained by dividing the cross-sectional area of the pipe into a number of concentric, equal area rings and a central circle. The standard (ASME, 1983) 10-point system is shown on figure 14-10a. More equal area divisions may be used if required by large flow distortions or other unusual flow conditions. Velocity measurements are taken at specific locations in these subareas (figure 14-10a) and are adjusted in terms of average velocity head by the equation:

$$v_{avg} = \sqrt{2g}\,(\sqrt{h_v})_{avg} \qquad (14\text{-}5)$$

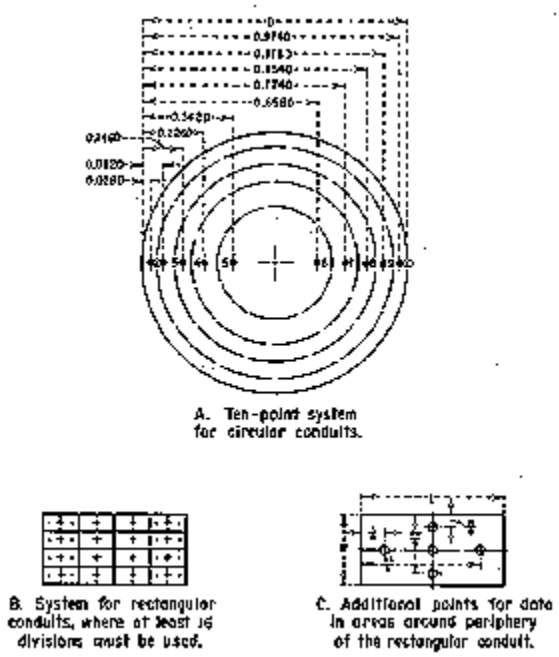



Figure 14-10 -- Locations for pitot tube measurements in circular and rectangular conduits (reproduced from British Standard 1042, Flow Measurement [1943], by permission of the British Standards Institution).

The mean velocity in rectangular ducts can be found by dividing the cross section into an even number (at least 16) of equal rectangles geometrically similar to the duct cross section and measuring the velocity at the center of each area (figure 14-9b). Additional readings should be taken in the areas along the periphery of the cross section according to the diagram on figure 14-9c. Then, the average velocity is determined from equation 14-5.

Acoustic devices, discussed in chapter 11, measure accurate average velocity along chords or diametral lines in planes across the flow section. The diametral arrangement uses the simple average of the line velocities corrected for the angle of the plane across the conduit. The multiple chordal systems use a specific weighting factor for each line velocity to determine the average (AMSE, 1992). The chord locations are specified to maximize accuracy.

## 12. California Pipe Method

This method measures the discharge from the open end of partially filled horizontal pipes discharging freely into the air (Vanleer, 1922; 1924). This method is sometimes considered a trajectory method. However, the measurement is really based on the brink depth at the end of the pipe. This method can be adapted to the measurement of discharge in small open channels where the discharge can be diverted through a horizontal pipe flowing partially full and discharging freely into the air.

Figure 14-11 illustrates one pipe fitting arrangement to accommodate the California pipe discharge measurement. Other arrangements may be possible. With such an arrangement, the only measurements necessary are the inside diameter of the pipe and the vertical distance from the upper inside surface of the pipe to the surface of the flowing water at the outlet end of the pipe. With this information, the discharge may be computed by:

$$Q = 8.69 \left(1 - \frac{a}{d}\right)^{1.88} d^{2.48} \qquad (14\text{-}6)$$

where:

$Q$ = discharge ($ft^3/s$)

$a$ = distance measured in the plane of the end of the pipe from the top of the inside surface of the pipe to the water surface (ft)

$d$ = internal diameter of the pipe (ft)

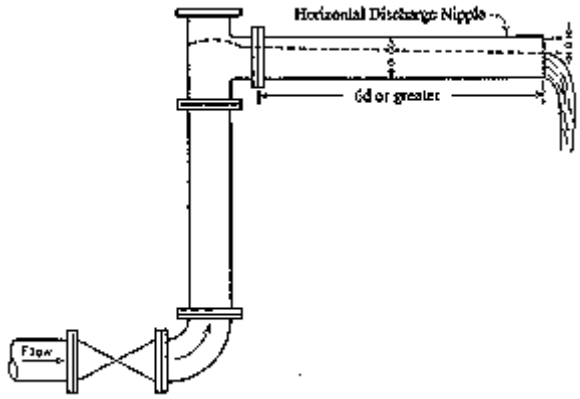



Figure 14-11 -- Typical arrangement for measuring flow by the California pipe method.

This equation, developed from experimental data for pipes 3 to 10 inches in diameter, gives reasonably accurate values of discharge for that range of sizes under certain flow conditions. However, tests by the Natural Resources Conservation Service (formerly U.S. Soil Conservation Service) (Rohwer, 1943) showed that for depths greater than about one-half the diameter of the pipe or *a/d* less than about 0.5, the discharge does not follow the Vanleer equation. Bos (1989) shows that brink depth must be less than 0.55*d*, or *a/d* must be greater than 0.45. Care should therefore be taken in using equation 14-6. The discharge uncertainty of this method is expected to be about +/-10 percent, assuming careful brink depth and pipe diameter measurements.

Some additional requirements for proper use and for attaining potential accuracy of the California pipe measurement method are:

(1) The discharge pipe must be level.

(2) The pipe must be partially full with *a/d* greater than 0.45.

(3) The flow must discharge freely into the air.

## 13. Trajectory Methods

Basically, trajectory methods consist of measuring the horizontal and vertical coordinates of a point in the jet issuing from the end of a pipe (Stock, 1955). The pipe may be oriented either vertically or horizontally. The principal difficulty with this method is in measuring the coordinates of the flowing stream accurately.

### (a) Vertical Pipes

Lawrence and Braunworth (1906) noted that two kinds of flow occur from the end of vertical pipes. With a small rise of water (up to 0.37*d*) above the end of the pipe, the flow acts like a circular weir. When the water rises more than 1.4*d*, jet flow occurs. When the rise is between these values, the mode of flow is in transition. Lawrence and Braunworth (1906) determined that when the height of the jet exceeded 1.4 *d*, as determined by sighting over the jet to obtain the maximum rise, the discharge is given by:

$$Q = 5.01d^{1.99}h^{0.53} \qquad (14\text{-}7)$$

where:

$Q$ = rate of flow, gal/min
$d$ = inside diameter of the pipe, in
$h$ = height of jet, in

When the rise of water above the end of the pipe is less than 0.37*d*, discharge is given by:

$$Q = 6.17d^{1.25}h^{1.35} \qquad (14\text{-}8)$$

For jet heights between 0.37*d* and 1.4*d*, the flow is considerably less than that given by either of these equations. Figure 14-12, prepared using data from Stock (1955) gives flow rates in gallons per minute for standard pipes 2 to 12 inches in diameter and jet heights from 12 to 60 in. Bos (1989) assigns to this method an accuracy of +/-10 percent for the jet flow range to +/-15 percent for the weir flow range.

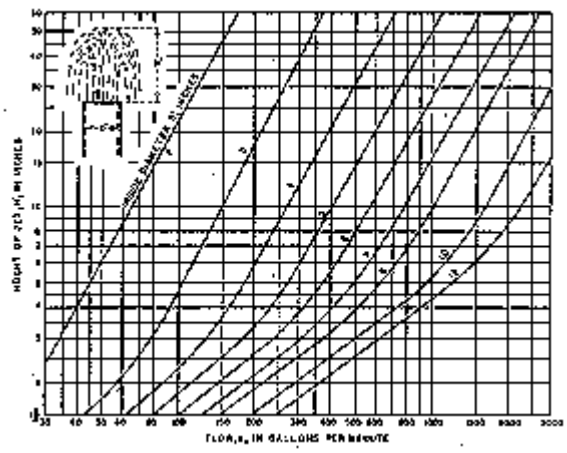
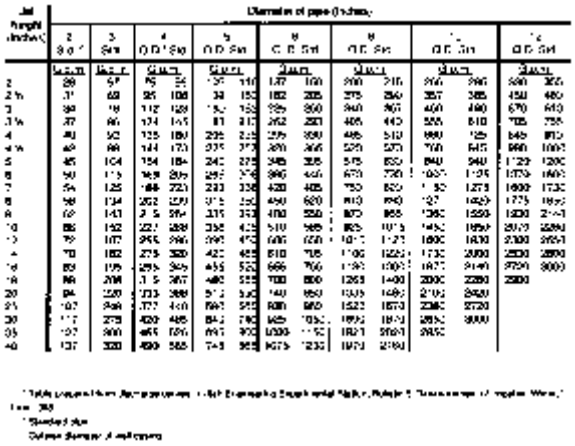


Figure 14-12 -- Discharge curves for measurement of flow from vertical standard pipes. The curves are based on data from experiments of Lawrence and Braunworth, American Society of Civil Engineers, Transactions, Vol. 57, 1906 (courtesy of Utah State University).

For irrigation convenience, the Natural Resources Conservation Service produced a table from curves for vertical pipes in Stock (1955) for the NRCS *National Engineering Handbook* (1962a). This table is reproduced here as table 14-1. The table gives discharges for different heads up to 40 in for standard nominal pipe diameters from 2 to 12 inches and for outside diameters of well casings from 4 to 12 inches. As mentioned before, accuracies better than 15 and 10 per-cent should not be expected, depending on whether the flow is acting as a weir or jet-type flow.

Table 14-1 -- Flow from vertical pipes[1]



[1] Table prepared from discharge curves in Utah Engineering Experimental Station, Bulletin 5, "Measurement of Irrigation Water," June 1955.

[2] Standard pipe.

[3] Outside diameter of well casing.

**(b) Horizontal Pipes**

When brink depths are greater than 0.5*D*, the more general Purdue pipe method developed by Greve (1928) should be used, rather than the California pipe method. The Purdue method applies equally well to both partially and completely filled pipes. The Purdue method consists of measuring coordinates of the upper surface of the jet as shown on figure 14-13. If the water in the pipe is flowing at a depth of less than 0.8*D* at the outlet, the vertical distance, *Y*, can be measured at the end of the pipe where $X = 0$. For higher rates of flow, *Y* may be measured at horizontal distances, *X*, from the pipe exit of 6, 12, or 18 in. Flow values in gallons per minute for 2- to 6-in-diameter standard pipes are shown in graphs on figure 14-14 (Stock, 1955).

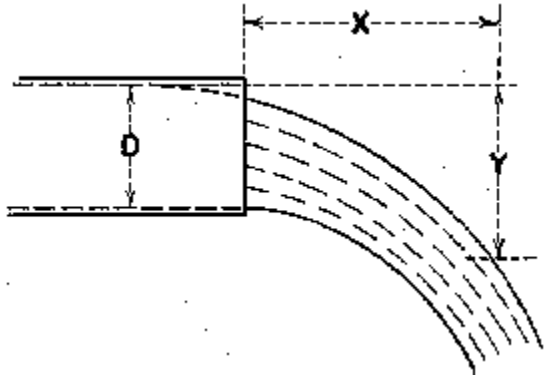



Figure 14-13 -- Purdue method of measuring flow from a horizontal pipe (courtesy of Utah State University).

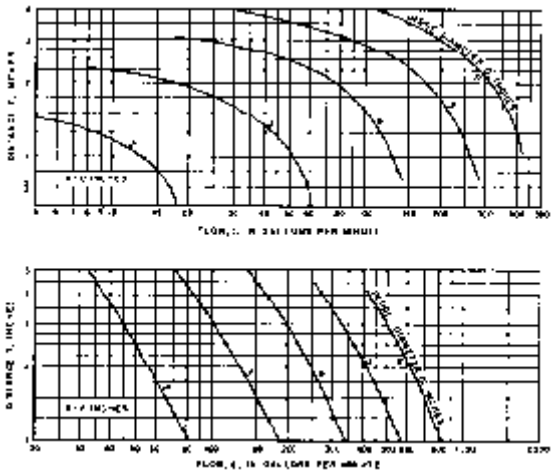


Figure 14-14 -- Flow from horizontal standard pipes by
Purdue coordinate method (courtesy of Utah State University)
(sheet 1 of 2).

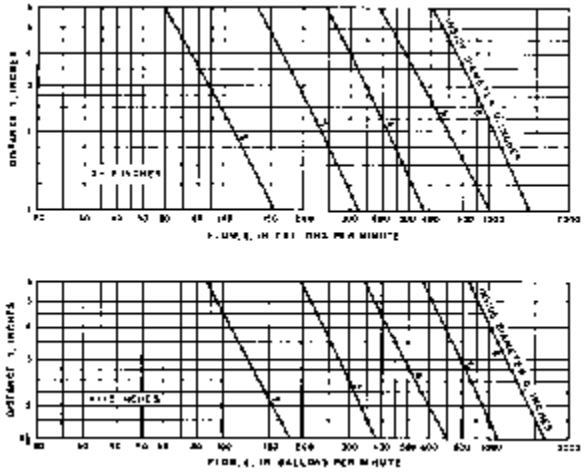


Figure 14-14 -- Flow from horizontal standard pipes by
Purdue coordinate method (courtesy of Utah State University)
(sheet 2 of 2).

The most accurate results will be obtained when the pipe is truly horizontal. If it slopes upward, the indicated discharge will be too high. If it slopes downward, the indicated discharge will be too low.

Difficulty occurs in making the vertical measurement, *Y*, because the top of the jet will usually not be smooth and well defined.

The NRCS produced table 14-2 for horizontal pipe discharge for *X* of 0, 6, 12 and 18 in and *Y* up to about 8 in for pipe diameters from 2 to 6 in. As mentioned previously, accuracies better than 10 percent should not be expected.

Table 14-2 Flow from horizontal pipes[1]

| Y (inches) | WHEN X=3: Size of pipe (nominal diameter) 2-inch | 3-inch | 4-inch | 5-inch | 6-inch |
|---|---|---|---|---|---|
| | G.p.m. | G.p.m. | G.p.m. | G.p.m. | G.p.m. |
| 0.20 | | [illegible] | 130 | 308 | |
| .30 | | [illegible] | 126 | [illegible] | [illegible] |
| .40 | | [illegible] | 171 | 258 | 518 |
| .50 | | [illegible] | 158 | [illegible] | [illegible] |
| .60 | [illegible] | [illegible] | 141 | 207 | 484 |
| .70 | [illegible] | [illegible] | 158 | 282 | 462 |
| .80 | [illegible] | [illegible] | 150 | 277 | 470 |
| .90 | [illegible] | [illegible] | 146 | [illegible] | 458 |
| 1.00 | [illegible] | [illegible] | 139 | 265 | 446 |
| 1.20 | [illegible] | [illegible] | 129 | [illegible] | 422 |
| 1.40 | [illegible] | [illegible] | [illegible] | [illegible] | 398 |
| 1.60 | | [illegible] | 102 | [illegible] | [illegible] |
| 1.80 | | [illegible] | 90 | [illegible] | 347 |
| 2.00 | | [illegible] | 77 | 187 | [illegible] |
| 2.20 | | [illegible] | 64 | 167 | 296 |
| 2.40 | | [illegible] | 52 | 147 | 270 |
| 2.60 | | | 41 | 127 | 246 |
| 2.80 | | | 32 | 108 | 225 |
| 3.00 | | | 24 | 90 | 204 |
| 3.20 | | | 15 | 65 | 157 |
| 3.40 | | | | 45 | 137 |
| 3.60 | | | | 29 | [illegible] |
| 4.20 | | | | | 88 |
| 4.60 | | | | | 56 |
| 4.80 | | | | | 45 |

[illegible]

| Y (inches) | WHEN X=5 INCHES Size of pipe (nominal diameter) 2-inch | 3-inch | 4-inch | 5-inch | 6-inch |
|---|---|---|---|---|---|
| | G.p.m. | G.p.m. | G.p.m. | G.p.m. | G.p.m. |
| 0.24 | 137 | [illegible] | 543 | | |
| .36 | 146 | 274 | 503 | 990 | 1243 |
| .48 | 126 | [illegible] | 467 | 852 | [illegible] |
| .60 | 111 | 220 | 433 | 773 | [illegible] |
| .72 | 100 | [illegible] | 404 | 706 | 1147 |
| .84 | 92 | 202 | 377 | 646 | 933 |
| .96 | 85 | 189 | 355 | 604 | 1111 |
| 1.08 | 79 | 184 | 337 | 574 | 925 |
| 1.20 | 75 | [illegible] | 319 | 542 | [illegible] |
| 1.80 | 60 | 136 | 253 | 446 | 665 |
| 2.40 | 51 | 119 | 224 | 390 | 517 |
| 3.00 | 45 | 106 | 200 | 350 | 523 |
| 3.60 | 40 | 94 | 181 | 314 | 471 |
| 4.20 | 37 | 86 | 169 | 278 | 431 |
| 4.80 | 35 | 78 | 151 | 249 | 391 |
| 5.40 | 32 | 71 | 139 | 228 | 332 |
| 6.00 | 30 | 63 | 126 | 198 | 347 |
| 6.60 | 28 | 60 | 119 | 178 | |
| 7.20 | 27 | 57 | 111 | | |
| 7.80 | 23 | 53 | 99 | | |
| 8.40 | 20 | | | | |

Table 14-2 Flow from horizontal pipes[1] (continued)

| Y (inches) | WHEN X=12 INCHES Size of pipe (nominal diameter) 2-inch | 3-inch | 4-inch | 5-inch | 6-inch |
|---|---|---|---|---|---|
| | G.p.m. | G.p.m. | G.p.m. | G.p.m. | G.p.m. |
| .96 | 137 | 340 | [illegible] | 914 | |
| 1.26 | 148 | 326 | 568 | 874 | 1313 |
| 1.56 | 135 | 352 | 530 | 825 | 1277 |
| 1.86 | 114 | 337 | 494 | 783 | 1213 |
| 2.16 | 99 | 315 | 456 | 696 | 1125 |
| 2.46 | 87 | 293 | 390 | 693 | 1041 |
| 2.76 | 79 | 270 | 352 | 630 | 973 |
| 3.06 | 73 | 251 | 326 | 589 | 918 |
| 3.36 | 68 | 235 | 297 | 558 | 873 |
| 3.66 | 63 | 220 | 269 | 528 | 833 |
| 3.96 | 60 | 211 | 258 | 494 | 797 |
| 4.56 | 57 | 196 | 242 | 468 | 734 |
| 5.16 | 54 | 183 | 233 | 448 | 685 |
| 5.76 | 52 | 176 | 225 | 435 | 646 |

[illegible]

| Y (inches) | WHEN X=18 INCHES Size of pipe (nominal diameter) 2-inch | 3-inch | 4-inch | 5-inch | 6-inch |
|---|---|---|---|---|---|
| | G.p.m. | G.p.m. | G.p.m. | G.p.m. | G.p.m. |
| 1.50 | 197 | 341 | 534 | 1014 | 1439 |
| 2.40 | 184 | 317 | 497 | 947 | 1361 |
| 3.30 | 165 | 294 | 460 | 876 | 1253 |
| 4.20 | 152 | 271 | 432 | 794 | 1088 |
| 5.10 | 139 | 257 | 411 | 753 | 992 |
| 6.00 | 131 | 243 | 394 | 695 | 914 |
| 6.90 | 125 | 232 | 372 | 643 | 848 |
| 7.80 | 119 | 223 | 355 | 599 | 794 |
| 8.70 | 114 | 215 | 339 | 562 | 743 |
| 9.60 | 109 | 207 | 325 | 528 | 702 |
| 10.50 | 105 | 199 | 312 | 498 | 666 |
| 11.40 | 101 | 192 | 300 | 471 | 634 |
| 12.30 | 98 | 186 | 289 | 446 | 606 |
| 13.20 | 94 | 179 | 279 | 424 | 581 |
| 14.10 | 91 | 173 | 270 | 403 | 558 |
| 15.00 | 88 | 167 | 261 | 384 | 537 |
| 16.80 | 82 | 156 | 244 | 349 | 499 |
| 18.60 | 77 | 146 | 229 | 319 | 466 |
| 20.40 | 72 | 137 | 215 | 292 | 437 |
| 22.20 | 68 | 129 | 202 | 268 | 411 |

[illegible]

[1] Table for standard steel pipe prepared from data resulting from actual experiments conducted at Purdue University Experimental Station, Bulletin 32, "Measurement of Pipe Flow by the Coordinate Method," August 1928.

## 14. Small Tubes or Siphons

Plastic or aluminum siphons and tubes are commonly used to deliver water from a canal or ditch to the furrows (figure 14-15) (Scott and Houston, 1959). These conduits may also be used to measure the rate of flow. The head acting on siphons and straight pipes through banks is measured in the manner shown on figure 14-15. The rate of flow from figure 14-16 is used only for siphons and pipes where the flow exits the tube into free air. Figure 1417 is used only for the submerged exit case. The uncertainty for discharge is about +/-15 percent. Therefore, this method of determining discharge is approximate but could be useful for managing water allotments and apportionment over acreage.

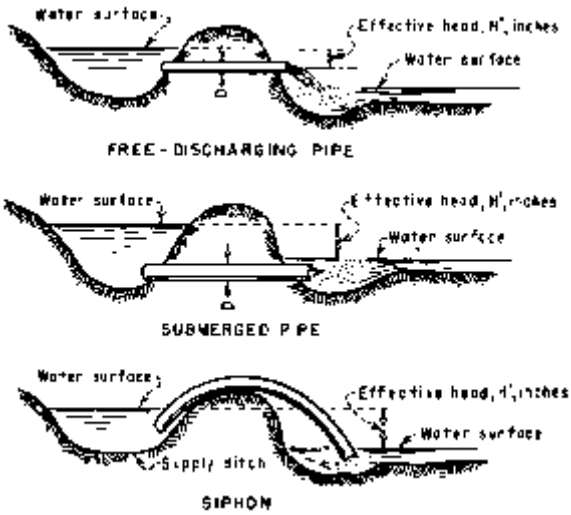



Figure 14-15 -- Discharge through ditch-to-furrow pipes and siphons (figures 14-16 and 14-17) may be determined by measuring the effective head.

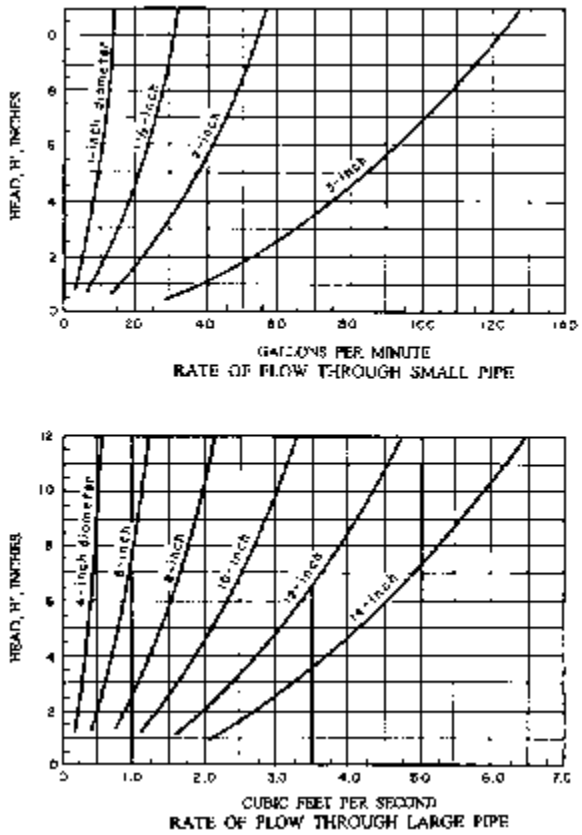



Figure 14-16 -- Rates of flow through ditch-to-furrow pipes for various heads.

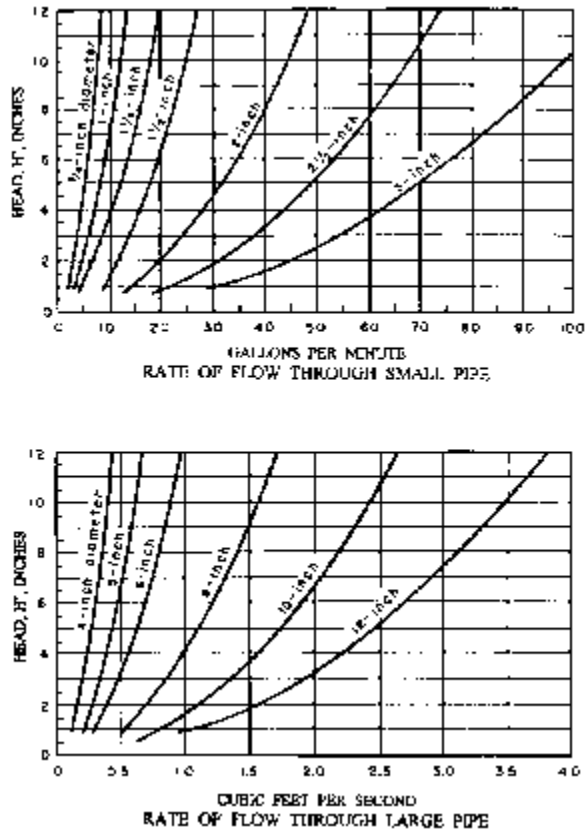



Figure 14-17 -- Rates of flow through ditch-to-furrow siphons

for various heads.

The pipe ends should be cut cleanly with no burrs. The tubes and ends should not be dented or deformed. Tight bends should be avoided. The flow past either end of the tube must be slow compared to tube velocity. Tubes can become partially or fully air locked at lower discharges of curves shown on figures 14-16 and 1417. The siphons should be reprimed periodically when operating at the low discharge region. Both submerged ends should be located a distance of 1.5 diameters from channel flow boundaries and water surface. If a vortex forms over the siphon entrance, the entrance should be lowered if possible; otherwise, the vortex should be suppressed. The vortex can be suppressed by rafting a wide board over the intake and hanging additional cross vanes from the board if needed. Bos (1989) gives more details concerning these requirements and provides rating curves in metric units.

Figure 14-18 (NRCS, 1962a) gives discharge in gallons per minute for heads up to 20 inches for siphon lengths common to furrow irrigation with pipe diameters from 2 to 6 inches. As mentioned previously, accuracies better than 10 percent should not be expected.

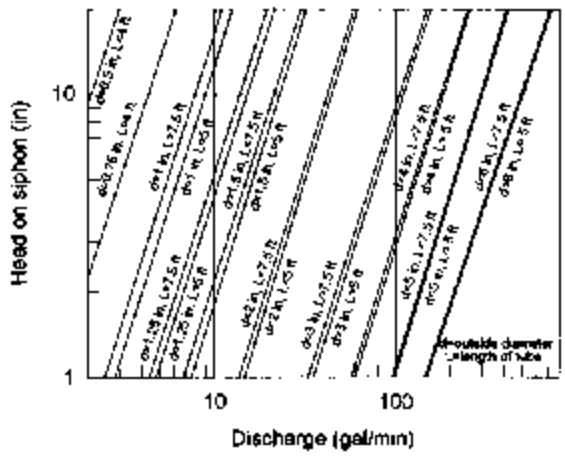



Figure 14-18 -- Discharge of aluminum or plastic siphon tubes at various heads for different tube lengths.

## 15. The Pressure-Time Method

The pressure-time data recorded during downstream closure of valves, wicket gates, or other devices can be used to calculate discharge (Gibson, 1923). Gibson developed elaborate equipment and detailed computational procedures for determining discharge. Modern pressure cells, electronic computers, and recording equipment have made the technique easier to accomplish. Codes such as those published by the ASME (1992) have been established for turbines. The pressure conduit should be at least 25 ft long, preferably longer.

Discharge is computed from:

(1) Pressure-time recording taken while the valve or other control device is closing.

(2) The cross-sectional area of the conduit.

(3) The length from control device to the entrance.

This method has recently been applied to shorter, low head turbines (Almquist et al., 1994). The pressure variation is automatically recorded with respect to time on equipment especially devised for this method. Use of the Gibson method requires specially trained personnel. Patents restricting the use of the equipment and method have expired.

## 16. Calibration of Turbines, Pumps, Gates, and Valves

Some irrigation distribution systems may require measurement of the flow by means of the turbines, pumps, gates, or valves through which the water flows. This measurement may be done if the structure is calibrated in the field using an approved flow measuring method or in the laboratory using hydraulic models. Properly prepared calibration curves are a reliable means for obtaining accurate discharge measurements.

Discharge is generally related to power in the case of turbines or pumps. The relationships may be determined by measuring the average power output or input during the period in which discharge measurements are made for various load conditions. Curves or tables are developed from these test data to show the rate of flow that occurs for specific power and operation conditions. Long- or short-term deterioration or damage may change machinery efficiency. Thus, these calibrations should be periodically checked, adjusted, and recalibrated as needed.

For gates and valves, discharge-versus-gate-opening curves for various appropriate heads are desired. These curves may be determined by measuring the rates of flow at given gate or valve openings under specific head conditions. By operating over the full range of openings and heads, data may be obtained for establishing the families of curves. Generally, the curves would show the rates of flow in cubic feet per second ($ft^3/s$) that occur through the gate or valve at specific openings, which are expressed in percent of opening, for the pertinent operating heads. These curves may also be prepared from model test data.

## 17. Acoustic Flowmeters

The most recent advances in measuring flow in pressure conduits has been with the further developments of acoustic flowmeters. This class of meters is covered in detail in chapter 11 of this manual. These meters are used extensively at powerplants and other major points of diversion. They are well suited to use in automated data acquisition systems. Their accuracy depends on type and installation, but generally varies from +/-3 percent down to +/-0.1 percent.

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# Elbow Flow Meters

Clifford A. Pugh, Water Resources Research Laboratory

Elbow meters are based on the principle of "conservation of momentum." Momentum conservation requires that the momentum flux (momentum per unit time) remain unchanged as steady flow occurs through an isolated system of fluid. Since momentum is a vector quantity, a change in direction of the flow causes a reduction of momentum in the original direction which is offset by an increase in the new direction. In an elbow, such as the mitred elbow shown in figure 1, the momentum in the horizontal direction is changed by the pipe turning down. This change in direction causes the flow to exert a force on the pipe elbow.

$$F = \rho Q (V2-V1) \qquad \text{[Momentum Equation]} \qquad (1)$$

Where,

F = Force
$\rho$ = the fluid density
Q = the discharge (flow)
V = the velocity vector

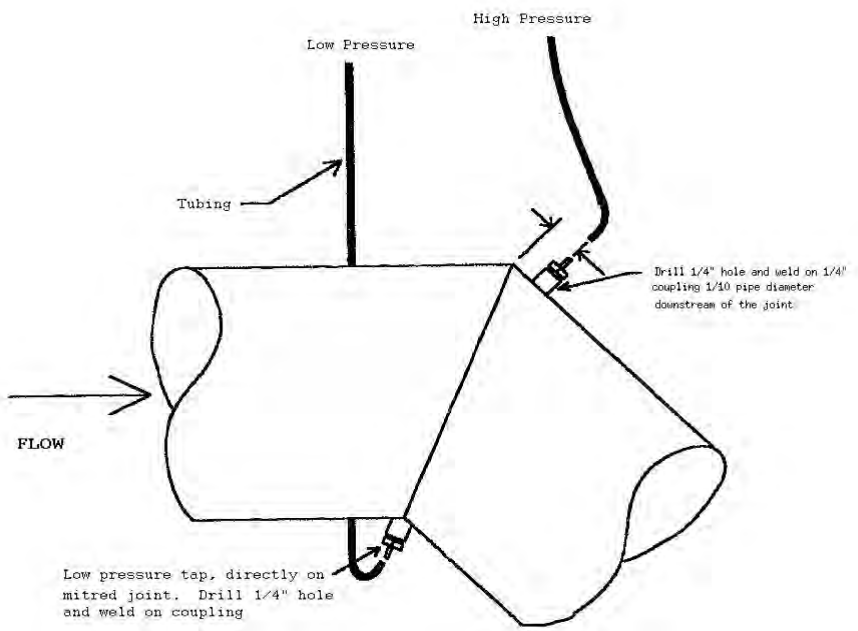


Figure 1 - Forty-five degree mitred bend with pressure taps on the inside and outside of the bend. The pressure differential is related to the square of the velocity.

This force results in an increased pressure on the outside of the bend and a decreased pressure on the inside. The pressure difference is proportional to the square of the velocity. The general form of the equation would be :

$$Q = C_d A \sqrt{2g\Delta h} \qquad (2)$$

Figure 1 shows recommended pressure tap locations for a mitred bend according to ID Tech, inc. ID Tech sells an "Electronic Flow Calculator" based on an elbow meter. The coefficents of discharge ($C_d$) for mitred bends (determined empirically by ID Tech) are proprietary. Their toll free phone number is 888-782-0498.

Figure 2 shows a multiple level outlet at Beltzville Dam in Pennsylvania. Differential pressures across opposing pressure taps (P1 and P2) and stream gage measurements were used to develop the rating curve and equation shown in figure 3 (Hart and Pugh, 1975).

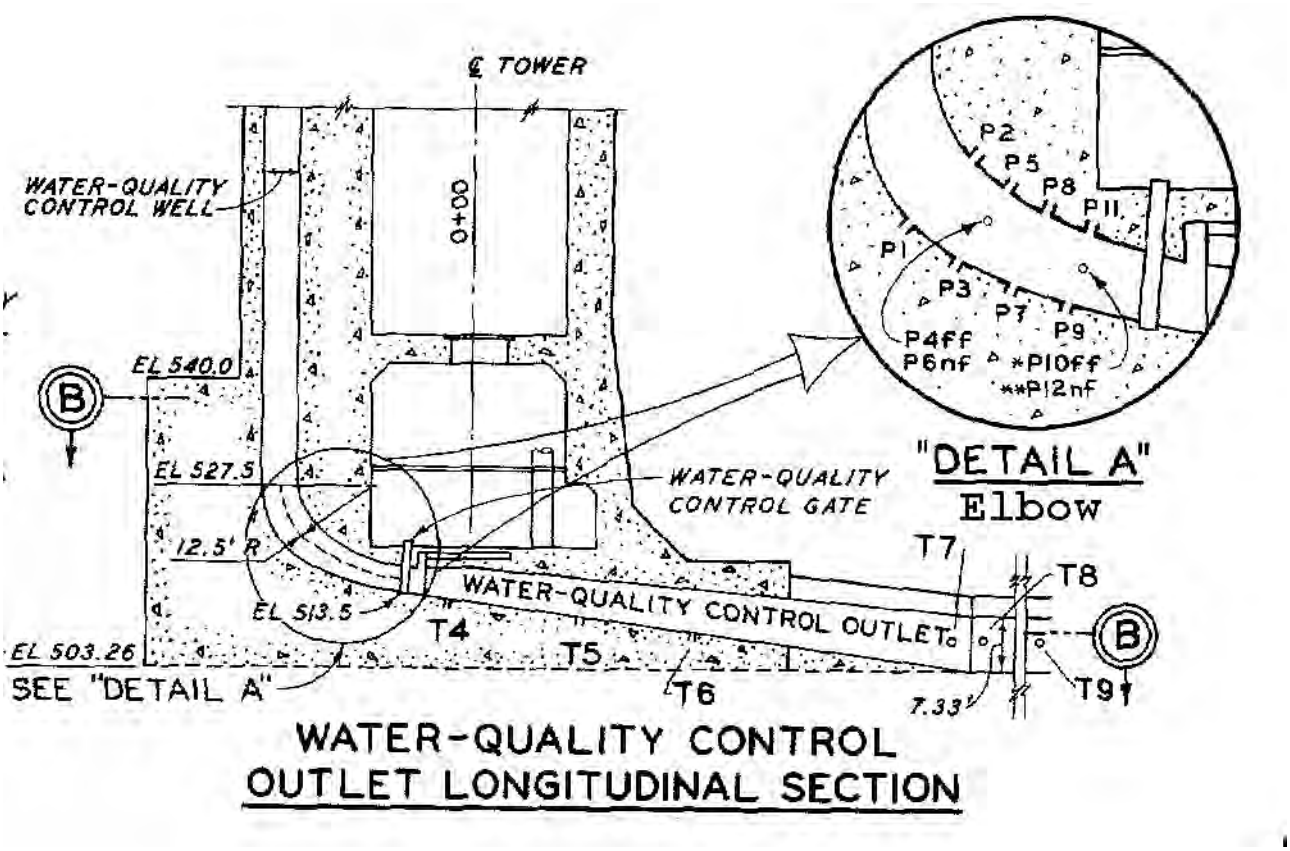


Figure 2 - Water Quality Control outlet at Beltzville Dam (Hart and Pugh, 1975). The pressure differential between P1 and P2 was empirically calibrated to obtain a discharge relationship. The elbow meter is used to set desired outlet flows for normal operations.

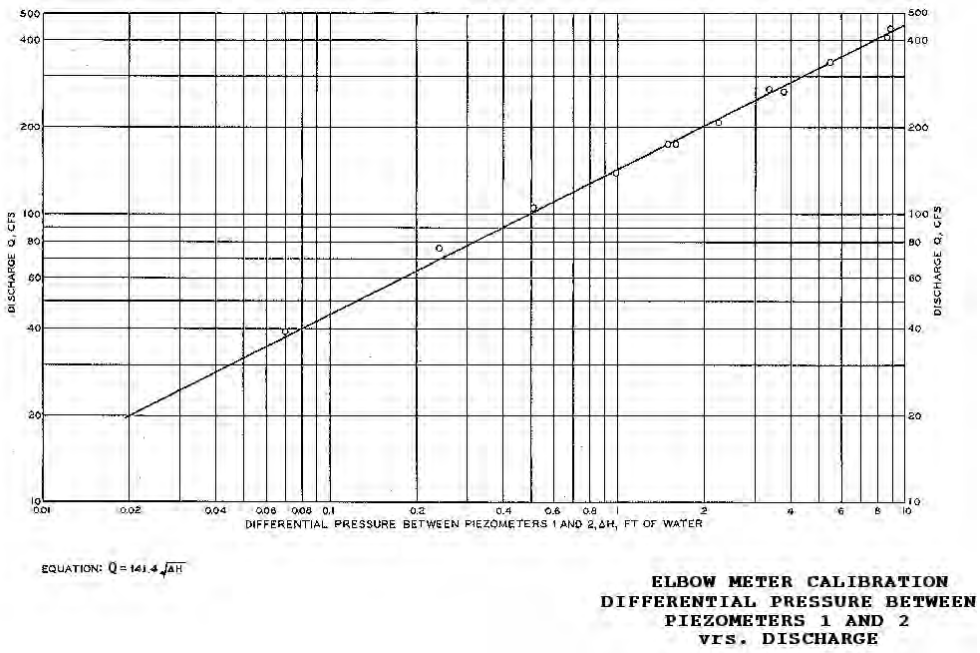


Figure 3 - Elbow Meter Calibration, Beltzville Dam.

Similar empirical relationships could be developed for pipe bends in the field by using a strap on acoustic flowmeter (or another flow measurement method) to obtain the data and develop the equation. One differential pressure transducer would be connected to the high and low pressure taps to measure the differential and obtain flow. This is a simple and relatively accurate device if the pressure taps are properly installed and the "burrs" are cleaned from the inside of the tap. A slight rounding of the edge of the taps helps to improve their performance.

As a practical matter, the lower limit of an elbow meter is about 2 ft/s. Pressure differences and discharge measurement accuracy are very low below this velocity. Flow Tech recommends an upper velocity limit of 10 ft/s, this is probably due to seperation at the sharp bend in the mitred elbow. Higher velocities may be allowable for

elbows with a constant radius such as the example in figure 2 and 3.

(1) Hart, E. D., and Pugh, C. A. , "Outlet Works for Beltzville Dam, Pohopoco Creek, Pennsylvania," Technical Report H-75-10, U. S. Army Corps of Engineers, Waterways Experiment Station, May, 1975.

# Nomenclature

| | |
|---|---|
| $A$ | flow section area |
| $A_c$ | contracted area of flow |
| $A_o$ | orifice area |
| $a$ | area |
| $B$ | average width |
| $b_c$ | width |
| $C$ | Chezy factor, general coefficient, concentration of a tracer, or constant |
| $C_a$ | gate angle correction factor |
| $C_c$ | contraction coefficient |
| $C_d$ | discharge coefficient |
| $C_e$ | effective discharge coefficient |
| $C_v$ | velocity of approach coefficient |
| $C_{va}$ | coefficient to account for exclusion of approach velocity head |
| $C_{vf}$ | velocity coefficient caused by friction loss |
| $c$ | velocity of sound |
| $D$ | pipe diameter |
| $d_v$ | distance water will travel at a given velocity in a pipe of constant diameter |
| $E$ | specific energy |
| $E_{\%QCs}$ | error in percent comparison standard discharge |
| $E_{\%QFS}$ | error in percent full-scale discharge |
| $e$ | a subscript denoting "effective" |
| $egl$ | energy grade line |
| $F$ | Froude number |

| | |
|---|---|
| $F_b$ | canal freeboard |
| $F_c$ | critical Froude number |
| $F_p$ | pressure force |
| $f$ | friction factor |
| $G_o$ | gate opening |
| $g$ | acceleration caused by gravity |
| $H$ | total energy head |
| $H_c$ | critical total energy head |
| $h$ | head or height |
| $h_a$ | measuring head |
| $h_b$ | submergence head |
| $h_b/h_a$ | submergence ratio |
| $h_c$ | critical head |
| $h_{cm}$ | critical hydraulic mean depth |
| $h_e$ | effective measurement head |
| $h_f$ | head loss |
| $h_m$ | hydraulic mean depth |
| $h_v$ | measured velocity head |
| $h_{1e}$ | $h_1 + k_h$ |
| $h_1$ | head measure above a weir crest (upstream head) |
| $\Delta h$ | upstream head minus downstream head (differential head) |
| $h_{f(1\text{-}2)}$ | friction head loss between two stations |
| $hgl$ | hydraulic grade line |
| $K$ | constant |

| | |
|---|---|
| $k$ | boundary roughness size |
| $k_b$ | correction factor to obtain effective weir length |
| $k_h$ | correction factor to obtain effective head |
| $L$ | length |
| $L_b$ | cross-sectional width |
| $L_e$ | $L + k_b$ or effective crest length |
| $N$ | sample number |
| $n$ | friction or roughness factor |
| $PH$ | pinion height |
| $P_w$ | wetted perimeter |
| $p$ | pressure or height of crest above approach invert |
| $Q$ | discharge |
| $Q_a$ | actual discharge |
| $Q_c$ | critical discharge |
| $Q_{cs}$ | comparison standard discharge |
| $Q_s$ | suppressed orifice discharge |
| $Q_{eq}$ | discharge computed using measured heads and the regression equation |
| $Q_{FS}$ | full scale or maximum discharge |
| $Q_{ind}$ | indicated discharge from device output |
| $Q_{max}$ | maximum discharge |
| $Q_{min}$ | minimum discharge |
| $Q_t$ | theoretical discharge through an orifice |
| $\Delta Q\%$ | percent deviation of discharge |
| $q$ | unit or partial discharge |

| | |
|---|---|
| $Re$ | Reynolds number |
| $R_h$ | hydraulic radius |
| $r$ | ratio of suppressed portion of the perimeter of an orifice to total perimeter |
| $r$ | radius of curvature |
| $S$ | slope or estimate of standard deviation |
| $S_o$ | invert or bottom slope |
| $S_{ws}$ | water surface slope |
| $s$ | estimate of standard deviation |
| $T$ | time |
| $T$ | top water surface width |
| $T_c$ | top water surface width at critical conditions |
| $t$ | time |
| $t_d$ | downstream travel time of the acoustic signal |
| $t_u$ | upstream travel time of the acoustic signal |
| $\Delta t$ | difference in times |
| $U$ | equation coefficient or exponent |
| $V$ | mean velocity |
| $V_c$ | critical velocity |
| $V_{axial}$ | average axial velocity of water flow |
| $V_0$ | volume |
| $W$ | weight |
| $X_{avg}$ | mean of a set of values |
| $X_{ind}$ | each individual value from a set of values |
| $Z$ | potential energy head |

| | |
|---|---|
| $\beta$ | ratio of orifice hole diameter to pipe diameter |
| $\gamma$ | unit weight of water |
| $\theta$ | angle |
| $\nu$ | kinematic viscosity |
| $\sigma$ | standard deviation |

# Conversion Factors

| Length | | |
|---|---|---|
| Multiply | By | To obtain |
| Miles | 1.60935 | Kilometers |
| | 1,760 | Yards |
| | 5,280 | Feet |
| | 63,360 | Inches |
| Meters | 0.00062137 | Miles |
| | 1.0936 | Yards |
| | 3.28088 | Feet |
| | 39.37 | Inches |
| | 100 | Centimeters |
| | 0.001 | Kilometers |
| Yards | 0.9144 | Meters |
| | 0.00056818 | Miles |
| | 3.0 | Feet |
| | 36 | Inches |
| Feet | 0.3048 | Meters |
| | 0.00018939 | Miles |
| | 0.33333 | Yards |
| | 12 | Inches |
| Inches | 0.08333 | Feet |
| | 0.027778 | Yards |
| | 0.000015783 | Miles |
| | 2.54 | Centimeters |
| **Area** | | |
| Square miles | 4,014,489,600 | Square inches |
| | 27,878,400 | Square feet |
| | 3,097,600 | Square yards |
| | 640 | Acres |
| | 259 | Hectares |
| Acres | 208.71 | Square feet |
| | 0.404687 | Hectares |
| | 0.0015625 | Square miles |
| | 4,840 | Square yards |
| | 43,560 | Square feet |
| | 4,047 | Square meters |
| Square yards | 0.83613 | |
| | 0.0000003228 | Square miles |
| | 0.0002066 | Acres |
| | 9 | Square feet |
| | 1,296 | Square inches |
| Square feet | 0.092903 | Square meters |
| | 0.000000003587 | Square miles |
| | 0.000022957 | Acres |
| | 0.11111 | Square yards |
| | 144 | Square inches |
| Square inches | 0.0000000002491 | Square miles |
| | 6.45163 | Square centimeters |
| | 0.0000001594 | Acres |
| | 0.0007716 | Square yards |
| | 0.006944 | Square feet |
| **Volume** | | |
| Acre-feet | 325,851 | U.S. gallons |
| | 43,560 | Cubic feet |
| | 1,613.3 | Cubic yards |
| | 1,233.49 | Cubic meters |
| Cubic yards | 27 | Cubic feet |
| | 46,656 | Cubic inches |
| | 0.00061983 | Acre-feet |
| | 0.76456 | Cubic meters |
| Cubic feet | 1,728 | Cubic inches |
| | 7.4805 | U.S. gallons |
| | 28.317 | Liters |
| | 0.037037 | Cubic yards |
| | 0.000022957 | Acre-feet |

# Conversion Factors (continued)

| Multiply | By | To obtain |
|---|---|---|
| **Volume** (continued) | | |
| U.S. gallons | 231 | Cubic inches |
| | 3.78543 | Liters |
| | 0.13368 | Cubic feet |
| | 0.00000307 | Acre-feet |
| Cubic inches | 16.3872 | Cubic centimeters |
| | 0.004329 | U.S. gallons |
| | 0.0005787 | Cubic feet |
| **Discharge** | | |
| Cubic feet per second[a] | 448.8 | U.S. gallons per minute |
| | 60 | Cubic feet per minute |
| | 3,600 | Cubic feet per hour |
| | 86,400 | Cubic feet per day |
| | 723.9669 | Acre-feet per year |
| | 1.9835 | Acre-feet per day |
| | 0.9917 | Acre-inches per hour |
| | 50 | Miner's inch in Idaho, Kansas, Nebraska, South Dakota, North Dakota, New Mexico, Utah, Washington, southern California |
| | 40 | (customary) |
| | 38.4 | Miner's inch in Arizona, Montana, Oregon, Nevada, and California (statutory) |
| | 0.028317 | Miner's inch in Colorado |
| | 1.699 | Cubic meters per second |
| | 101.941 | Cubic meters per minute |
| | 2,446.58 | Cubic meters per hour |
| | 28.317 | Cubic meters per day |
| Million gallons per day | 1.547 | Liters per second |
| | 3.07 | Cubic feet per second[a] |
| | 2.629 | Acre-feet per day |
| Gallons per minute | 0.06309 | Cubic meters per minute |
| | 3.7854 | Liters per second |
| | | Liters per minute |
| **Velocity** | | |
| Feet per second | 0.68 | Miles per hour |
| | 1.097 | Kilometers per hour |
| | 30.48 | Centimeters per second |
| Inches per hour | 2.540 | Centimeters per hour |
| Feet per year | 0.3048 | Meters per year |
| **Acceleration** | | |
| Feet per second per second | 0.3048 | Meters per second per second |
| **Weight, Mass** | | |
| Pounds, avoirdupois | 0.4536 | Kilograms |
| | 16 | Ounces |
| | 7,000 | Grains |
| | 1.21528 | Pounds, troy |
| Kilograms | 1,000 | Grams |
| | 15,432 | Grains |
| | 2.2046 | Pounds, avoirdupois |
| Tons (2,000 pounds) | 907.185 | Kilograms |

# Conversion Factors (continued)

| Multiply | By | To obtain |
|---|---|---|
| **Density** | | |
| Pounds per cubic foot | 16.0185 | Kilograms per cubic meter |
| | 0.0160185 | Grams per cubic centimeter |
| **Pressure** | | |
| Atmosphere, at sea level | 76.0 | Centimeters of mercury |
| | 29.92 | Inches of mercury |
| | 33.90 | Feet of water |
| | 14.70 | Pounds per square inch |
| Pounds per square inch | 0.070307 | Kilograms per square centimeter |
| | 2.308 | Feet of water |
| Pounds per square foot | 4.88243 | Kilograms per square meter |
| Feet of water column (at 20 $^{0}$C) | 2.246 | Centimeters of mercury column |
| | 0.03041 | Kilograms per square centimeter |
| | 0.4333 | Pounds per square inch |
| **Angular Distance** | | |
| Degrees | 60 | Minutes |
| | 3,600 | Seconds |
| | 0.01745 | Radians |
| **Power** | | |
| Horsepower | 33,000 | Foot-pounds per minute |
| | 550 | Foot-pounds per second |
| | 745.7 | Watts |
| | 0.7457 | Kilowatts |
| | 1.014 | Horsepower (metric) |
| Horsepower (metric) | 75 | Kilogram-meters per second |
| **Work** | | |
| British thermal units | 778 | Foot-pounds |
| | 1055 | Joules |
| **Seepage** | | |
| Cubic feet per square foot per day | 304.8 | Liters per square meter per day |
| **Viscosity** | | |
| Dynamic viscosity (pound second per square foot) | 4.8824 | Kilogram second per square meter |
| Kinematic viscosity (square feet per second) | 0.092903 | Square meters per second |
| **Surface Tension** | | |
| Pounds per foot | 1.4882 | Kilograms per meter |
| **Gas Constant** | | |
| Feet per degree F | 0.5486 | Meters per degree Celsius |

NOTES:

1 $ft^3/s$ falling 8.81 feet = 1 horsepower.
1 $ft^3/s$ falling 10.0 feet = 1.135 horsepower.
1 $ft^3/s$ falling 11.0 feet = 1 horsepower at 80-percent efficiency.
1 $ft^3/s$ flowing for 1 year will cover 1 square mile to a depth of 1.131 feet, or 13.572 inches.
1 inch depth of water on 1 square mile = 2,323,200 cubic feet = 0.0737 $ft^3/s$ for 1 year.

[a]The cubic foot per second is also commonly referred to as the second-foot.

# Appendix
# Water Measurement Manual

Appendix tables are numbered by chapter, beginning with the next number in sequence following the tables contained in the main body of each chapter. The following tables are located in the main body of the chapters: 7-1, 8-1, 8-2, 8-3, 8-4, 8-5, 8-6, and 9-1. Appendix tables for chapters 7, 8, and 9 begin with tables A7-2, A8-7, and A9-2, respectively.

## Sharp-Crest Weirs

A7-2. Discharge of standard contracted rectangular weirs in ft3/sec.
A7-3. Discharge of standard suppressed rectangular weirs in ft3/sec.
A7-4. Discharge of 90° V-notch weirs, in ft3/sec.
A7-5. Discharge of standard Cipolletti weirs in ft3/sec. Shaded entries determined experimentally.

## Parshall Flumes

A8-7. Free-flow discharge through 1-inch Parshall measuring flume in ft3/sec.
A8-8. Free-flow discharge through 2-inch Parshall measuring flume in ft3/sec.
A8-9. Free-flow discharge through 3-inch Parshall measuring flume in ft3/sec.
A8-10. Free-flow discharge through 6-inch Parshall measuring flume in ft3/sec.
A8-11. Free-flow discharge through 9-inch Parshall measuring flume in ft3/sec.
A8-12. Free-flow discharges in ft3/sec through 1- to 8-foot Parshall flumes.
A8-13. Free-flow discharge through 10-ft Parshall measuring flume in ft3/sec.
A8-14. Free-flow discharge through 12-ft Parshall measuring flume in ft3/sec.
A8-15. Free-flow discharge through 15-ft Parshall measuring flume in ft3/sec.
A8-16. Free-flow discharge through 20-ft Parshall measuring flume in ft3/sec.
A8-17. Free-flow discharge through 25-ft Parshall measuring flume in ft3/sec.
A8-18. Free-flow discharge through 30-ft Parshall measuring flume in ft3/sec.
A8-19. Free-flow discharge through 40-ft Parshall measuring flume in ft3/sec.
A8-20. Free-flow discharge through 50-ft Parshall measuring flume in ft3/sec.

## Submerged Orifice Flow Meters

A9-2. Discharge of fully contracted standard submerged rectangular orifice in ft3/sec.
A9-3. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec.
A9-4. Discharge of constant-head orifice (CHO) turnout in ft3/sec.
A9-5. Discharge of constant-head orifice (CHO) turnout in ft3/sec.
A9-6. Discharges for standard sized constant-head orifice (CHO) turnouts.

**Table A7-2**. Discharge of standard contracted rectangular weirs in $ft^3$/sec. Shaded entries determined experimentally. All others computed from the formula $Q = 3.33(L - 0.2h_1)h_1^{1.5}$.

| Head, $h_1$ | Weir Length, $L$, ft | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ft | 0.5 | 1.0 | 1.5 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| 0.18 | 0.122 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| .19 | .132 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| .20 | .142 | 0.286 | 0.435 | 0.584 | 0.882 | 1.18 | 1.48 | 1.78 | 2.07 |
| .21 | .152 | .307 | .467 | .627 | .948 | 1.27 | 1.59 | 1.91 | 2.23 |
| .22 | .162 | .329 | .500 | .672 | 1.02 | 1.36 | 1.70 | 2.05 | 2.39 |
| .23 | .173 | .350 | .534 | .718 | 1.09 | 1.45 | 1.82 | 2.19 | 2.55 |
| .24 | .184 | .373 | .568 | .764 | 1.16 | 1.55 | 1.94 | 2.33 | 2.72 |
| .25 | .195 | .395 | .604 | .812 | 1.23 | 1.64 | 2.06 | 2.48 | 2.89 |
| .26 | ----- | .419 | .639 | .860 | 1.30 | 1.74 | 2.18 | 2.63 | 3.07 |
| .27 | ----- | .442 | .676 | .909 | 1.38 | 1.84 | 2.31 | 2.78 | 3.25 |
| .28 | ----- | .466 | .712 | .959 | 1.45 | 1.95 | 2.44 | 2.93 | 3.43 |
| .29 | ----- | .490 | .750 | 1.01 | 1.53 | 2.05 | 2.57 | 3.09 | 3.61 |
| .30 | ----- | .514 | .788 | 1.06 | 1.61 | 2.16 | 2.70 | 3.25 | 3.80 |
| .31 | ----- | .539 | .827 | 1.11 | 1.69 | 2.26 | 2.84 | 3.41 | 3.99 |
| .32 | ----- | .564 | .866 | 1.17 | 1.77 | 2.37 | 2.98 | 3.58 | 4.18 |
| .33 | ----- | .590 | .905 | 1.22 | 1.85 | 2.48 | 3.11 | 3.75 | 4.38 |
| .34 | ----- | .615 | .945 | 1.28 | 1.94 | 2.60 | 3.26 | 3.92 | 4.58 |
| .35 | ----- | .658 | .986 | 1.33 | 2.02 | 2.71 | 3.40 | 4.09 | 4.78 |
| .36 | ----- | .686 | 1.03 | 1.39 | 2.11 | 2.83 | 3.54 | 4.26 | 4.98 |
| .37 | ----- | .714 | 1.07 | 1.44 | 2.19 | 2.94 | 3.69 | 4.44 | 5.19 |
| .38 | ----- | .743 | 1.11 | 1.50 | 2.28 | 3.06 | 3.84 | 4.62 | 5.40 |
| .39 | ----- | .772 | 1.15 | 1.56 | 2.37 | 3.18 | 3.99 | 4.80 | 5.61 |
| .40 | ----- | .801 | 1.20 | 1.62 | 2.46 | 3.30 | 4.14 | 4.99 | 5.83 |
| .41 | ----- | .830 | 1.24 | 1.68 | 2.55 | 3.43 | 4.30 | 5.17 | 6.05 |
| .42 | ----- | .860 | 1.28 | 1.74 | 2.64 | 3.55 | 4.46 | 5.36 | 6.27 |
| .43 | ----- | .890 | 1.33 | 1.80 | 2.74 | 3.68 | 4.61 | 5.55 | 6.49 |
| .44 | ----- | .920 | 1.37 | 1.86 | 2.83 | 3.80 | 4.77 | 5.75 | 6.72 |
| .45 | ----- | .950 | 1.42 | 1.92 | 2.93 | 3.93 | 4.94 | 5.94 | 6.95 |
| .46 | ----- | .981 | 1.46 | 1.98 | 3.02 | 4.06 | 5.10 | 6.14 | 7.18 |
| .47 | ----- | 1.01 | 1.51 | 2.05 | 3.12 | 4.19 | 5.26 | 6.34 | 7.41 |
| .48 | ----- | 1.04 | 1.55 | 2.11 | 3.22 | 4.32 | 5.43 | 6.54 | 7.65 |
| .49 | ----- | 1.08 | 1.60 | 2.17 | 3.31 | 4.46 | 5.60 | 6.74 | 7.88 |
| .50 | ----- | 1.11 | 1.65 | 2.24 | 3.41 | 4.59 | 5.77 | 6.95 | 8.12 |
| .51 | ----- | ----- | ----- | 2.30 | 3.51 | 4.73 | 5.94 | 7.15 | 8.37 |
| .52 | ----- | ----- | ----- | 2.37 | 3.62 | 4.86 | 6.11 | 7.36 | 8.61 |
| .53 | ----- | ----- | ----- | 2.43 | 3.72 | 5.00 | 6.29 | 7.57 | 8.86 |
| .54 | ----- | ----- | ----- | 2.50 | 3.82 | 5.14 | 6.46 | 7.79 | 9.11 |
| .55 | ----- | ----- | ----- | 2.57 | 3.93 | 5.28 | 6.64 | 8.00 | 9.36 |
| .56 | ----- | ----- | ----- | 2.63 | 4.03 | 5.43 | 6.82 | 8.22 | 9.61 |
| .57 | ----- | ----- | ----- | 2.70 | 4.14 | 5.57 | 7.00 | 8.43 | 9.87 |
| .58 | ----- | ----- | ----- | 2.77 | 4.24 | 5.71 | 7.18 | 8.65 | 10.1 |
| .59 | ----- | ----- | ----- | 2.84 | 4.35 | 5.86 | 7.37 | 8.88 | 10.4 |
| .60 | ----- | ----- | ----- | 2.91 | 4.46 | 6.00 | 7.55 | 9.10 | 10.6 |

**Table A7-2 [continued]**. Discharge of standard contracted rectangular weirs in $ft^3$/sec. Shaded entries determined experimentally. All others computed from the formula $Q = 3.33(L - 0.2h_1)h_1^{1.5}$

| Head, $h_1$ ft | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
|---|---|---|---|---|---|---|
| 0.61 | 2.98 | 4.57 | 6.15 | 7.74 | 9.33 | 10.9 |
| .62 | 3.05 | 4.68 | 6.30 | 7.93 | 9.55 | 11.2 |
| .63 | 3.12 | 4.79 | 6.45 | 8.12 | 9.78 | 11.4 |
| .64 | 3.19 | 4.90 | 6.60 | 8.31 | 10.0 | 11.7 |
| .65 | 3.26 | 5.01 | 6.75 | 8.50 | 10.2 | 12.0 |
| .66 | 3.34 | 5.12 | 6.91 | 8.69 | 10.5 | 12.3 |
| .67 | 3.41 | 5.23 | 7.06 | 8.89 | 10.7 | 12.5 |
| .68 | 3.58 | 5.35 | 7.22 | 9.08 | 10.9 | 12.8 |
| .69 | 3.66 | 5.46 | 7.37 | 9.28 | 11.2 | 13.1 |
| .70 | 3.74 | 5.58 | 7.53 | 9.48 | 11.4 | 13.4 |
| .71 | 3.82 | 5.69 | 7.69 | 9.68 | 11.7 | 13.7 |
| .72 | 3.90 | 5.81 | 7.84 | 9.88 | 11.9 | 13.9 |
| .73 | 3.98 | 5.93 | 8.00 | 10.1 | 12.2 | 14.2 |
| .74 | 4.06 | 6.05 | 8.17 | 10.3 | 12.4 | 14.5 |
| .75 | 4.14 | 6.16 | 8.33 | 10.5 | 12.7 | 14.8 |
| .76 | 4.22 | 6.28 | 8.49 | 10.7 | 12.9 | 15.1 |
| .77 | 4.30 | 6.40 | 8.65 | 10.9 | 13.2 | 15.4 |
| .78 | 4.38 | 6.52 | 8.82 | 11.1 | 13.4 | 15.7 |
| .79 | 4.46 | 6.65 | 8.98 | 11.3 | 13.7 | 16.0 |
| .80 | 4.54 | 6.77 | 9.15 | 11.5 | 13.9 | 16.3 |
| .81 | 4.62 | 6.89 | 9.32 | 11.7 | 14.2 | 16.6 |
| .82 | 4.70 | 7.01 | 9.49 | 12.0 | 14.4 | 16.9 |
| .83 | 4.78 | 7.14 | 9.65 | 12.2 | 14.7 | 17.2 |
| .84 | 4.87 | 7.26 | 9.82 | 12.4 | 15.0 | 17.5 |
| .85 | 4.96 | 7.39 | 9.99 | 12.6 | 15.2 | 17.8 |
| .86 | 5.05 | 7.51 | 10.2 | 12.8 | 15.5 | 18.1 |
| .87 | 5.14 | 7.64 | 10.3 | 13.0 | 15.7 | 18.4 |
| .88 | 5.23 | 7.76 | 10.5 | 13.3 | 16.0 | 18.8 |
| .89 | 5.32 | 7.89 | 10.7 | 13.5 | 16.3 | 19.1 |
| .90 | 5.41 | 8.02 | 10.9 | 13.7 | 16.5 | 19.4 |
| .91 | 5.50 | 8.15 | 11.0 | 13.9 | 16.8 | 19.7 |
| .92 | 5.59 | 8.27 | 11.2 | 14.2 | 17.1 | 20.0 |
| .93 | 5.68 | 8.40 | 11.4 | 14.4 | 17.4 | 20.4 |
| .94 | 5.77 | 8.53 | 11.6 | 14.6 | 17.6 | 20.7 |
| .95 | 5.86 | 8.66 | 11.7 | 14.8 | 17.9 | 21.0 |
| .96 | 5.95 | 8.80 | 11.9 | 15.1 | 18.2 | 21.3 |
| .97 | 6.04 | 8.93 | 12.1 | 15.3 | 18.5 | 21.7 |
| .98 | 6.13 | 9.06 | 12.3 | 15.5 | 18.8 | 22.0 |
| .99 | 6.22 | 9.19 | 12.5 | 15.8 | 19.0 | 22.3 |
| 1.00 | 6.31 | 9.32 | 12.7 | 16.0 | 19.3 | 22.6 |
| 1.01 | ----- | ----- | 12.8 | 16.2 | 19.6 | 23.0 |
| 1.02 | ----- | ----- | 13.0 | 16.5 | 19.9 | 23.3 |
| 1.03 | ----- | ----- | 13.2 | 16.7 | 20.2 | 23.6 |
| 1.04 | ----- | ----- | 13.4 | 16.9 | 20.5 | 24.0 |
| 1.05 | ----- | ----- | 13.6 | 17.2 | 20.7 | 24.3 |

**Table A7-2 [continued]**. Discharge of standard contracted rectangular weirs in $ft^3$/sec. Shaded entries determined experimentally. All others computed from the formula $Q = 3.33(L - 0.2h_1)h_1^{1.5}$

| Head, $h_1$ ft | Weir Length, $L$, ft 4.0 | 5.0 | 6.0 | 7.0 |
|---|---|---|---|---|
| 1.06 | 13.8 | 17.4 | 21.0 | 24.7 |
| 1.07 | 14.0 | 17.6 | 21.3 | 25.0 |
| 1.08 | 14.1 | 17.9 | 21.6 | 25.4 |
| 1.09 | 14.3 | 18.1 | 21.9 | 25.7 |
| 1.10 | 14.5 | 18.4 | 22.2 | 26.0 |
| 1.11 | 14.7 | 18.6 | 22.5 | 26.4 |
| 1.12 | 14.9 | 18.9 | 22.8 | 26.7 |
| 1.13 | 15.1 | 19.1 | 23.1 | 27.1 |
| 1.14 | 15.3 | 19.3 | 23.4 | 27.4 |
| 1.15 | 15.5 | 19.6 | 23.7 | 27.8 |
| 1.16 | 15.7 | 19.8 | 24.0 | 28.2 |
| 1.17 | 15.9 | 20.1 | 24.3 | 28.5 |
| 1.18 | 16.1 | 20.3 | 24.6 | 28.9 |
| 1.19 | 16.3 | 20.6 | 24.9 | 29.2 |
| 1.20 | 16.5 | 20.8 | 25.2 | 29.6 |
| 1.21 | 16.7 | 21.1 | 25.5 | 30.0 |
| 1.22 | 16.9 | 21.3 | 25.8 | 30.3 |
| 1.23 | 17.1 | 21.6 | 26.1 | 30.7 |
| 1.24 | 17.3 | 21.9 | 26.4 | 31.0 |
| 1.25 | 17.5 | 22.1 | 26.8 | 31.4 |
| 1.26 | 17.7 | 22.4 | 27.1 | 31.8 |
| 1.27 | 17.9 | 22.6 | 27.4 | 32.2 |
| 1.28 | 18.1 | 22.9 | 27.7 | 32.5 |
| 1.29 | 18.3 | 23.1 | 28.0 | 32.9 |
| 1.30 | 18.5 | 23.4 | 28.3 | 33.3 |
| 1.31 | 18.7 | 23.7 | 28.6 | 33.6 |
| 1.32 | 18.9 | 23.9 | 29.0 | 34.0 |
| 1.33 | 19.1 | 24.2 | 29.3 | 34.4 |
| 1.34 | ----- | 24.4 | 29.6 | 34.8 |
| 1.35 | ----- | 24.7 | 29.9 | 35.2 |
| 1.36 | ----- | 25.0 | 30.3 | 35.5 |
| 1.37 | ----- | 25.2 | 30.6 | 35.9 |
| 1.38 | ----- | 25.5 | 30.9 | 36.3 |
| 1.39 | ----- | 25.8 | 31.2 | 36.7 |
| 1.40 | ----- | 26.0 | 31.6 | 37.1 |
| 1.41 | ----- | 26.3 | 31.9 | 37.5 |
| 1.42 | ----- | 26.6 | 32.2 | 37.8 |
| 1.43 | ----- | 26.8 | 32.5 | 38.2 |
| 1.44 | ----- | 27.1 | 32.9 | 38.6 |
| 1.45 | ----- | 27.4 | 33.2 | 39.0 |
| 1.46 | ----- | 27.7 | 33.5 | 39.4 |
| 1.47 | ----- | 27.9 | 33.9 | 39.8 |
| 1.48 | ----- | 28.2 | 34.2 | 40.2 |
| 1.49 | ----- | 28.5 | 34.5 | 40.6 |
| 1.50 | ----- | 28.8 | 34.9 | 41.0 |

| Head, $h_1$ ft | Weir Length, $L$, ft 5.0 | 6.0 | 7.0 |
|---|---|---|---|
| 1.51 | 29.0 | 35.2 | 41.4 |
| 1.52 | 29.3 | 35.5 | 41.8 |
| 1.53 | 29.6 | 35.9 | 42.2 |
| 1.54 | 29.9 | 36.2 | 42.6 |
| 1.55 | 30.1 | 36.6 | 43.0 |
| 1.56 | 30.4 | 36.9 | 43.4 |
| 1.57 | 30.7 | 37.2 | 43.8 |
| 1.58 | 31.0 | 37.6 | 44.2 |
| 1.59 | 31.3 | 37.9 | 44.6 |
| 1.60 | 31.5 | 38.3 | 45.0 |
| 1.61 | 31.8 | 38.6 | 45.4 |
| 1.62 | 32.1 | 39.0 | 45.8 |
| 1.63 | 32.4 | 39.3 | 46.3 |
| 1.64 | 32.7 | 39.7 | 46.7 |
| 1.65 | 33.0 | 40.0 | 47.1 |
| 1.66 | 33.2 | 40.4 | 47.5 |
| 1.67 | 33.5 | 40.7 | 47.9 |
| 1.68 | ----- | 41.1 | 48.3 |
| 1.69 | ----- | 41.4 | 48.7 |
| 1.70 | ----- | 41.8 | 49.2 |
| 1.71 | ----- | 42.1 | 49.6 |
| 1.72 | ----- | 42.5 | 50.0 |
| 1.73 | ----- | 42.8 | 50.4 |
| 1.74 | ----- | 43.2 | 50.8 |
| 1.75 | ----- | 43.6 | 51.3 |
| 1.76 | ----- | 43.9 | 51.7 |
| 1.77 | ----- | 44.3 | 52.1 |
| 1.78 | ----- | 44.6 | 52.5 |
| 1.79 | ----- | 45.0 | 53.0 |
| 1.80 | ----- | 45.4 | 53.4 |
| 1.81 | ----- | 45.7 | 53.8 |
| 1.82 | ----- | 46.1 | 54.3 |
| 1.83 | ----- | 46.4 | 54.7 |
| 1.84 | ----- | 46.8 | 55.1 |
| 1.85 | ----- | 47.2 | 55.6 |
| 1.86 | ----- | 47.5 | 56.0 |
| 1.87 | ----- | 47.9 | 56.4 |
| 1.88 | ----- | 48.3 | 56.9 |
| 1.89 | ----- | 48.6 | 57.3 |
| 1.90 | ----- | 49.0 | 57.7 |
| 1.91 | ----- | 49.4 | 58.2 |
| 1.92 | ----- | 49.8 | 58.6 |
| 1.93 | ----- | 50.1 | 59.1 |
| 1.94 | ----- | 50.5 | 59.5 |
| 1.95 | ----- | 50.9 | 59.9 |

**Table A7-2 [continued]**. Discharge of standard contracted rectangular weirs in $ft^3$/sec. Shaded entries determined experimentally. All others computed from the formula $Q = 3.33(L - 0.2h_1)h_1^{1.5}$

| Head, $h_1$ ft | 6.0 | 7.0 |
|---|---|---|
| 1.96 | 51.2 | 60.4 |
| 1.97 | 51.6 | 60.8 |
| 1.98 | 52.0 | 61.3 |
| 1.99 | 52.4 | 61.7 |
| 2.00 | 52.7 | 62.2 |
| 2.01 | ----- | 62.6 |
| 2.02 | ----- | 63.1 |
| 2.03 | ----- | 63.5 |
| 2.04 | ----- | 64.0 |
| 2.05 | ----- | 64.4 |
| 2.06 | ----- | 64.9 |
| 2.07 | ----- | 65.3 |
| 2.08 | ----- | 65.8 |
| 2.09 | ----- | 66.2 |
| 2.10 | ----- | 66.7 |
| 2.11 | ----- | 67.1 |
| 2.12 | ----- | 67.6 |
| 2.13 | ----- | 68.1 |
| 2.14 | ----- | 68.5 |
| 2.15 | ----- | 69.0 |
| 2.16 | ----- | 69.4 |
| 2.17 | ----- | 69.9 |
| 2.18 | ----- | 70.4 |
| 2.19 | ----- | 70.8 |
| 2.20 | ----- | 71.3 |
| 2.21 | ----- | 71.7 |
| 2.22 | ----- | 72.2 |
| 2.23 | ----- | 72.7 |
| 2.24 | ----- | 73.1 |
| 2.25 | ----- | 73.6 |
| 2.26 | ----- | 74.1 |
| 2.27 | ----- | 74.6 |
| 2.28 | ----- | 75.0 |
| 2.29 | ----- | 75.5 |
| 2.30 | ----- | 76.0 |
| 2.31 | ----- | 76.4 |
| 2.32 | ----- | 76.9 |
| 2.33 | ----- | 77.4 |

**Table A7-2 [continued]**. Discharge of standard contracted rectangular weirs in $ft^3$/sec. Shaded entries determined experimentally. All others computed from the formula $Q = 3.33(L - 0.2h_1)h_1^{1.5}$

| Head, $h_1$ | Weir Length, $L$, ft | | | | | | |
|---|---|---|---|---|---|---|---|
| ft | 8.0 | 9.0 | 10.0 | 12.0 | 15.0 | 18.0 | 20.0 |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 0.20 | 2.37 | 2.67 | 2.97 | 3.56 | 4.46 | 5.35 | 5.94 |
| .30 | 4.34 | 4.89 | 5.44 | 6.53 | 8.17 | 9.82 | 10.91 |
| .40 | 6.67 | 7.51 | 8.36 | 10.0 | 12.6 | 15.1 | 16.8 |
| .50 | 9.30 | 10.5 | 11.7 | 14.0 | 17.5 | 21.1 | 23.4 |
| .60 | 12.2 | 13.7 | 15.3 | 18.4 | 23.0 | 27.7 | 30.8 |
| .70 | 15.3 | 17.3 | 19.2 | 23.1 | 29.0 | 34.8 | 38.7 |
| .80 | 18.7 | 21.1 | 23.4 | 28.2 | 35.4 | 42.5 | 47.3 |
| .90 | 22.2 | 25.1 | 27.9 | 33.6 | 42.1 | 50.7 | 56.4 |
| 1.00 | 26.0 | 29.3 | 32.6 | 39.3 | 49.3 | 59.3 | 65.9 |
| 1.10 | 29.9 | 33.7 | 37.6 | 45.3 | 56.8 | 68.3 | 76.0 |
| 1.20 | 34.0 | 38.3 | 42.7 | 51.5 | 64.6 | 77.7 | 86.5 |
| 1.30 | 38.2 | 43.1 | 48.1 | 57.9 | 72.8 | 87.6 | 97.4 |
| 1.40 | 42.6 | 48.1 | 53.6 | 64.6 | 81.2 | 97.7 | 109. |
| 1.50 | 47.1 | 53.2 | 59.3 | 71.6 | 89.9 | 108. | 121. |
| 1.60 | 51.8 | 58.5 | 65.2 | 78.7 | 98.9 | 119. | 133. |
| 1.70 | 56.5 | 63.9 | 71.3 | 86.1 | 108. | 130. | 145. |
| 1.80 | 61.4 | 69.5 | 77.5 | 93.6 | 118. | 142. | 158. |
| 1.90 | 66.5 | 75.2 | 83.9 | 101. | 128. | 154. | 171. |
| 2.00 | 71.6 | 81.0 | 90.4 | 109. | 138. | 166. | 185. |
| 2.10 | 76.8 | 86.9 | 97.1 | 117. | 148. | 178. | 198. |
| 2.20 | 82.1 | 93.0 | 104. | 126. | 158. | 191. | 213. |
| 2.30 | 87.6 | 99.2 | 111. | 134. | 169. | 204. | 227. |
| 2.40 | 93.1 | 105. | 118. | 143. | 180. | 217. | 242. |
| 2.50 | 98.7 | 112. | 125. | 151. | 191. | 230. | 257. |
| 2.60 | 104. | 118. | 132. | 160. | 202. | 244. | 272. |
| 2.70 | 110. | 125. | 140. | 169. | 214. | 258. | 287. |
| 2.80 | ----- | 132. | 147. | 178. | 225. | 272. | 303. |
| 2.90 | ----- | 138. | 155. | 188. | 237. | 286. | 319. |
| 3.00 | ----- | 145. | 163. | 197. | 249. | 301. | 336. |
| 3.10 | ----- | ----- | 170. | 207. | 261. | 316. | 352. |
| 3.20 | ----- | ----- | 178. | 217. | 274. | 331. | 369. |
| 3.30 | ----- | ----- | 186. | 226. | 286. | 346. | 386. |
| 3.40 | ----- | ----- | ----- | 236. | 299. | 362. | 403. |
| 3.50 | ----- | ----- | ----- | 246. | 312. | 377. | 421. |
| 3.60 | ----- | ----- | ----- | 257. | 325. | 393. | 439. |
| 3.70 | ----- | ----- | ----- | 267. | 338. | 409. | 456. |
| 3.80 | ----- | ----- | ----- | 277. | 351. | 425. | 475. |
| 3.90 | ----- | ----- | ----- | 288. | 365. | 442. | 493. |
| 4.00 | ----- | ----- | ----- | 298. | 378. | 458. | 511. |
| 4.10 | ----- | ----- | ----- | ----- | 392. | 475. | 530. |
| 4.20 | ----- | ----- | ----- | ----- | 406. | 492. | 549. |
| 4.30 | ----- | ----- | ----- | ----- | 420. | 509. | 568. |
| 4.40 | ----- | ----- | ----- | ----- | 434. | 526. | 588. |
| 4.50 | ----- | ----- | ----- | ----- | 448. | 544. | 607. |

**Table A7-3**. Discharge of standard suppressed rectangular weirs in ft$^3$/sec. Computed from the formula $Q = 3.33Lh_1^{1.5}$

| Head $h_1$, ft | Weir Length, $L$, ft 1.0 | 1.5 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|
| 0.20 | 0.298 | 0.447 | 0.596 | 0.894 | 1.19 | 1.49 |
| .21 | .320 | .481 | .641 | .961 | 1.28 | 1.60 |
| .22 | .344 | .515 | .687 | 1.03 | 1.37 | 1.72 |
| .23 | .367 | .551 | .735 | 1.10 | 1.47 | 1.84 |
| .24 | .392 | .587 | .783 | 1.17 | 1.57 | 1.96 |
| .25 | .416 | .624 | .833 | 1.25 | 1.67 | 2.08 |
| .26 | .441 | .662 | .883 | 1.32 | 1.77 | 2.21 |
| .27 | .467 | .701 | .934 | 1.40 | 1.87 | 2.34 |
| .28 | .493 | .740 | .987 | 1.48 | 1.97 | 2.47 |
| .29 | .520 | .780 | 1.04 | 1.56 | 2.08 | 2.60 |
| .30 | .547 | .821 | 1.09 | 1.64 | 2.19 | 2.74 |
| .31 | .575 | .862 | 1.15 | 1.72 | 2.30 | 2.87 |
| .32 | .603 | .904 | 1.21 | 1.81 | 2.41 | 3.01 |
| .33 | .631 | .947 | 1.26 | 1.89 | 2.53 | 3.16 |
| .34 | ----- | .990 | 1.32 | 1.98 | 2.64 | 3.30 |
| .35 | ----- | 1.03 | 1.38 | 2.07 | 2.76 | 3.45 |
| .36 | ----- | 1.08 | 1.44 | 2.16 | 2.88 | 3.60 |
| .37 | ----- | 1.12 | 1.50 | 2.25 | 3.00 | 3.75 |
| .38 | ----- | 1.17 | 1.56 | 2.34 | 3.12 | 3.90 |
| .39 | ----- | 1.22 | 1.62 | 2.43 | 3.24 | 4.06 |
| .40 | ----- | 1.26 | 1.68 | 2.53 | 3.37 | 4.21 |
| .41 | ----- | 1.31 | 1.75 | 2.62 | 3.50 | 4.37 |
| .42 | ----- | 1.36 | 1.81 | 2.72 | 3.63 | 4.53 |
| .43 | ----- | 1.41 | 1.88 | 2.82 | 3.76 | 4.69 |
| .44 | ----- | 1.46 | 1.94 | 2.92 | 3.89 | 4.86 |
| .45 | ----- | 1.51 | 2.01 | 3.02 | 4.02 | 5.03 |
| .46 | ----- | 1.56 | 2.08 | 3.12 | 4.16 | 5.19 |
| .47 | ----- | 1.61 | 2.15 | 3.22 | 4.29 | 5.36 |
| .48 | ----- | 1.66 | 2.21 | 3.32 | 4.43 | 5.54 |
| .49 | ----- | 1.71 | 2.28 | 3.43 | 4.57 | 5.71 |
| .50 | ----- | 1.77 | 2.35 | 3.53 | 4.71 | 5.89 |
| .51 | ----- | ----- | 2.43 | 3.64 | 4.85 | 6.06 |
| .52 | ----- | ----- | 2.50 | 3.75 | 4.99 | 6.24 |
| .53 | ----- | ----- | 2.57 | 3.85 | 5.14 | 6.42 |
| .54 | ----- | ----- | 2.64 | 3.96 | 5.29 | 6.61 |
| .55 | ----- | ----- | 2.72 | 4.07 | 5.43 | 6.79 |
| .56 | ----- | ----- | 2.79 | 4.19 | 5.58 | 6.98 |
| .57 | ----- | ----- | 2.87 | 4.30 | 5.73 | 7.17 |
| .58 | ----- | ----- | 2.94 | 4.41 | 5.88 | 7.35 |
| .59 | ----- | ----- | 3.02 | 4.53 | 6.04 | 7.55 |
| .60 | ----- | ----- | 3.10 | 4.64 | 6.19 | 7.74 |
| .61 | ----- | ----- | 3.17 | 4.76 | 6.35 | 7.93 |
| .62 | ----- | ----- | 3.25 | 4.88 | 6.50 | 8.13 |
| .63 | ----- | ----- | 3.33 | 5.00 | 6.66 | 8.33 |
| .64 | ----- | ----- | 3.41 | 5.11 | 6.82 | 8.52 |

**Table A7-3 [continued]**. Discharge of standard suppressed rectangular weirs in ft$^3$/sec. Computed from the formula $Q = 3.33Lh_1^{1.5}$

| Head $h_1$, ft | Weir Length, $L$, ft 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|
| 0.65 | 3.49 | 5.24 | 6.98 | 8.73 |
| .66 | 3.57 | 5.36 | 7.14 | 8.93 |
| .67 | 3.65 | 5.48 | 7.30 | 9.13 |
| .68 | ----- | 5.60 | 7.47 | 9.34 |
| .69 | ----- | 5.73 | 7.63 | 9.54 |
| .70 | ----- | 5.85 | 7.80 | 9.75 |
| .71 | ----- | 5.98 | 7.97 | 9.96 |
| .72 | ----- | 6.10 | 8.14 | 10.2 |
| .73 | ----- | 6.23 | 8.31 | 10.4 |
| .74 | ----- | 6.36 | 8.48 | 10.6 |
| .75 | ----- | 6.49 | 8.65 | 10.8 |
| .76 | ----- | 6.62 | 8.83 | 11.0 |
| .77 | ----- | 6.75 | 9.00 | 11.2 |
| .78 | ----- | 6.88 | 9.18 | 11.5 |
| .79 | ----- | 7.01 | 9.35 | 11.7 |
| .80 | ----- | 7.15 | 9.53 | 11.9 |
| .81 | ----- | 7.28 | 9.71 | 12.1 |
| .82 | ----- | 7.42 | 9.89 | 12.4 |
| .83 | ----- | 7.55 | 10.1 | 12.6 |
| .84 | ----- | 7.69 | 10.3 | 12.8 |
| .85 | ----- | 7.83 | 10.4 | 13.0 |
| .86 | ----- | 7.97 | 10.6 | 13.3 |
| .87 | ----- | 8.11 | 10.8 | 13.5 |
| .88 | ----- | 8.25 | 11.0 | 13.7 |
| .89 | ----- | 8.39 | 11.2 | 14.0 |
| .90 | ----- | 8.53 | 11.4 | 14.2 |
| .91 | ----- | 8.67 | 11.6 | 14.5 |
| .92 | ----- | 8.82 | 11.8 | 14.7 |
| .93 | ----- | 8.96 | 11.9 | 14.9 |
| .94 | ----- | 9.10 | 12.1 | 15.2 |
| .95 | ----- | 9.25 | 12.3 | 15.4 |
| .96 | ----- | 9.40 | 12.5 | 15.7 |
| .97 | ----- | 9.54 | 12.7 | 15.9 |
| .98 | ----- | 9.69 | 12.9 | 16.2 |
| .99 | ----- | 9.84 | 13.1 | 16.4 |
| 1.00 | ----- | 9.99 | 13.3 | 16.7 |
| 1.01 | ----- | ----- | 13.5 | 16.9 |
| 1.02 | ----- | ----- | 13.7 | 17.2 |
| 1.03 | ----- | ----- | 13.9 | 17.4 |
| 1.04 | ----- | ----- | 14.1 | 17.7 |
| 1.05 | ----- | ----- | 14.3 | 17.9 |
| 1.06 | ----- | ----- | 14.5 | 18.2 |
| 1.07 | ----- | ----- | 14.7 | 18.4 |
| 1.08 | ----- | ----- | 14.9 | 18.7 |
| 1.09 | ----- | ----- | 15.2 | 18.9 |

| Head $h_1$, ft | Weir Length, $L$, ft 4.0 | 5.0 |
|---|---|---|
| 1.10 | 15.4 | 19.2 |
| 1.11 | 15.6 | 19.5 |
| 1.12 | 15.8 | 19.7 |
| 1.13 | 16.0 | 20.0 |
| 1.14 | 16.2 | 20.3 |
| 1.15 | 16.4 | 20.5 |
| 1.16 | 16.6 | 20.8 |
| 1.17 | 16.9 | 21.1 |
| 1.18 | 17.1 | 21.3 |
| 1.19 | 17.3 | 21.6 |
| 1.20 | 17.5 | 21.9 |
| 1.21 | 17.7 | 22.2 |
| 1.22 | 17.9 | 22.4 |
| 1.23 | 18.2 | 22.7 |
| 1.24 | 18.4 | 23.0 |
| 1.25 | 18.6 | 23.3 |
| 1.26 | 18.8 | 23.5 |
| 1.27 | 19.1 | 23.8 |
| 1.28 | 19.3 | 24.1 |
| 1.29 | 19.5 | 24.4 |
| 1.30 | 19.7 | 24.7 |
| 1.31 | 20.0 | 25.0 |
| 1.32 | 20.2 | 25.3 |
| 1.33 | 20.4 | 25.5 |
| 1.34 | ----- | 25.8 |
| 1.35 | ----- | 26.1 |
| 1.36 | ----- | 26.4 |
| 1.37 | ----- | 26.7 |
| 1.38 | ----- | 27.0 |
| 1.39 | ----- | 27.3 |
| 1.40 | ----- | 27.6 |
| 1.41 | ----- | 27.9 |
| 1.42 | ----- | 28.2 |
| 1.43 | ----- | 28.5 |
| 1.44 | ----- | 28.8 |
| 1.45 | ----- | 29.1 |
| 1.46 | ----- | 29.4 |
| 1.47 | ----- | 29.7 |
| 1.48 | ----- | 30.0 |
| 1.49 | ----- | 30.3 |
| 1.50 | ----- | 30.6 |
| 1.51 | ----- | 30.9 |
| 1.52 | ----- | 31.2 |
| 1.53 | ----- | 31.5 |
| 1.54 | ----- | 31.8 |

| Head $h_1$, ft | $L$ 5.0 |
|---|---|
| 1.55 | 32.1 |
| 1.56 | 32.4 |
| 1.57 | 32.8 |
| 1.58 | 33.1 |
| 1.59 | 33.4 |
| 1.60 | 33.7 |
| 1.61 | 34.0 |
| 1.62 | 34.3 |
| 1.63 | 34.6 |
| 1.64 | 35.0 |
| 1.65 | 35.3 |
| 1.66 | 35.6 |
| 1.67 | 35.9 |

**Table A7-4**. Discharge of 90° V-notch weirs, in ft$^3$/sec, computed from the formula $Q = 2.49h_1^{2.48}$.

| Head $H$, ft | Discharge $Q$, ft³/sec | Head $H$, ft | Discharge $Q$, ft³/sec | Head $H$, ft | Discharge $Q$, ft³/sec | Head $H$, ft | Discharge $Q$, ft³/sec |
|---|---|---|---|---|---|---|---|
| 0.20 | 0.046 | 0.65 | 0.856 | 1.10 | 3.15 | 1.55 | 7.38 |
| .21 | .052 | .66 | .889 | 1.11 | 3.23 | 1.56 | 7.50 |
| .22 | .058 | .67 | .922 | 1.12 | 3.30 | 1.57 | 7.62 |
| .23 | .065 | .68 | .957 | 1.13 | 3.37 | 1.58 | 7.74 |
| .24 | .072 | .69 | .992 | 1.14 | 3.45 | 1.59 | 7.86 |
| .25 | .080 | .70 | 1.03 | 1.15 | 3.52 | 1.60 | 7.99 |
| .26 | .088 | .71 | 1.06 | 1.16 | 3.60 | 1.61 | 8.11 |
| .27 | .097 | .72 | 1.10 | 1.17 | 3.68 | 1.62 | 8.24 |
| .28 | .106 | .73 | 1.14 | 1.18 | 3.75 | 1.63 | 8.36 |
| .29 | .116 | .74 | 1.18 | 1.19 | 3.83 | 1.64 | 8.49 |
| .30 | .126 | .75 | 1.22 | 1.20 | 3.91 | 1.65 | 8.62 |
| .31 | .136 | .76 | 1.26 | 1.21 | 3.99 | 1.66 | 8.75 |
| .32 | .148 | .77 | 1.30 | 1.22 | 4.08 | 1.67 | 8.88 |
| .33 | .159 | .78 | 1.34 | 1.23 | 4.16 | 1.68 | 9.02 |
| .34 | .172 | .79 | 1.39 | 1.24 | 4.25 | 1.69 | 9.15 |
| .35 | .184 | .80 | 1.43 | 1.25 | 4.33 | 1.70 | 9.28 |
| .36 | .198 | .81 | 1.48 | 1.26 | 4.42 | 1.71 | 9.42 |
| .37 | .212 | .82 | 1.52 | 1.27 | 4.50 | 1.72 | 9.56 |
| .38 | .226 | .83 | 1.57 | 1.28 | 4.59 | 1.73 | 9.70 |
| .39 | .241 | .84 | 1.62 | 1.29 | 4.68 | 1.74 | 9.83 |
| .40 | .257 | .85 | 1.66 | 1.30 | 4.77 | 1.75 | 9.98 |
| .41 | .273 | .86 | 1.71 | 1.31 | 4.86 | 1.76 | 10.1 |
| .42 | .290 | .87 | 1.76 | 1.32 | 4.96 | 1.77 | 10.3 |
| .43 | .307 | .88 | 1.81 | 1.33 | 5.05 | 1.78 | 10.4 |
| .44 | .325 | .89 | 1.87 | 1.34 | 5.15 | 1.79 | 10.6 |
| .45 | .344 | .90 | 1.92 | 1.35 | 5.24 | 1.80 | 10.7 |
| .46 | .363 | .91 | 1.97 | 1.36 | 5.34 | 1.81 | 10.8 |
| .47 | .383 | .92 | 2.02 | 1.37 | 5.44 | 1.82 | 11.0 |
| .48 | .403 | .93 | 2.08 | 1.38 | 5.53 | 1.83 | 11.1 |
| .49 | .425 | .94 | 2.14 | 1.39 | 5.63 | 1.84 | 11.3 |
| .50 | .446 | .95 | 2.19 | 1.40 | 5.74 | 1.85 | 11.4 |
| .51 | .469 | .96 | 2.25 | 1.41 | 5.84 | 1.86 | 11.6 |
| .52 | .492 | .97 | 2.31 | 1.42 | 5.94 | 1.87 | 11.8 |
| .53 | .516 | .98 | 2.37 | 1.43 | 6.05 | 1.88 | 11.9 |
| .54 | .540 | .99 | 2.43 | 1.44 | 6.15 | 1.89 | 12.1 |
| .55 | .565 | 1.00 | 2.49 | 1.45 | 6.26 | 1.90 | 12.2 |
| .56 | .591 | 1.01 | 2.55 | 1.46 | 6.36 | 1.91 | 12.4 |
| .57 | .618 | 1.02 | 2.62 | 1.47 | 6.47 | 1.92 | 12.6 |
| .58 | .645 | 1.03 | 2.68 | 1.48 | 6.58 | 1.93 | 12.7 |
| .59 | .673 | 1.04 | 2.74 | 1.49 | 6.69 | 1.94 | 12.9 |
| .60 | .701 | 1.05 | 2.81 | 1.50 | 6.81 | 1.95 | 13.0 |
| .61 | .731 | 1.06 | 2.88 | 1.51 | 6.92 | 1.96 | 13.2 |
| .62 | .761 | 1.07 | 2.94 | 1.52 | 7.03 | 1.97 | 13.4 |
| .63 | .792 | 1.08 | 3.01 | 1.53 | 7.15 | 1.98 | 13.5 |
| .64 | .823 | 1.09 | 3.08 | 1.54 | 7.27 | 1.99 | 13.7 |

**Table A7-5**. Discharge of standard Cipolletti weirs in ft³/sec. Shaded entries determined experimentally. Others computed from the formula $Q = 3.367 L h_1^{1.5}$

| Head $H$, ft | Weir Length, $L$, ft 0.5 | 1.0 | 1.5 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| .18 | .129 | ----- | ----- | ----- | ----- | ----- | ----- |
| .19 | .139 | ----- | ----- | ----- | ----- | ----- | ----- |
| .20 | .151 | .301 | .452 | .602 | .903 | 1.20 | 1.51 |
| .21 | .162 | .324 | .486 | .648 | .972 | 1.30 | 1.62 |
| .22 | .174 | .347 | .521 | .695 | 1.04 | 1.39 | 1.74 |
| .23 | .186 | .371 | .557 | .743 | 1.11 | 1.49 | 1.86 |
| .24 | .200 | .396 | .594 | .792 | 1.19 | 1.58 | 1.98 |
| .25 | .214 | .421 | .631 | .842 | 1.26 | 1.68 | 2.10 |
| .26 | ----- | .446 | .670 | .893 | 1.34 | 1.79 | 2.23 |
| .27 | ----- | .472 | .709 | .945 | 1.42 | 1.89 | 2.36 |
| .28 | ----- | .499 | .748 | .998 | 1.50 | 2.00 | 2.49 |
| .29 | ----- | .526 | .789 | 1.05 | 1.58 | 2.10 | 2.63 |
| .30 | ----- | .553 | .830 | 1.11 | 1.66 | 2.21 | 2.77 |
| .31 | ----- | .581 | .872 | 1.16 | 1.74 | 2.32 | 2.91 |
| .32 | ----- | .609 | .914 | 1.22 | 1.83 | 2.44 | 3.05 |
| .33 | ----- | .638 | .957 | 1.28 | 1.91 | 2.55 | 3.19 |
| .34 | ----- | .668 | 1.00 | 1.34 | 2.00 | 2.67 | 3.34 |
| .35 | ----- | .697 | 1.05 | 1.39 | 2.09 | 2.79 | 3.49 |
| .36 | ----- | .727 | 1.09 | 1.45 | 2.18 | 2.91 | 3.64 |
| .37 | ----- | .758 | 1.14 | 1.52 | 2.27 | 3.03 | 3.79 |
| .38 | ----- | .789 | 1.18 | 1.58 | 2.37 | 3.15 | 3.94 |
| .39 | ----- | .820 | 1.23 | 1.64 | 2.46 | 3.28 | 4.10 |
| .40 | ----- | .852 | 1.28 | 1.70 | 2.56 | 3.41 | 4.26 |
| .41 | ----- | .884 | 1.33 | 1.77 | 2.65 | 3.54 | 4.42 |
| .42 | ----- | .916 | 1.37 | 1.83 | 2.75 | 3.67 | 4.58 |
| .43 | ----- | .949 | 1.42 | 1.90 | 2.85 | 3.80 | 4.75 |
| .44 | ----- | .983 | 1.47 | 1.97 | 2.95 | 3.93 | 4.91 |
| .45 | ----- | 1.02 | 1.52 | 2.03 | 3.05 | 4.07 | 5.08 |
| .46 | ----- | 1.05 | 1.58 | 2.10 | 3.15 | 4.20 | 5.25 |
| .47 | ----- | 1.08 | 1.63 | 2.17 | 3.25 | 4.34 | 5.42 |
| .48 | ----- | 1.12 | 1.68 | 2.24 | 3.36 | 4.48 | 5.60 |
| .49 | ----- | 1.16 | 1.73 | 2.31 | 3.46 | 4.62 | 5.77 |
| .50 | ----- | 1.20 | 1.79 | 2.38 | 3.57 | 4.76 | 5.95 |
| .51 | ----- | ----- | ----- | 2.45 | 3.68 | 4.91 | 6.13 |
| .52 | ----- | ----- | ----- | 2.53 | 3.79 | 5.05 | 6.31 |
| .53 | ----- | ----- | ----- | 2.60 | 3.90 | 5.20 | 6.50 |
| .54 | ----- | ----- | ----- | 2.67 | 4.01 | 5.34 | 6.68 |
| .55 | ----- | ----- | ----- | 2.75 | 4.12 | 5.49 | 6.87 |
| .56 | ----- | ----- | ----- | 2.82 | 4.23 | 5.64 | 7.05 |
| .57 | ----- | ----- | ----- | 2.90 | 4.35 | 5.80 | 7.24 |
| .58 | ----- | ----- | ----- | 2.97 | 4.46 | 5.95 | 7.44 |
| .59 | ----- | ----- | ----- | 3.05 | 4.58 | 6.10 | 7.63 |
| .60 | ----- | ----- | ----- | 3.13 | 4.69 | 6.26 | 7.82 |

**Table A7-5 [continued]**. Discharge of standard Cipolletti weirs in $ft^3$/sec. Shaded entries determined experimentally. Others computed from the formula $Q = 3.367 L h_1^{1.5}$

| Head $H$, ft | Weir Length, $L$, ft 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|
| 0.61 | 3.21 | 4.81 | 6.42 | 8.02 |
| .62 | 3.29 | 4.93 | 6.57 | 8.22 |
| .63 | 3.37 | 5.05 | 6.73 | 8.42 |
| .64 | 3.45 | 5.17 | 6.90 | 8.62 |
| .65 | 3.53 | 5.29 | 7.06 | 8.82 |
| .66 | 3.61 | 5.42 | 7.22 | 9.03 |
| .67 | 3.69 | 5.54 | 7.39 | 9.23 |
| .68 | 3.81 | 5.66 | 7.55 | 9.44 |
| .69 | 3.90 | 5.79 | 7.72 | 9.65 |
| .70 | 3.98 | 5.92 | 7.89 | 9.86 |
| .71 | 4.06 | 6.04 | 8.06 | 10.1 |
| .72 | 4.15 | 6.17 | 8.23 | 10.3 |
| .73 | 4.24 | 6.30 | 8.40 | 10.5 |
| .74 | 4.33 | 6.43 | 8.57 | 10.7 |
| .75 | 4.42 | 6.56 | 8.75 | 10.9 |
| .76 | 4.51 | 6.69 | 8.92 | 11.2 |
| .77 | 4.60 | 6.82 | 9.10 | 11.4 |
| .78 | 4.69 | 6.96 | 9.28 | 11.6 |
| .79 | 4.78 | 7.09 | 9.46 | 11.8 |
| .80 | 4.87 | 7.23 | 9.64 | 12.0 |
| .81 | 4.96 | 7.36 | 9.82 | 12.3 |
| .82 | 5.05 | 7.50 | 10.0 | 12.5 |
| .83 | 5.14 | 7.64 | 10.2 | 12.7 |
| .84 | 5.24 | 7.78 | 10.4 | 13.0 |
| .85 | 5.34 | 7.92 | 10.6 | 13.2 |
| .86 | 5.44 | 8.06 | 10.7 | 13.4 |
| .87 | 5.54 | 8.20 | 10.9 | 13.7 |
| .88 | 5.64 | 8.34 | 11.1 | 13.9 |
| .89 | 5.74 | 8.48 | 11.3 | 14.1 |
| .90 | 5.84 | 8.62 | 11.5 | 14.4 |
| .91 | 5.94 | 8.77 | 11.7 | 14.6 |
| .92 | 6.04 | 8.91 | 11.9 | 14.9 |
| .93 | 6.14 | 9.06 | 12.1 | 15.1 |
| .94 | 6.25 | 9.21 | 12.3 | 15.3 |
| .95 | 6.36 | 9.35 | 12.5 | 15.6 |
| .96 | 6.47 | 9.50 | 12.7 | 15.8 |
| .97 | 6.58 | 9.65 | 12.9 | 16.1 |
| .98 | 6.69 | 9.80 | 13.1 | 16.3 |
| .99 | 6.80 | 9.95 | 13.3 | 16.6 |
| 1.00 | 6.91 | 10.1 | 13.5 | 16.8 |
| 1.01 | ----- | 10.5 | 13.7 | 17.1 |
| 1.02 | ----- | 10.6 | 13.9 | 17.3 |
| 1.03 | ----- | 10.8 | 14.1 | 17.6 |
| 1.04 | ----- | 10.9 | 14.3 | 17.9 |
| 1.05 | ----- | 11.1 | 14.5 | 18.1 |

| Head $H$, ft | Weir Length, $L$, ft 3.0 | 4.0 | 5.0 |
|---|---|---|---|
| 1.06 | 11.3 | 14.7 | 18.4 |
| 1.07 | 11.4 | 14.9 | 18.6 |
| 1.08 | 11.6 | 15.1 | 18.9 |
| 1.09 | 11.7 | 15.3 | 19.2 |
| 1.10 | 11.9 | 15.5 | 19.4 |
| 1.11 | 12.1 | 15.8 | 19.7 |
| 1.12 | 12.2 | 16.0 | 20.0 |
| 1.13 | 12.4 | 16.2 | 20.2 |
| 1.14 | 12.5 | 16.4 | 20.5 |
| 1.15 | 12.7 | 16.6 | 20.8 |
| 1.16 | 12.9 | 16.8 | 21.0 |
| 1.17 | 13.0 | 17.0 | 21.3 |
| 1.18 | 13.2 | 17.3 | 21.6 |
| 1.19 | 13.4 | 17.5 | 21.9 |
| 1.20 | 13.6 | 17.7 | 22.1 |
| 1.21 | 13.7 | 17.9 | 22.4 |
| 1.22 | 13.9 | 18.1 | 22.7 |
| 1.23 | 14.1 | 18.4 | 23.0 |
| 1.24 | 14.3 | 18.6 | 23.2 |
| 1.25 | 14.4 | 18.8 | 23.5 |
| 1.26 | 14.6 | 19.0 | 23.8 |
| 1.27 | 14.8 | 19.3 | 24.1 |
| 1.28 | 15.0 | 19.5 | 24.4 |
| 1.29 | 15.2 | 19.7 | 24.7 |
| 1.30 | 15.4 | 20.0 | 25.0 |
| 1.31 | 15.5 | 20.2 | 25.2 |
| 1.32 | 15.7 | 20.4 | 25.5 |
| 1.33 | 15.9 | 20.7 | 25.8 |
| 1.34 | 16.1 | ----- | 26.1 |
| 1.35 | 16.2 | ----- | 26.4 |
| 1.36 | 16.4 | ----- | 26.7 |
| 1.37 | 16.6 | ----- | 27.0 |
| 1.38 | 16.8 | ----- | 27.3 |
| 1.39 | 17.0 | ----- | 27.6 |
| 1.40 | 17.2 | ----- | 27.9 |
| 1.41 | 17.4 | ----- | 28.2 |
| 1.42 | 17.6 | ----- | 28.5 |
| 1.43 | 17.8 | ----- | 28.8 |
| 1.44 | 18.0 | ----- | 29.1 |
| 1.45 | 18.2 | ----- | 29.4 |
| 1.46 | 18.3 | ----- | 29.7 |
| 1.47 | 18.5 | ----- | 30.0 |
| 1.48 | 18.7 | ----- | 30.3 |
| 1.49 | 18.9 | ----- | 30.6 |
| 1.50 | 19.1 | ----- | 30.9 |

| Head $H$, ft | $L$ 5.0 |
|---|---|
| 1.51 | 31.2 |
| 1.52 | 31.5 |
| 1.53 | 31.9 |
| 1.54 | 32.2 |
| 1.55 | 32.5 |
| 1.56 | 32.8 |
| 1.57 | 33.1 |
| 1.58 | 33.4 |
| 1.59 | 33.8 |
| 1.60 | 34.1 |
| 1.61 | 34.4 |
| 1.62 | 34.7 |
| 1.63 | 35.0 |
| 1.64 | 35.4 |
| 1.65 | 35.7 |
| 1.66 | 36.0 |
| 1.67 | 36.3 |

**Table A7-5 [continued]**. Discharge of standard Cipolletti weirs in $ft^3$/sec. Shaded entries determined experimentally. Others computed from the formula $Q = 3.367 L h_1^{1.5}$

| Head $H$, ft | Weir Length, $L$, ft 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|
| 0.20 | 1.81 | 2.11 | 2.41 | 2.71 |
| .21 | 1.94 | 2.27 | 2.59 | 2.92 |
| .22 | 2.08 | 2.43 | 2.78 | 3.13 |
| .23 | 2.23 | 2.60 | 2.97 | 3.34 |
| .24 | 2.38 | 2.77 | 3.17 | 3.56 |
| .25 | 2.53 | 2.95 | 3.37 | 3.79 |
| .26 | 2.68 | 3.12 | 3.57 | 4.02 |
| .27 | 2.83 | 3.31 | 3.78 | 4.25 |
| .28 | 2.99 | 3.49 | 3.99 | 4.49 |
| .29 | 3.15 | 3.68 | 4.21 | 4.73 |
| .30 | 3.32 | 3.87 | 4.43 | 4.98 |
| .31 | 3.49 | 4.07 | 4.65 | 5.23 |
| .32 | 3.66 | 4.27 | 4.88 | 5.49 |
| .33 | 3.83 | 4.47 | 5.11 | 5.74 |
| .34 | 4.01 | 4.67 | 5.34 | 6.01 |
| .35 | 4.18 | 4.88 | 5.58 | 6.27 |
| .36 | 4.36 | 5.09 | 5.82 | 6.55 |
| .37 | 4.55 | 5.30 | 6.06 | 6.82 |
| .38 | 4.73 | 5.52 | 6.31 | 7.10 |
| .39 | 4.92 | 5.74 | 6.56 | 7.38 |
| .40 | 5.11 | 5.96 | 6.81 | 7.67 |
| .41 | 5.30 | 6.19 | 7.07 | 7.96 |
| .42 | 5.50 | 6.42 | 7.33 | 8.25 |
| .43 | 5.70 | 6.65 | 7.60 | 8.54 |
| .44 | 5.90 | 6.88 | 7.86 | 8.84 |
| .45 | 6.10 | 7.11 | 8.13 | 9.15 |
| .46 | 6.30 | 7.35 | 8.40 | 9.45 |
| .47 | 6.51 | 7.59 | 8.68 | 9.76 |
| .48 | 6.72 | 7.84 | 8.96 | 10.1 |
| .49 | 6.93 | 8.08 | 9.24 | 10.4 |
| .50 | 7.14 | 8.33 | 9.52 | 10.7 |
| .51 | 7.36 | 8.58 | 9.81 | 11.0 |
| .52 | 7.58 | 8.84 | 10.1 | 11.4 |
| .53 | 7.79 | 9.09 | 10.4 | 11.7 |
| .54 | 8.02 | 9.35 | 10.7 | 12.0 |
| .55 | 8.24 | 9.61 | 11.0 | 12.4 |
| .56 | 8.47 | 9.88 | 11.3 | 12.7 |
| .57 | 8.69 | 10.1 | 11.6 | 13.0 |
| .58 | 8.92 | 10.4 | 11.9 | 13.4 |
| .59 | 9.16 | 10.7 | 12.2 | 13.7 |
| .60 | 9.39 | 11.0 | 12.5 | 14.1 |
| .61 | 9.62 | 11.2 | 12.8 | 14.4 |
| .62 | 9.86 | 11.5 | 13.1 | 14.8 |
| .63 | 10.1 | 11.8 | 13.5 | 15.2 |
| .64 | 10.3 | 12.1 | 13.8 | 15.5 |

| Head $H$, ft | Weir Length, $L$, ft 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|
| 0.65 | 10.6 | 12.4 | 14.1 | 15.9 |
| .66 | 10.8 | 12.6 | 14.4 | 16.2 |
| .67 | 11.1 | 12.9 | 14.8 | 16.6 |
| .68 | 11.3 | 13.2 | 15.1 | 17.0 |
| .69 | 11.6 | 13.5 | 15.4 | 17.4 |
| .70 | 11.8 | 13.8 | 15.8 | 17.7 |
| .71 | 12.1 | 14.1 | 16.1 | 18.1 |
| .72 | 12.3 | 14.4 | 16.5 | 18.5 |
| .73 | 12.6 | 14.7 | 16.8 | 18.9 |
| .74 | 12.9 | 15.0 | 17.1 | 19.3 |
| .75 | 13.1 | 15.3 | 17.5 | 19.7 |
| .76 | 13.4 | 15.6 | 17.8 | 20.1 |
| .77 | 13.6 | 15.9 | 18.2 | 20.5 |
| .78 | 13.9 | 16.2 | 18.6 | 20.9 |
| .79 | 14.2 | 16.5 | 18.9 | 21.3 |
| .80 | 14.5 | 16.9 | 19.3 | 21.7 |
| .81 | 14.7 | 17.2 | 19.6 | 22.1 |
| .82 | 15.0 | 17.5 | 20.0 | 22.5 |
| .83 | 15.3 | 17.8 | 20.4 | 22.9 |
| .84 | 15.6 | 18.1 | 20.7 | 23.3 |
| .85 | 15.8 | 18.5 | 21.1 | 23.7 |
| .86 | 16.1 | 18.8 | 21.5 | 24.2 |
| .87 | 16.4 | 19.1 | 21.9 | 24.6 |
| .88 | 16.7 | 19.5 | 22.2 | 25.0 |
| .89 | 17.0 | 19.8 | 22.6 | 25.4 |
| .90 | 17.2 | 20.1 | 23.0 | 25.9 |
| .91 | 17.5 | 20.5 | 23.4 | 26.3 |
| .92 | 17.8 | 20.8 | 23.8 | 26.7 |
| .93 | 18.1 | 21.1 | 24.2 | 27.2 |
| .94 | 18.4 | 21.5 | 24.5 | 27.6 |
| .95 | 18.7 | 21.8 | 24.9 | 28.1 |
| .96 | 19.0 | 22.2 | 25.3 | 28.5 |
| .97 | 19.3 | 22.5 | 25.7 | 28.9 |
| .98 | 19.6 | 22.9 | 26.1 | 29.4 |
| .99 | 19.9 | 23.2 | 26.5 | 29.8 |
| 1.00 | 20.2 | 23.6 | 26.9 | 30.3 |
| 1.01 | 20.5 | 23.9 | 27.3 | 30.8 |
| 1.02 | 20.8 | 24.3 | 27.7 | 31.2 |
| 1.03 | 21.1 | 24.6 | 28.2 | 31.7 |
| 1.04 | 21.4 | 25.0 | 28.6 | 32.1 |
| 1.05 | 21.7 | 25.4 | 29.0 | 32.6 |
| 1.06 | 22.0 | 25.7 | 29.4 | 33.1 |
| 1.07 | 22.4 | 26.1 | 29.8 | 33.5 |
| 1.08 | 22.7 | 26.5 | 30.2 | 34.0 |
| 1.09 | 23.0 | 26.8 | 30.7 | 34.5 |

**Table A7-5 [continued]**. Discharge of standard Cipolletti weirs in $ft^3$/sec. Shaded entries determined experimentally. Others computed from the formula $Q = 3.367 L h_1^{1.5}$

| Head $H$, ft | Weir Length, $L$, ft 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|
| 1.10 | 23.3 | 27.2 | 31.1 | 35.0 |
| 1.11 | 23.6 | 27.6 | 31.5 | 35.4 |
| 1.12 | 23.9 | 27.9 | 31.9 | 35.9 |
| 1.13 | 24.3 | 28.3 | 32.4 | 36.4 |
| 1.14 | 24.6 | 28.7 | 32.8 | 36.9 |
| 1.15 | 24.9 | 29.1 | 33.2 | 37.4 |
| 1.16 | 25.2 | 29.4 | 33.7 | 37.9 |
| 1.17 | 25.6 | 29.8 | 34.1 | 38.3 |
| 1.18 | 25.9 | 30.2 | 34.5 | 38.8 |
| 1.19 | 26.2 | 30.6 | 35.0 | 39.3 |
| 1.20 | 26.6 | 31.0 | 35.4 | 39.8 |
| 1.21 | 26.9 | 31.4 | 35.9 | 40.3 |
| 1.22 | 27.2 | 31.8 | 36.3 | 40.8 |
| 1.23 | 27.6 | 32.2 | 36.7 | 41.3 |
| 1.24 | 27.9 | 32.5 | 37.2 | 41.8 |
| 1.25 | 28.2 | 32.9 | 37.6 | 42.3 |
| 1.26 | 28.6 | 33.3 | 38.1 | 42.9 |
| 1.27 | 28.9 | 33.7 | 38.6 | 43.4 |
| 1.28 | 29.3 | 34.1 | 39.0 | 43.9 |
| 1.29 | 29.6 | 34.5 | 39.5 | 44.4 |
| 1.30 | 29.9 | 34.9 | 39.9 | 44.9 |
| 1.31 | 30.3 | 35.3 | 40.4 | 45.4 |
| 1.32 | 30.6 | 35.7 | 40.9 | 46.0 |
| 1.33 | 31.0 | 36.2 | 41.3 | 46.5 |
| 1.34 | 31.3 | 36.6 | 41.8 | 47.0 |
| 1.35 | 31.7 | 37.0 | 42.3 | 47.5 |
| 1.36 | 32.0 | 37.4 | 42.7 | 48.1 |
| 1.37 | 32.4 | 37.8 | 43.2 | 48.6 |
| 1.38 | 32.8 | 38.2 | 43.7 | 49.1 |
| 1.39 | 33.1 | 38.6 | 44.1 | 49.7 |
| 1.40 | 33.5 | 39.0 | 44.6 | 50.2 |
| 1.41 | 33.8 | 39.5 | 45.1 | 50.7 |
| 1.42 | 34.2 | 39.9 | 45.6 | 51.3 |
| 1.43 | 34.5 | 40.3 | 46.1 | 51.8 |
| 1.44 | 34.9 | 40.7 | 46.5 | 52.4 |
| 1.45 | 35.3 | 41.2 | 47.0 | 52.9 |
| 1.46 | 35.6 | 41.6 | 47.5 | 53.5 |
| 1.47 | 36.0 | 42.0 | 48.0 | 54.0 |
| 1.48 | 36.4 | 42.4 | 48.5 | 54.6 |
| 1.49 | 36.7 | 42.9 | 49.0 | 55.1 |
| 1.50 | 37.1 | 43.3 | 49.5 | 55.7 |
| 1.51 | 37.5 | 43.7 | 50.0 | 56.2 |
| 1.52 | 37.9 | 44.2 | 50.5 | 56.8 |
| 1.53 | 38.2 | 44.6 | 51.0 | 57.3 |
| 1.54 | 38.6 | 45.0 | 51.5 | 57.9 |

| Head $H$, ft | Weir Length, $L$, ft 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|
| 1.55 | 39.0 | 45.5 | 52.0 | 58.5 |
| 1.56 | 39.4 | 45.9 | 52.5 | 59.0 |
| 1.57 | 39.7 | 46.4 | 53.0 | 59.6 |
| 1.58 | 40.1 | 46.8 | 53.5 | 60.2 |
| 1.59 | 40.5 | 47.3 | 54.0 | 60.8 |
| 1.60 | 40.9 | 47.7 | 54.5 | 61.3 |
| 1.61 | 41.3 | 48.1 | 55.0 | 61.9 |
| 1.62 | 41.7 | 48.6 | 55.5 | 62.5 |
| 1.63 | 42.0 | 49.0 | 56.1 | 63.1 |
| 1.64 | 42.4 | 49.5 | 56.6 | 63.6 |
| 1.65 | 42.8 | 50.0 | 57.1 | 64.2 |
| 1.66 | 43.2 | 50.4 | 57.6 | 64.8 |
| 1.67 | 43.6 | 50.9 | 58.1 | 65.4 |
| 1.68 | 44.0 | 51.3 | 58.7 | 66.0 |
| 1.69 | 44.4 | 51.8 | 59.2 | 66.6 |
| 1.70 | 44.8 | 52.2 | 59.7 | 67.2 |
| 1.71 | 45.2 | 52.7 | 60.2 | 67.8 |
| 1.72 | 45.6 | 53.2 | 60.8 | 68.4 |
| 1.73 | 46.0 | 53.6 | 61.3 | 69.0 |
| 1.74 | 46.4 | 54.1 | 61.8 | 69.6 |
| 1.75 | 46.8 | 54.6 | 62.4 | 70.2 |
| 1.76 | 47.2 | 55.0 | 62.9 | 70.8 |
| 1.77 | 47.6 | 55.5 | 63.4 | 71.4 |
| 1.78 | 48.0 | 56.0 | 64.0 | 72.0 |
| 1.79 | 48.4 | 56.4 | 64.5 | 72.6 |
| 1.80 | 48.8 | 56.9 | 65.0 | 73.2 |
| 1.81 | 49.2 | 57.4 | 65.6 | 73.8 |
| 1.82 | 49.6 | 57.9 | 66.1 | 74.4 |
| 1.83 | 50.0 | 58.3 | 66.7 | 75.0 |
| 1.84 | 50.4 | 58.8 | 67.2 | 75.6 |
| 1.85 | 50.8 | 59.3 | 67.8 | 76.3 |
| 1.86 | 51.2 | 59.8 | 68.3 | 76.9 |
| 1.87 | 51.7 | 60.3 | 68.9 | 77.5 |
| 1.88 | 52.1 | 60.8 | 69.4 | 78.1 |
| 1.89 | 52.5 | 61.2 | 70.0 | 78.7 |
| 1.90 | 52.9 | 61.7 | 70.5 | 79.4 |
| 1.91 | 53.3 | 62.2 | 71.1 | 80.0 |
| 1.92 | 53.7 | 62.7 | 71.7 | 80.6 |
| 1.93 | 54.2 | 63.2 | 72.2 | 81.2 |
| 1.94 | 54.6 | 63.7 | 72.8 | 81.9 |
| 1.95 | 55.0 | 64.2 | 73.3 | 82.5 |
| 1.96 | 55.4 | 64.7 | 73.9 | 83.2 |
| 1.97 | 55.9 | 65.2 | 74.5 | 83.8 |
| 1.98 | 56.3 | 65.7 | 75.0 | 84.4 |
| 1.99 | 56.7 | 66.2 | 75.6 | 85.1 |

**Table A7-5 [continued]**. Discharge of standard Cipolletti weirs in $ft^3$/sec. Shaded entries determined experimentally. Others computed from the formula $Q = 3.367 L h_1^{1.5}$

| Head $H$, ft | Weir Length, $L$, ft 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|
| 2.00 | 57.1 | 66.7 | 76.2 | 85.7 |
| 2.01 | ----- | 67.2 | 76.8 | 86.4 |
| 2.02 | ----- | 67.7 | 77.3 | 87.0 |
| 2.03 | ----- | 68.2 | 77.9 | 87.6 |
| 2.04 | ----- | 68.7 | 78.5 | 88.3 |
| 2.05 | ----- | 69.2 | 79.1 | 88.9 |
| 2.06 | ----- | 69.7 | 79.6 | 89.6 |
| 2.07 | ----- | 70.2 | 80.2 | 90.2 |
| 2.08 | ----- | 70.7 | 80.8 | 90.9 |
| 2.09 | ----- | 71.2 | 81.4 | 91.6 |
| 2.10 | ----- | 71.7 | 82.0 | 92.2 |
| 2.11 | ----- | 72.2 | 82.6 | 92.9 |
| 2.12 | ----- | 72.8 | 83.1 | 93.5 |
| 2.13 | ----- | 73.3 | 83.7 | 94.2 |
| 2.14 | ----- | 73.8 | 84.3 | 94.9 |
| 2.15 | ----- | 74.3 | 84.9 | 95.5 |
| 2.16 | ----- | 74.8 | 85.5 | 96.2 |
| 2.17 | ----- | 75.3 | 86.1 | 96.9 |
| 2.18 | ----- | 75.9 | 86.7 | 97.5 |
| 2.19 | ----- | 76.4 | 87.3 | 98.2 |
| 2.20 | ----- | 76.9 | 87.9 | 98.9 |
| 2.21 | ----- | 77.4 | 88.5 | 100. |
| 2.22 | ----- | 78.0 | 89.1 | 100. |
| 2.23 | ----- | 78.5 | 89.7 | 101. |
| 2.24 | ----- | 79.0 | 90.3 | 102. |
| 2.25 | ----- | 79.5 | 90.9 | 102. |
| 2.26 | ----- | 80.1 | 91.5 | 103. |
| 2.27 | ----- | 80.6 | 92.1 | 104. |
| 2.28 | ----- | 81.1 | 92.7 | 104. |
| 2.29 | ----- | 81.7 | 93.3 | 105. |
| 2.30 | ----- | 82.2 | 94.0 | 106. |
| 2.31 | ----- | 82.7 | 94.6 | 106. |
| 2.32 | ----- | 83.3 | 95.2 | 107. |
| 2.33 | ----- | 83.8 | 95.8 | 108. |
| 2.34 | ----- | ----- | 96.4 | 108. |
| 2.35 | ----- | ----- | 97.0 | 109. |
| 2.36 | ----- | ----- | 97.7 | 110. |
| 2.37 | ----- | ----- | 98.3 | 111. |
| 2.38 | ----- | ----- | 98.9 | 111. |
| 2.39 | ----- | ----- | 100. | 112. |
| 2.40 | ----- | ----- | 100. | 113. |
| 2.41 | ----- | ----- | 101. | 113. |
| 2.42 | ----- | ----- | 101. | 114. |
| 2.43 | ----- | ----- | 102. | 115. |
| 2.44 | ----- | ----- | 103. | 115. |

| Head $H$, ft | $L$, ft 8.0 | 9.0 |
|---|---|---|
| 2.45 | 103. | 116. |
| 2.46 | 104. | 117. |
| 2.47 | 105. | 118. |
| 2.48 | 105. | 118. |
| 2.49 | 106. | 119. |
| 2.50 | 106. | 120. |
| 2.51 | 107. | 121. |
| 2.52 | 108. | 121. |
| 2.53 | 108. | 122. |
| 2.54 | 109. | 123. |
| 2.55 | 110. | 123. |
| 2.56 | 110. | 124. |
| 2.57 | 111. | 125. |
| 2.58 | 112. | 126. |
| 2.59 | 112. | 126. |
| 2.60 | 113. | 127. |
| 2.61 | 114. | 128. |
| 2.62 | 114. | 129. |
| 2.63 | 115. | 129. |
| 2.64 | 116. | 130. |
| 2.65 | 116. | 131. |
| 2.66 | 117. | 131. |
| 2.67 | 118. | 132. |
| 2.68 | ----- | 133. |
| 2.69 | ----- | 134. |
| 2.70 | ----- | 134. |
| 2.71 | ----- | 135. |
| 2.72 | ----- | 136. |
| 2.73 | ----- | 137. |
| 2.74 | ----- | 137. |
| 2.75 | ----- | 138. |
| 2.76 | ----- | 139. |
| 2.77 | ----- | 140. |
| 2.78 | ----- | 140. |
| 2.79 | ----- | 141. |
| 2.80 | ----- | 142. |
| 2.81 | ----- | 143. |
| 2.82 | ----- | 144. |
| 2.83 | ----- | 144. |
| 2.84 | ----- | 145. |
| 2.85 | ----- | 146. |
| 2.86 | ----- | 147. |
| 2.87 | ----- | 147. |
| 2.88 | ----- | 148. |
| 2.89 | ----- | 149. |

| Head $H$, ft | $L$ 9.0 |
|---|---|
| 2.90 | 150. |
| 2.91 | 150. |
| 2.92 | 151. |
| 2.93 | 152. |
| 2.94 | 153. |
| 2.95 | 154. |
| 2.96 | 154. |
| 2.97 | 155. |
| 2.98 | 156. |
| 2.99 | 157. |
| 3.00 | 157. |

**Table A8-7**. Free-flow discharge through 1-inch Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 0.338 h_a^{1.55}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | ----- | ----- | ----- | ----- | ----- | 0.0033 | 0.0043 | 0.0055 | 0.0067 | 0.0081 |
| 0.10 | 0.0095 | 0.0110 | 0.0126 | 0.0143 | 0.0160 | .0179 | .0197 | .0217 | .0237 | .0258 |
| 0.20 | .028 | .030 | .032 | .035 | .037 | .039 | .042 | .044 | .047 | .050 |
| 0.30 | .052 | .055 | .058 | .061 | .063 | .066 | .069 | .072 | .075 | .079 |
| 0.40 | .082 | .085 | .088 | .091 | .095 | .098 | .101 | .105 | .108 | .112 |
| 0.50 | .115 | .119 | .123 | .126 | .130 | .134 | .138 | .141 | .145 | .149 |
| 0.60 | .153 | .157 | .161 | .165 | .169 | .173 | .178 | .182 | .186 | .190 |

**Table A8-8**. Free-flow discharge through 2-inch Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 0.676 h_a^{1.55}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | ----- | ----- | ----- | ----- | ----- | 0.0065 | 0.0086 | 0.0110 | 0.0135 | 0.0162 |
| 0.10 | 0.0191 | 0.0221 | 0.0253 | 0.0286 | 0.0321 | .0357 | .0395 | .0434 | .0474 | .0515 |
| 0.20 | .056 | .060 | .065 | .069 | .074 | .079 | .084 | .089 | .094 | .099 |
| 0.30 | .105 | .110 | .116 | .121 | .127 | .133 | .139 | .145 | .151 | .157 |
| 0.40 | .163 | .170 | .176 | .183 | .189 | .196 | .203 | .210 | .217 | .224 |
| 0.50 | .231 | .238 | .245 | .253 | .260 | .268 | .275 | .283 | .291 | .298 |
| 0.60 | .306 | .314 | .322 | .330 | .338 | .347 | .355 | .363 | .372 | .380 |
| 0.70 | .389 | .398 | .406 | .415 | .424 | .433 | .442 | .451 | .460 | .469 |

**Table A8-9**. Free-flow discharge through 3-inch Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 0.992 h_a^{1.55}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | ----- | ----- | ----- | ----- | ----- | 0.0095 | 0.0127 | 0.0161 | 0.0198 | 0.0237 |
| 0.10 | 0.0280 | 0.0324 | 0.0371 | 0.0420 | 0.0471 | .0524 | .0579 | .0636 | .0695 | .0756 |
| 0.20 | .082 | .088 | .095 | .102 | .109 | .116 | .123 | .130 | .138 | .146 |
| 0.30 | .153 | .161 | .170 | .178 | .186 | .195 | .204 | .212 | .221 | .230 |
| 0.40 | .240 | .249 | .259 | .268 | .278 | .288 | .298 | .308 | .318 | .328 |
| 0.50 | .339 | .349 | .360 | .371 | .382 | .393 | .404 | .415 | .426 | .438 |
| 0.60 | .449 | .461 | .473 | .485 | .497 | .509 | .521 | .533 | .546 | .558 |
| 0.70 | .571 | .583 | .596 | .609 | .622 | .635 | .648 | .662 | .675 | .688 |
| 0.80 | .702 | .716 | .729 | .743 | .757 | .771 | .785 | .799 | .814 | .828 |
| 0.90 | .843 | .857 | .872 | .886 | .901 | .916 | .931 | .946 | .961 | .977 |
| 1.00 | .992 | 1.007 | 1.023 | 1.039 | 1.054 | 1.070 | 1.086 | 1.102 | 1.118 | 1.134 |

**Table A8-10**. Free-flow discharge through 6-inch Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 2.06 h_a^{1.58}$

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.15 |
| .20 | .16 | .17 | .19 | .20 | .22 | .23 | .25 | .26 | .28 | .29 |
| .30 | .31 | .32 | .34 | .36 | .37 | .39 | .41 | .43 | .45 | .47 |
| .40 | .48 | .50 | .52 | .54 | .56 | .58 | .60 | .62 | .65 | .67 |
| .50 | .69 | .71 | .73 | .76 | .78 | .80 | .82 | .85 | .87 | .89 |
| .60 | .92 | .94 | .97 | .99 | 1.02 | 1.04 | 1.07 | 1.09 | 1.12 | 1.15 |
| .70 | 1.17 | 1.20 | 1.23 | 1.25 | 1.28 | 1.31 | 1.34 | 1.36 | 1.39 | 1.42 |
| .80 | 1.45 | 1.48 | 1.51 | 1.53 | 1.56 | 1.59 | 1.62 | 1.65 | 1.68 | 1.71 |
| .90 | 1.74 | 1.77 | 1.81 | 1.84 | 1.87 | 1.90 | 1.93 | 1.96 | 2.00 | 2.03 |
| 1.00 | 2.06 | 2.09 | 2.13 | 2.16 | 2.19 | 2.23 | 2.26 | 2.29 | 2.33 | 2.36 |
| 1.10 | 2.39 | 2.43 | 2.46 | 2.50 | 2.53 | 2.57 | 2.60 | 2.64 | 2.68 | 2.71 |
| 1.20 | 2.75 | 2.78 | 2.82 | 2.86 | 2.89 | 2.93 | 2.97 | 3.01 | 3.04 | 3.08 |

**Table A8-11**. Free-flow discharge through 9-inch Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 3.07 h_a^{1.53}$

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.09 | 0.10 | 0.12 | 0.14 | 0.15 | 0.17 | 0.19 | 0.20 | 0.22 | 0.24 |
| .20 | .26 | .28 | .30 | .32 | .35 | .37 | .39 | .41 | .44 | .46 |
| .30 | .49 | .51 | .54 | .56 | .59 | .62 | .64 | .67 | .70 | .73 |
| .40 | .76 | .78 | .81 | .84 | .87 | .90 | .94 | .97 | 1.00 | 1.03 |
| .50 | 1.06 | 1.10 | 1.13 | 1.16 | 1.20 | 1.23 | 1.26 | 1.30 | 1.33 | 1.37 |
| .60 | 1.41 | 1.44 | 1.48 | 1.51 | 1.55 | 1.59 | 1.63 | 1.66 | 1.70 | 1.74 |
| .70 | 1.78 | 1.82 | 1.86 | 1.90 | 1.94 | 1.98 | 2.02 | 2.06 | 2.10 | 2.14 |
| .80 | 2.18 | 2.22 | 2.27 | 2.31 | 2.35 | 2.39 | 2.44 | 2.48 | 2.52 | 2.57 |
| .90 | 2.61 | 2.66 | 2.70 | 2.75 | 2.79 | 2.84 | 2.88 | 2.93 | 2.98 | 3.02 |
| 1.00 | 3.07 | 3.12 | 3.16 | 3.21 | 3.26 | 3.31 | 3.36 | 3.40 | 3.45 | 3.50 |
| 1.10 | 3.55 | 3.60 | 3.65 | 3.70 | 3.75 | 3.80 | 3.85 | 3.90 | 3.95 | 4.01 |
| 1.20 | 4.06 | 4.11 | 4.16 | 4.21 | 4.27 | 4.32 | 4.37 | 4.43 | 4.48 | 4.53 |
| 1.30 | 4.59 | 4.64 | 4.69 | 4.75 | 4.80 | 4.86 | 4.91 | 4.97 | 5.03 | 5.08 |
| 1.40 | 5.14 | 5.19 | 5.25 | 5.31 | 5.36 | 5.42 | 5.48 | 5.54 | 5.59 | 5.65 |
| 1.50 | 5.71 | 5.77 | 5.83 | 5.88 | 5.94 | 6.00 | 6.06 | 6.12 | 6.18 | 6.24 |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00 W h_a^{1.522(W^{0.026})}$. Discharges for 1-ft flume computed from the formula $Q = 3.95 h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 0.20 | 0.33 | 0.66 | 0.96 | 1.26 | ----- | ----- | ----- | ----- |
| .21 | .35 | .71 | 1.04 | 1.36 | ----- | ----- | ----- | ----- |
| .22 | .38 | .77 | 1.12 | 1.47 | ----- | ----- | ----- | ----- |
| .23 | .40 | .82 | 1.20 | 1.57 | ----- | ----- | ----- | ----- |
| .24 | .43 | .88 | 1.28 | 1.68 | ----- | ----- | ----- | ----- |
| .25 | .46 | .93 | 1.37 | 1.80 | 2.22 | 2.63 | ----- | ----- |
| .26 | .49 | .99 | 1.46 | 1.91 | 2.36 | 2.80 | ----- | ----- |
| .27 | .52 | 1.05 | 1.54 | 2.03 | 2.50 | 2.97 | ----- | ----- |
| .28 | .55 | 1.11 | 1.63 | 2.15 | 2.65 | 3.15 | ----- | ----- |
| .29 | .58 | 1.17 | 1.73 | 2.27 | 2.80 | 3.33 | ----- | ----- |
| .30 | .61 | 1.24 | 1.82 | 2.39 | 2.96 | 3.52 | 4.07 | 4.63 |
| .31 | .64 | 1.30 | 1.92 | 2.52 | 3.12 | 3.71 | 4.29 | 4.88 |
| .32 | .68 | 1.37 | 2.01 | 2.65 | 3.28 | 3.90 | 4.52 | 5.13 |
| .33 | .71 | 1.44 | 2.11 | 2.78 | 3.44 | 4.10 | 4.75 | 5.39 |
| .34 | .74 | 1.50 | 2.22 | 2.92 | 3.61 | 4.30 | 4.98 | 5.66 |
| .35 | .78 | 1.57 | 2.32 | 3.05 | 3.78 | 4.50 | 5.21 | 5.92 |
| .36 | .81 | 1.64 | 2.42 | 3.19 | 3.95 | 4.71 | 5.46 | 6.20 |
| .37 | .85 | 1.71 | 2.53 | 3.33 | 4.13 | 4.92 | 5.70 | 6.48 |
| .38 | .88 | 1.79 | 2.64 | 3.48 | 4.31 | 5.13 | 5.95 | 6.76 |
| .39 | .92 | 1.86 | 2.75 | 3.62 | 4.49 | 5.35 | 6.20 | 7.05 |
| .40 | .95 | 1.93 | 2.86 | 3.77 | 4.67 | 5.57 | 6.46 | 7.34 |
| .41 | .99 | 2.01 | 2.97 | 3.92 | 4.86 | 5.79 | 6.72 | 7.64 |
| .42 | 1.03 | 2.09 | 3.08 | 4.07 | 5.05 | 6.02 | 6.98 | 7.94 |
| .43 | 1.07 | 2.16 | 3.20 | 4.22 | 5.24 | 6.25 | 7.25 | 8.25 |
| .44 | 1.11 | 2.24 | 3.32 | 4.38 | 5.43 | 6.48 | 7.52 | 8.56 |
| .45 | 1.15 | 2.32 | 3.44 | 4.54 | 5.63 | 6.72 | 7.80 | 8.87 |
| .46 | 1.19 | 2.40 | 3.56 | 4.70 | 5.83 | 6.96 | 8.08 | 9.19 |
| .47 | 1.23 | 2.48 | 3.68 | 4.86 | 6.03 | 7.20 | 8.36 | 9.51 |
| .48 | 1.27 | 2.57 | 3.80 | 5.03 | 6.24 | 7.45 | 8.65 | 9.84 |
| .49 | 1.31 | 2.65 | 3.93 | 5.19 | 6.45 | 7.69 | 8.94 | 10.2 |
| .50 | 1.35 | 2.73 | 4.05 | 5.36 | 6.66 | 7.95 | 9.23 | 10.5 |
| .51 | 1.39 | 2.82 | 4.18 | 5.53 | 6.87 | 8.20 | 9.53 | 10.8 |
| .52 | 1.43 | 2.90 | 4.31 | 5.70 | 7.08 | 8.46 | 9.83 | 11.2 |
| .53 | 1.48 | 2.99 | 4.44 | 5.88 | 7.30 | 8.72 | 10.1 | 11.5 |
| .54 | 1.52 | 3.08 | 4.57 | 6.05 | 7.52 | 8.98 | 10.4 | 11.9 |
| .55 | 1.56 | 3.17 | 4.71 | 6.23 | 7.74 | 9.25 | 10.8 | 12.2 |
| .56 | 1.61 | 3.26 | 4.84 | 6.41 | 7.97 | 9.52 | 11.1 | 12.6 |
| .57 | 1.65 | 3.35 | 4.98 | 6.59 | 8.20 | 9.79 | 11.4 | 13.0 |
| .58 | 1.70 | 3.44 | 5.11 | 6.77 | 8.43 | 10.1 | 11.7 | 13.3 |
| .59 | 1.74 | 3.53 | 5.25 | 6.96 | 8.66 | 10.3 | 12.0 | 13.7 |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00Wh_a^{1.522(W\wedge 0.026)}$. Discharges for 1-ft flume computed from the formula $Q = 3.95h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 0.60 | 1.79 | 3.62 | 5.39 | 7.15 | 8.89 | 10.6 | 12.4 | 14.1 |
| .61 | 1.84 | 3.72 | 5.53 | 7.34 | 9.13 | 10.9 | 12.7 | 14.5 |
| .62 | 1.88 | 3.81 | 5.68 | 7.53 | 9.37 | 11.2 | 13.0 | 14.8 |
| .63 | 1.93 | 3.91 | 5.82 | 7.72 | 9.61 | 11.5 | 13.4 | 15.2 |
| .64 | 1.98 | 4.01 | 5.97 | 7.91 | 9.85 | 11.8 | 13.7 | 15.6 |
| .65 | 2.03 | 4.10 | 6.11 | 8.11 | 10.1 | 12.1 | 14.0 | 16.0 |
| .66 | 2.07 | 4.20 | 6.26 | 8.31 | 10.3 | 12.4 | 14.4 | 16.4 |
| .67 | 2.12 | 4.30 | 6.41 | 8.51 | 10.6 | 12.7 | 14.7 | 16.8 |
| .68 | 2.17 | 4.40 | 6.56 | 8.71 | 10.8 | 13.0 | 15.1 | 17.2 |
| .69 | 2.22 | 4.50 | 6.71 | 8.91 | 11.1 | 13.3 | 15.5 | 17.6 |
| .70 | 2.27 | 4.60 | 6.86 | 9.11 | 11.4 | 13.6 | 15.8 | 18.0 |
| .71 | 2.32 | 4.71 | 7.02 | 9.32 | 11.6 | 13.9 | 16.2 | 18.5 |
| .72 | 2.37 | 4.81 | 7.17 | 9.53 | 11.9 | 14.2 | 16.5 | 18.9 |
| .73 | 2.43 | 4.91 | 7.33 | 9.74 | 12.1 | 14.5 | 16.9 | 19.3 |
| .74 | 2.48 | 5.02 | 7.49 | 9.95 | 12.4 | 14.8 | 17.3 | 19.7 |
| .75 | 2.53 | 5.12 | 7.65 | 10.2 | 12.7 | 15.2 | 17.7 | 20.2 |
| .76 | 2.58 | 5.23 | 7.81 | 10.4 | 12.9 | 15.5 | 18.0 | 20.6 |
| .77 | 2.63 | 5.34 | 7.97 | 10.6 | 13.2 | 15.8 | 18.4 | 21.0 |
| .78 | 2.69 | 5.44 | 8.13 | 10.8 | 13.5 | 16.1 | 18.8 | 21.5 |
| .79 | 2.74 | 5.55 | 8.30 | 11.0 | 13.8 | 16.5 | 19.2 | 21.9 |
| .80 | 2.80 | 5.66 | 8.46 | 11.3 | 14.0 | 16.8 | 19.6 | 22.4 |
| .81 | 2.85 | 5.77 | 8.63 | 11.5 | 14.3 | 17.2 | 20.0 | 22.8 |
| .82 | 2.90 | 5.88 | 8.79 | 11.7 | 14.6 | 17.5 | 20.4 | 23.3 |
| .83 | 2.96 | 5.99 | 8.96 | 11.9 | 14.9 | 17.8 | 20.8 | 23.7 |
| .84 | 3.01 | 6.11 | 9.13 | 12.2 | 15.2 | 18.2 | 21.2 | 24.2 |
| .85 | 3.07 | 6.22 | 9.30 | 12.4 | 15.5 | 18.5 | 21.6 | 24.6 |
| .86 | 3.13 | 6.33 | 9.48 | 12.6 | 15.7 | 18.9 | 22.0 | 25.1 |
| .87 | 3.18 | 6.45 | 9.65 | 12.8 | 16.0 | 19.2 | 22.4 | 25.6 |
| .88 | 3.24 | 6.56 | 9.82 | 13.1 | 16.3 | 19.6 | 22.8 | 26.1 |
| .89 | 3.30 | 6.68 | 10.0 | 13.3 | 16.6 | 19.9 | 23.2 | 26.5 |
| .90 | 3.35 | 6.79 | 10.2 | 13.5 | 16.9 | 20.3 | 23.7 | 27.0 |
| .91 | 3.41 | 6.91 | 10.4 | 13.8 | 17.2 | 20.6 | 24.1 | 27.5 |
| .92 | 3.47 | 7.03 | 10.5 | 14.0 | 17.5 | 21.0 | 24.5 | 28.0 |
| .93 | 3.53 | 7.15 | 10.7 | 14.3 | 17.8 | 21.4 | 24.9 | 28.5 |
| .94 | 3.59 | 7.27 | 10.9 | 14.5 | 18.1 | 21.7 | 25.4 | 29.0 |
| .95 | 3.65 | 7.39 | 11.1 | 14.8 | 18.4 | 22.1 | 25.8 | 29.5 |
| .96 | 3.71 | 7.51 | 11.3 | 15.0 | 18.7 | 22.5 | 26.2 | 30.0 |
| .97 | 3.77 | 7.63 | 11.4 | 15.2 | 19.1 | 22.9 | 26.7 | 30.5 |
| .98 | 3.83 | 7.75 | 11.6 | 15.5 | 19.4 | 23.2 | 27.1 | 31.0 |
| .99 | 3.89 | 7.88 | 11.8 | 15.7 | 19.7 | 23.6 | 27.6 | 31.5 |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00 W h_a^{1.522(W \wedge 0.026)}$. Discharges for 1-ft flume computed from the formula $Q = 3.95 h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 1.00 | 3.95 | 8.00 | 12.0 | 16.0 | 20.0 | 24.0 | 28.0 | 32.0 |
| 1.01 | 4.01 | 8.12 | 12.2 | 16.3 | 20.3 | 24.4 | 28.4 | 32.5 |
| 1.02 | 4.07 | 8.25 | 12.4 | 16.5 | 20.6 | 24.8 | 28.9 | 33.0 |
| 1.03 | 4.14 | 8.37 | 12.6 | 16.8 | 21.0 | 25.2 | 29.4 | 33.6 |
| 1.04 | 4.20 | 8.50 | 12.8 | 17.0 | 21.3 | 25.5 | 29.8 | 34.1 |
| 1.05 | 4.26 | 8.63 | 13.0 | 17.3 | 21.6 | 25.9 | 30.3 | 34.6 |
| 1.06 | 4.32 | 8.76 | 13.1 | 17.5 | 21.9 | 26.3 | 30.7 | 35.1 |
| 1.07 | 4.39 | 8.88 | 13.3 | 17.8 | 22.3 | 26.7 | 31.2 | 35.7 |
| 1.08 | 4.45 | 9.01 | 13.5 | 18.1 | 22.6 | 27.1 | 31.7 | 36.2 |
| 1.09 | 4.51 | 9.14 | 13.7 | 18.3 | 22.9 | 27.5 | 32.1 | 36.8 |
| 1.10 | 4.58 | 9.27 | 13.9 | 18.6 | 23.3 | 27.9 | 32.6 | 37.3 |
| 1.11 | 4.64 | 9.40 | 14.1 | 18.9 | 23.6 | 28.3 | 33.1 | 37.8 |
| 1.12 | 4.71 | 9.54 | 14.3 | 19.1 | 23.9 | 28.8 | 33.6 | 38.4 |
| 1.13 | 4.77 | 9.67 | 14.5 | 19.4 | 24.3 | 29.2 | 34.1 | 38.9 |
| 1.14 | 4.84 | 9.80 | 14.7 | 19.7 | 24.6 | 29.6 | 34.5 | 39.5 |
| 1.15 | 4.91 | 9.93 | 14.9 | 19.9 | 25.0 | 30.0 | 35.0 | 40.1 |
| 1.16 | 4.97 | 10.1 | 15.1 | 20.2 | 25.3 | 30.4 | 35.5 | 40.6 |
| 1.17 | 5.04 | 10.2 | 15.3 | 20.5 | 25.7 | 30.8 | 36.0 | 41.2 |
| 1.18 | 5.11 | 10.3 | 15.6 | 20.8 | 26.0 | 31.2 | 36.5 | 41.7 |
| 1.19 | 5.17 | 10.5 | 15.8 | 21.1 | 26.4 | 31.7 | 37.0 | 42.3 |
| 1.20 | 5.24 | 10.6 | 16.0 | 21.3 | 26.7 | 32.1 | 37.5 | 42.9 |
| 1.21 | 5.31 | 10.7 | 16.2 | 21.6 | 27.1 | 32.5 | 38.0 | 43.5 |
| 1.22 | 5.38 | 10.9 | 16.4 | 21.9 | 27.4 | 33.0 | 38.5 | 44.0 |
| 1.23 | 5.44 | 11.0 | 16.6 | 22.2 | 27.8 | 33.4 | 39.0 | 44.6 |
| 1.24 | 5.51 | 11.2 | 16.8 | 22.5 | 28.1 | 33.8 | 39.5 | 45.2 |
| 1.25 | 5.58 | 11.3 | 17.0 | 22.8 | 28.5 | 34.3 | 40.0 | 45.8 |
| 1.26 | 5.65 | 11.4 | 17.2 | 23.0 | 28.9 | 34.7 | 40.5 | 46.4 |
| 1.27 | 5.72 | 11.6 | 17.4 | 23.3 | 29.2 | 35.1 | 41.1 | 47.0 |
| 1.28 | 5.79 | 11.7 | 17.7 | 23.6 | 29.6 | 35.6 | 41.6 | 47.6 |
| 1.29 | 5.86 | 11.9 | 17.9 | 23.9 | 30.0 | 36.0 | 42.1 | 48.2 |
| 1.30 | 5.93 | 12.0 | 18.1 | 24.2 | 30.3 | 36.5 | 42.6 | 48.8 |
| 1.31 | 6.00 | 12.2 | 18.3 | 24.5 | 30.7 | 36.9 | 43.1 | 49.4 |
| 1.32 | 6.07 | 12.3 | 18.5 | 24.8 | 31.1 | 37.4 | 43.7 | 50.0 |
| 1.33 | 6.15 | 12.4 | 18.8 | 25.1 | 31.4 | 37.8 | 44.2 | 50.6 |
| 1.34 | 6.22 | 12.6 | 19.0 | 25.4 | 31.8 | 38.3 | 44.7 | 51.2 |
| 1.35 | 6.29 | 12.7 | 19.2 | 25.7 | 32.2 | 38.7 | 45.3 | 51.8 |
| 1.36 | 6.36 | 12.9 | 19.4 | 26.0 | 32.6 | 39.2 | 45.8 | 52.4 |
| 1.37 | 6.43 | 13.0 | 19.6 | 26.3 | 33.0 | 39.6 | 46.3 | 53.1 |
| 1.38 | 6.51 | 13.2 | 19.9 | 26.6 | 33.3 | 40.1 | 46.9 | 53.7 |
| 1.39 | 6.58 | 13.3 | 20.1 | 26.9 | 33.7 | 40.6 | 47.4 | 54.3 |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00Wh_a^{1.522(W\wedge 0.026)}$. Discharges for 1-ft flume computed from the formula $Q = 3.95h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 1.40 | 6.65 | 13.5 | 20.3 | 27.2 | 34.1 | 41.0 | 48.0 | 54.9 |
| 1.41 | 6.73 | 13.6 | 20.6 | 27.5 | 34.5 | 41.5 | 48.5 | 55.6 |
| 1.42 | 6.80 | 13.8 | 20.8 | 27.8 | 34.9 | 42.0 | 49.1 | 56.2 |
| 1.43 | 6.88 | 13.9 | 21.0 | 28.1 | 35.3 | 42.5 | 49.6 | 56.8 |
| 1.44 | 6.95 | 14.1 | 21.2 | 28.4 | 35.7 | 42.9 | 50.2 | 57.5 |
| 1.45 | 7.03 | 14.2 | 21.5 | 28.8 | 36.1 | 43.4 | 50.8 | 58.1 |
| 1.46 | 7.10 | 14.4 | 21.7 | 29.1 | 36.5 | 43.9 | 51.3 | 58.8 |
| 1.47 | 7.18 | 14.5 | 21.9 | 29.4 | 36.9 | 44.4 | 51.9 | 59.4 |
| 1.48 | 7.25 | 14.7 | 22.2 | 29.7 | 37.3 | 44.8 | 52.4 | 60.1 |
| 1.49 | 7.33 | 14.8 | 22.4 | 30.0 | 37.7 | 45.3 | 53.0 | 60.7 |
| 1.50 | 7.41 | 15.0 | 22.6 | 30.3 | 38.1 | 45.8 | 53.6 | 61.4 |
| 1.51 | 7.48 | 15.2 | 22.9 | 30.7 | 38.5 | 46.3 | 54.2 | 62.0 |
| 1.52 | 7.56 | 15.3 | 23.1 | 31.0 | 38.9 | 46.8 | 54.7 | 62.7 |
| 1.53 | 7.64 | 15.5 | 23.4 | 31.3 | 39.3 | 47.3 | 55.3 | 63.4 |
| 1.54 | 7.71 | 15.6 | 23.6 | 31.6 | 39.7 | 47.8 | 55.9 | 64.0 |
| 1.55 | 7.79 | 15.8 | 23.8 | 31.9 | 40.1 | 48.3 | 56.5 | 64.7 |
| 1.56 | 7.87 | 15.9 | 24.1 | 32.3 | 40.5 | 48.8 | 57.1 | 65.4 |
| 1.57 | 7.95 | 16.1 | 24.3 | 32.6 | 40.9 | 49.3 | 57.6 | 66.1 |
| 1.58 | 8.03 | 16.3 | 24.6 | 32.9 | 41.3 | 49.8 | 58.2 | 66.7 |
| 1.59 | 8.11 | 16.4 | 24.8 | 33.3 | 41.7 | 50.3 | 58.8 | 67.4 |
| 1.60 | 8.18 | 16.6 | 25.1 | 33.6 | 42.2 | 50.8 | 59.4 | 68.1 |
| 1.61 | 8.26 | 16.7 | 25.3 | 33.9 | 42.6 | 51.3 | 60.0 | 68.8 |
| 1.62 | 8.34 | 16.9 | 25.5 | 34.3 | 43.0 | 51.8 | 60.6 | 69.5 |
| 1.63 | 8.42 | 17.1 | 25.8 | 34.6 | 43.4 | 52.3 | 61.2 | 70.2 |
| 1.64 | 8.50 | 17.2 | 26.0 | 34.9 | 43.9 | 52.8 | 61.8 | 70.8 |
| 1.65 | 8.58 | 17.4 | 26.3 | 35.3 | 44.3 | 53.3 | 62.4 | 71.5 |
| 1.66 | 8.66 | 17.5 | 26.5 | 35.6 | 44.7 | 53.9 | 63.0 | 72.2 |
| 1.67 | 8.75 | 17.7 | 26.8 | 35.9 | 45.1 | 54.4 | 63.6 | 72.9 |
| 1.68 | 8.83 | 17.9 | 27.0 | 36.3 | 45.6 | 54.9 | 64.3 | 73.6 |
| 1.69 | 8.91 | 18.0 | 27.3 | 36.6 | 46.0 | 55.4 | 64.9 | 74.3 |
| 1.70 | 8.99 | 18.2 | 27.5 | 37.0 | 46.4 | 55.9 | 65.5 | 75.1 |
| 1.71 | 9.07 | 18.4 | 27.8 | 37.3 | 46.9 | 56.5 | 66.1 | 75.8 |
| 1.72 | 9.16 | 18.5 | 28.1 | 37.6 | 47.3 | 57.0 | 66.7 | 76.5 |
| 1.73 | 9.24 | 18.7 | 28.3 | 38.0 | 47.7 | 57.5 | 67.3 | 77.2 |
| 1.74 | 9.32 | 18.9 | 28.6 | 38.3 | 48.2 | 58.0 | 68.0 | 77.9 |
| 1.75 | 9.40 | 19.0 | 28.8 | 38.7 | 48.6 | 58.6 | 68.6 | 78.6 |
| 1.76 | 9.49 | 19.2 | 29.1 | 39.0 | 49.1 | 59.1 | 69.2 | 79.4 |
| 1.77 | 9.57 | 19.4 | 29.3 | 39.4 | 49.5 | 59.7 | 69.8 | 80.1 |
| 1.78 | 9.65 | 19.6 | 29.6 | 39.7 | 49.9 | 60.2 | 70.5 | 80.8 |
| 1.79 | 9.74 | 19.7 | 29.9 | 40.1 | 50.4 | 60.7 | 71.1 | 81.5 |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00 W h_a^{1.522(W^{0.026})}$. Discharges for 1-ft flume computed from the formula $Q = 3.95 h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 1.80 | 9.82 | 19.9 | 30.1 | 40.4 | 50.8 | 61.3 | 71.8 | 82.3 |
| 1.81 | 9.91 | 20.1 | 30.4 | 40.8 | 51.3 | 61.8 | 72.4 | 83.0 |
| 1.82 | 9.99 | 20.2 | 30.7 | 41.2 | 51.7 | 62.4 | 73.0 | 83.7 |
| 1.83 | 10.1 | 20.4 | 30.9 | 41.5 | 52.2 | 62.9 | 73.7 | 84.5 |
| 1.84 | 10.2 | 20.6 | 31.2 | 41.9 | 52.6 | 63.5 | 74.3 | 85.2 |
| 1.85 | 10.2 | 20.8 | 31.4 | 42.2 | 53.1 | 64.0 | 75.0 | 86.0 |
| 1.86 | 10.3 | 20.9 | 31.7 | 42.6 | 53.5 | 64.6 | 75.6 | 86.7 |
| 1.87 | 10.4 | 21.1 | 32.0 | 43.0 | 54.0 | 65.1 | 76.3 | 87.5 |
| 1.88 | 10.5 | 21.3 | 32.3 | 43.3 | 54.5 | 65.7 | 76.9 | 88.2 |
| 1.89 | 10.6 | 21.5 | 32.5 | 43.7 | 54.9 | 66.2 | 77.6 | 89.0 |
| 1.90 | 10.7 | 21.6 | 32.8 | 44.1 | 55.4 | 66.8 | 78.2 | 89.7 |
| 1.91 | 10.8 | 21.8 | 33.1 | 44.4 | 55.9 | 67.4 | 78.9 | 90.5 |
| 1.92 | 10.9 | 22.0 | 33.3 | 44.8 | 56.3 | 67.9 | 79.6 | 91.3 |
| 1.93 | 10.9 | 22.2 | 33.6 | 45.2 | 56.8 | 68.5 | 80.2 | 92.0 |
| 1.94 | 11.0 | 22.3 | 33.9 | 45.5 | 57.3 | 69.0 | 80.9 | 92.8 |
| 1.95 | 11.1 | 22.5 | 34.2 | 45.9 | 57.7 | 69.6 | 81.6 | 93.6 |
| 1.96 | 11.2 | 22.7 | 34.4 | 46.3 | 58.2 | 70.2 | 82.2 | 94.3 |
| 1.97 | 11.3 | 22.9 | 34.7 | 46.6 | 58.7 | 70.8 | 82.9 | 95.1 |
| 1.98 | 11.4 | 23.1 | 35.0 | 47.0 | 59.1 | 71.3 | 83.6 | 95.9 |
| 1.99 | 11.5 | 23.2 | 35.3 | 47.4 | 59.6 | 71.9 | 84.3 | 96.7 |
| 2.00 | 11.6 | 23.4 | 35.5 | 47.8 | 60.1 | 72.5 | 84.9 | 97.4 |
| 2.01 | 11.7 | 23.6 | 35.8 | 48.1 | 60.6 | 73.1 | 85.6 | 98.2 |
| 2.02 | 11.7 | 23.8 | 36.1 | 48.5 | 61.0 | 73.6 | 86.3 | 99.0 |
| 2.03 | 11.8 | 24.0 | 36.4 | 48.9 | 61.5 | 74.2 | 87.0 | 99.8 |
| 2.04 | 11.9 | 24.1 | 36.7 | 49.3 | 62.0 | 74.8 | 87.7 | 101. |
| 2.05 | 12.0 | 24.3 | 36.9 | 49.7 | 62.5 | 75.4 | 88.4 | 101. |
| 2.06 | 12.1 | 24.5 | 37.2 | 50.0 | 63.0 | 76.0 | 89.1 | 102. |
| 2.07 | 12.2 | 24.7 | 37.5 | 50.4 | 63.5 | 76.6 | 89.7 | 103. |
| 2.08 | 12.3 | 24.9 | 37.8 | 50.8 | 63.9 | 77.2 | 90.4 | 104. |
| 2.09 | 12.4 | 25.1 | 38.1 | 51.2 | 64.4 | 77.8 | 91.1 | 105. |
| 2.10 | 12.5 | 25.3 | 38.4 | 51.6 | 64.9 | 78.3 | 91.8 | 105. |
| 2.11 | 12.6 | 25.4 | 38.6 | 52.0 | 65.4 | 78.9 | 92.5 | 106. |
| 2.12 | 12.7 | 25.6 | 38.9 | 52.4 | 65.9 | 79.5 | 93.2 | 107. |
| 2.13 | 12.8 | 25.8 | 39.2 | 52.8 | 66.4 | 80.1 | 93.9 | 108. |
| 2.14 | 12.8 | 26.0 | 39.5 | 53.1 | 66.9 | 80.7 | 94.7 | 109. |
| 2.15 | 12.9 | 26.2 | 39.8 | 53.5 | 67.4 | 81.3 | 95.4 | 109. |
| 2.16 | 13.0 | 26.4 | 40.1 | 53.9 | 67.9 | 81.9 | 96.1 | 110. |
| 2.17 | 13.1 | 26.6 | 40.4 | 54.3 | 68.4 | 82.6 | 96.8 | 111. |
| 2.18 | 13.2 | 26.8 | 40.7 | 54.7 | 68.9 | 83.2 | 97.5 | 112. |
| 2.19 | 13.3 | 27.0 | 41.0 | 55.1 | 69.4 | 83.8 | 98.2 | 113. |

**Table A8-12 [continued]**. Free-flow discharges in $ft^3$/sec through 1- to 8-foot Parshall flumes. Discharges for 2- to 8-ft flumes computed from the formula $Q = 4.00 W h_a^{1.522(W^{0.026})}$. Discharges for 1-ft flume computed from the formula $Q = 3.95 h_a^{1.55}$.

| Upper Head $h_a$, ft | Discharge for flumes of various throat widths, $W$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
| 2.20 | 13.4 | 27.1 | 41.3 | 55.5 | 69.9 | 84.4 | 98.9 | 114. |
| 2.21 | 13.5 | 27.3 | 41.5 | 55.9 | 70.4 | 85.0 | 99.7 | 114. |
| 2.22 | 13.6 | 27.5 | 41.8 | 56.3 | 70.9 | 85.6 | 100. | 115. |
| 2.23 | 13.7 | 27.7 | 42.1 | 56.7 | 71.4 | 86.2 | 101. | 116. |
| 2.24 | 13.8 | 27.9 | 42.4 | 57.1 | 71.9 | 86.8 | 102. | 117. |
| 2.25 | 13.9 | 28.1 | 42.7 | 57.5 | 72.4 | 87.5 | 103. | 118. |
| 2.26 | 14.0 | 28.3 | 43.0 | 57.9 | 72.9 | 88.1 | 103. | 119. |
| 2.27 | 14.1 | 28.5 | 43.3 | 58.3 | 73.5 | 88.7 | 104. | 119. |
| 2.28 | 14.2 | 28.7 | 43.6 | 58.7 | 74.0 | 89.3 | 105. | 120. |
| 2.29 | 14.3 | 28.9 | 43.9 | 59.1 | 74.5 | 89.9 | 105. | 121. |
| 2.30 | 14.4 | 29.1 | 44.2 | 59.5 | 75.0 | 90.6 | 106. | 122. |
| 2.31 | 14.5 | 29.3 | 44.5 | 60.0 | 75.5 | 91.2 | 107. | 123. |
| 2.32 | 14.6 | 29.5 | 44.8 | 60.4 | 76.0 | 91.8 | 108. | 124. |
| 2.33 | 14.7 | 29.7 | 45.1 | 60.8 | 76.6 | 92.5 | 108. | 125. |
| 2.34 | 14.8 | 29.9 | 45.4 | 61.2 | 77.1 | 93.1 | 109. | 125. |
| 2.35 | 14.9 | 30.1 | 45.7 | 61.6 | 77.6 | 93.7 | 110. | 126. |
| 2.36 | 14.9 | 30.3 | 46.0 | 62.0 | 78.1 | 94.4 | 111. | 127. |
| 2.37 | 15.0 | 30.5 | 46.4 | 62.4 | 78.7 | 95.0 | 111. | 128. |
| 2.38 | 15.1 | 30.7 | 46.7 | 62.9 | 79.2 | 95.7 | 112. | 129. |
| 2.39 | 15.2 | 30.9 | 47.0 | 63.3 | 79.7 | 96.3 | 113. | 130. |
| 2.40 | 15.3 | 31.1 | 47.3 | 63.7 | 80.2 | 96.9 | 114. | 131. |
| 2.41 | 15.4 | 31.3 | 47.6 | 64.1 | 80.8 | 97.6 | 114. | 131. |
| 2.42 | 15.5 | 31.5 | 47.9 | 64.5 | 81.3 | 98.2 | 115. | 132. |
| 2.43 | 15.6 | 31.7 | 48.2 | 64.9 | 81.8 | 98.9 | 116. | 133. |
| 2.44 | 15.7 | 31.9 | 48.5 | 65.4 | 82.4 | 99.5 | 117. | 134. |
| 2.45 | 15.8 | 32.1 | 48.8 | 65.8 | 82.9 | 100. | 118. | 135. |
| 2.46 | 15.9 | 32.3 | 49.1 | 66.2 | 83.5 | 101. | 118. | 136. |
| 2.47 | 16.0 | 32.5 | 49.5 | 66.6 | 84.0 | 101. | 119. | 137. |
| 2.48 | 16.1 | 32.7 | 49.8 | 67.1 | 84.5 | 102. | 120. | 138. |
| 2.49 | 16.2 | 32.9 | 50.1 | 67.5 | 85.1 | 103. | 121. | 139. |
| 2.50 | 16.3 | 33.1 | 50.4 | 67.9 | 85.6 | 103. | 121. | 139. |

**Table A8-13**. Free-flow discharge through 10-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 39.38 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.99 | 1.15 | 1.32 | 1.51 | 1.69 | 1.89 | 2.10 | 2.31 | 2.53 | 2.76 |
| .20 | 3.00 | 3.24 | 3.49 | 3.75 | 4.01 | 4.29 | 4.56 | 4.85 | 5.14 | 5.43 |
| .30 | 5.74 | 6.05 | 6.36 | 6.68 | 7.01 | 7.34 | 7.68 | 8.02 | 8.37 | 8.73 |
| .40 | 9.09 | 9.46 | 9.83 | 10.2 | 10.6 | 11.0 | 11.4 | 11.8 | 12.2 | 12.6 |
| .50 | 13.0 | 13.4 | 13.8 | 14.3 | 14.7 | 15.1 | 15.6 | 16.0 | 16.5 | 16.9 |
| .60 | 17.4 | 17.9 | 18.3 | 18.8 | 19.3 | 19.8 | 20.3 | 20.7 | 21.2 | 21.7 |
| .70 | 22.3 | 22.8 | 23.3 | 23.8 | 24.3 | 24.9 | 25.4 | 25.9 | 26.5 | 27.0 |
| .80 | 27.6 | 28.1 | 28.7 | 29.2 | 29.8 | 30.4 | 30.9 | 31.5 | 32.1 | 32.7 |
| .90 | 33.3 | 33.9 | 34.5 | 35.1 | 35.7 | 36.3 | 36.9 | 37.5 | 38.1 | 38.8 |
| 1.00 | 39.4 | 40.0 | 40.6 | 41.3 | 41.9 | 42.6 | 43.2 | 43.9 | 44.5 | 45.2 |
| 1.10 | 45.9 | 46.5 | 47.2 | 47.9 | 48.6 | 49.2 | 49.9 | 50.6 | 51.3 | 52.0 |
| 1.20 | 52.7 | 53.4 | 54.1 | 54.8 | 55.6 | 56.3 | 57.0 | 57.7 | 58.5 | 59.2 |
| 1.30 | 59.9 | 60.7 | 61.4 | 62.1 | 62.9 | 63.7 | 64.4 | 65.2 | 65.9 | 66.7 |
| 1.40 | 67.5 | 68.2 | 69.0 | 69.8 | 70.6 | 71.4 | 72.2 | 72.9 | 73.7 | 74.5 |
| 1.50 | 75.3 | 76.1 | 77.0 | 77.8 | 78.6 | 79.4 | 80.2 | 81.0 | 81.9 | 82.7 |
| 1.60 | 83.5 | 84.4 | 85.2 | 86.1 | 86.9 | 87.8 | 88.6 | 89.5 | 90.3 | 91.2 |
| 1.70 | 92.0 | 92.9 | 93.8 | 94.7 | 95.5 | 96.4 | 97.3 | 98.2 | 99.1 | 100. |
| 1.80 | 101. | 102. | 103. | 104. | 104. | 105. | 106. | 107. | 108. | 109. |
| 1.90 | 110. | 111. | 112. | 113. | 114. | 115. | 116. | 117. | 117. | 118. |
| 2.00 | 119. | 120. | 121. | 122. | 123. | 124. | 125. | 126. | 127. | 128. |
| 2.10 | 129. | 130. | 131. | 132. | 133. | 134. | 135. | 136. | 137. | 138. |
| 2.20 | 139. | 140. | 141. | 142. | 143. | 144. | 145. | 146. | 147. | 148. |
| 2.30 | 149. | 150. | 151. | 152. | 153. | 155. | 156. | 157. | 158. | 159. |
| 2.40 | 160. | 161. | 162. | 163. | 164. | 165. | 166. | 167. | 168. | 170. |
| 2.50 | 171. | 172. | 173. | 174. | 175. | 176. | 177. | 178. | 179. | 181. |
| 2.60 | 182. | 183. | 184. | 185. | 186. | 187. | 188. | 190. | 191. | 192. |
| 2.70 | 193. | 194. | 195. | 196. | 198. | 199. | 200. | 201. | 202. | 203. |
| 2.80 | 205. | 206. | 207. | 208. | 209. | 210. | 212. | 213. | 214. | 215. |
| 2.90 | 216. | 218. | 219. | 220. | 221. | 222. | 224. | 225. | 226. | 227. |
| 3.00 | 228. | 230. | 231. | 232. | 233. | 235. | 236. | 237. | 238. | 239. |
| 3.10 | 241. | 242. | 243. | 244. | 246. | 247. | 248. | 249. | 251. | 252. |
| 3.20 | 253. | 254. | 256. | 257. | 258. | 260. | 261. | 262. | 263. | 265. |
| 3.30 | 266. | 267. | 269. | 270. | 271. | 272. | 274. | 275. | 276. | 278. |
| 3.40 | 279. | 280. | 282. | 283. | 284. | 286. | 287. | 288. | 290. | 291. |
| 3.50 | 292. | 294. | 295. | 296. | 298. | 299. | 300. | 302. | 303. | 304. |
| 3.60 | 306. | 307. | 308. | 310. | 311. | 313. | 314. | 315. | 317. | 318. |
| 3.70 | 319. | 321. | 322. | 324. | 325. | 326. | 328. | 329. | 331. | 332. |
| 3.80 | 333. | 335. | 336. | 338. | 339. | 340. | 342. | 343. | 345. | 346. |
| 3.90 | 348. | 349. | 350. | 352. | 353. | 355. | 356. | 358. | 359. | 360. |
| 4.00 | 362. | 363. | 365. | 366. | 368. | 369. | 371. | 372. | 374. | 375. |
| 4.10 | 376. | 378. | 379. | 381. | 382. | 384. | 385. | 387. | 388. | 390. |
| 4.20 | 391. | 393. | 394. | 396. | 397. | 399. | 400. | 402. | 403. | 405. |
| 4.30 | 406. | 408. | 409. | 411. | 412. | 414. | 415. | 417. | 418. | 420. |
| 4.40 | 422. | 423. | 425. | 426. | 428. | 429. | 431. | 432. | 434. | 435. |
| 4.50 | 437. | 438. | 440. | 442. | 443. | 445. | 446. | 448. | 449. | 451. |
| 4.60 | 453. | 454. | 456. | 457. | 459. | 460. | 462. | 464. | 465. | 467. |
| 4.70 | 468. | 470. | 472. | 473. | 475. | 476. | 478. | 480. | 481. | 483. |
| 4.80 | 484. | 486. | 488. | 489. | 491. | 493. | 494. | 496. | 497. | 499. |
| 4.90 | 501. | 502. | 504. | 506. | 507. | 509. | 511. | 512. | 514. | 516. |
| 5.00 | 517. | 519. | 520. | 522. | 524. | 525. | 527. | 529. | 530. | 532. |

**Table A8-14**. Free-flow discharge through 12-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 46.75 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 1.17 | 1.37 | 1.57 | 1.79 | 2.01 | 2.25 | 2.49 | 2.74 | 3.01 | 3.28 |
| .20 | 3.56 | 3.85 | 4.15 | 4.45 | 4.77 | 5.09 | 5.42 | 5.75 | 6.10 | 6.45 |
| .30 | 6.81 | 7.18 | 7.55 | 7.93 | 8.32 | 8.72 | 9.12 | 9.53 | 9.94 | 10.4 |
| .40 | 10.8 | 11.2 | 11.7 | 12.1 | 12.6 | 13.0 | 13.5 | 14.0 | 14.4 | 14.9 |
| .50 | 15.4 | 15.9 | 16.4 | 16.9 | 17.4 | 18.0 | 18.5 | 19.0 | 19.6 | 20.1 |
| .60 | 20.6 | 21.2 | 21.8 | 22.3 | 22.9 | 23.5 | 24.0 | 24.6 | 25.2 | 25.8 |
| .70 | 26.4 | 27.0 | 27.6 | 28.3 | 28.9 | 29.5 | 30.1 | 30.8 | 31.4 | 32.1 |
| .80 | 32.7 | 33.4 | 34.0 | 34.7 | 35.4 | 36.0 | 36.7 | 37.4 | 38.1 | 38.8 |
| .90 | 39.5 | 40.2 | 40.9 | 41.6 | 42.3 | 43.1 | 43.8 | 44.5 | 45.3 | 46.0 |
| 1.00 | 46.8 | 47.5 | 48.3 | 49.0 | 49.8 | 50.5 | 51.3 | 52.1 | 52.9 | 53.7 |
| 1.10 | 54.5 | 55.2 | 56.0 | 56.8 | 57.7 | 58.5 | 59.3 | 60.1 | 60.9 | 61.8 |
| 1.20 | 62.6 | 63.4 | 64.3 | 65.1 | 66.0 | 66.8 | 67.7 | 68.5 | 69.4 | 70.3 |
| 1.30 | 71.1 | 72.0 | 72.9 | 73.8 | 74.7 | 75.6 | 76.5 | 77.4 | 78.3 | 79.2 |
| 1.40 | 80.1 | 81.0 | 81.9 | 82.9 | 83.8 | 84.7 | 85.7 | 86.6 | 87.5 | 88.5 |
| 1.50 | 89.4 | 90.4 | 91.4 | 92.3 | 93.3 | 94.3 | 95.2 | 96.2 | 97.2 | 98.2 |
| 1.60 | 99.2 | 100. | 101. | 102. | 103. | 104. | 105. | 106. | 107. | 108. |
| 1.70 | 109. | 110. | 111. | 112. | 113. | 114. | 116. | 117. | 118. | 119. |
| 1.80 | 120. | 121. | 122. | 123. | 124. | 125. | 126. | 127. | 128. | 129. |
| 1.90 | 131. | 132. | 133. | 134. | 135. | 136. | 137. | 138. | 139. | 141. |
| 2.00 | 142. | 143. | 144. | 145. | 146. | 147. | 149. | 150. | 151. | 152. |
| 2.10 | 153. | 154. | 156. | 157. | 158. | 159. | 160. | 161. | 163. | 164. |
| 2.20 | 165. | 166. | 167. | 169. | 170. | 171. | 172. | 174. | 175. | 176. |
| 2.30 | 177. | 178. | 180. | 181. | 182. | 183. | 185. | 186. | 187. | 188. |
| 2.40 | 190. | 191. | 192. | 194. | 195. | 196. | 197. | 199. | 200. | 201. |
| 2.50 | 203. | 204. | 205. | 206. | 208. | 209. | 210. | 212. | 213. | 214. |
| 2.60 | 216. | 217. | 218. | 220. | 221. | 222. | 224. | 225. | 226. | 228. |
| 2.70 | 229. | 230. | 232. | 233. | 235. | 236. | 237. | 239. | 240. | 241. |
| 2.80 | 243. | 244. | 246. | 247. | 248. | 250. | 251. | 253. | 254. | 255. |
| 2.90 | 257. | 258. | 260. | 261. | 263. | 264. | 265. | 267. | 268. | 270. |
| 3.00 | 271. | 273. | 274. | 275. | 277. | 278. | 280. | 281. | 283. | 284. |
| 3.10 | 286. | 287. | 289. | 290. | 292. | 293. | 295. | 296. | 298. | 299. |
| 3.20 | 301. | 302. | 304. | 305. | 307. | 308. | 310. | 311. | 313. | 314. |
| 3.30 | 316. | 317. | 319. | 320. | 322. | 323. | 325. | 327. | 328. | 330. |
| 3.40 | 331. | 333. | 334. | 336. | 338. | 339. | 341. | 342. | 344. | 345. |
| 3.50 | 347. | 349. | 350. | 352. | 353. | 355. | 357. | 358. | 360. | 361. |
| 3.60 | 363. | 365. | 366. | 368. | 369. | 371. | 373. | 374. | 376. | 378. |
| 3.70 | 379. | 381. | 383. | 384. | 386. | 387. | 389. | 391. | 392. | 394. |
| 3.80 | 396. | 397. | 399. | 401. | 402. | 404. | 406. | 407. | 409. | 411. |
| 3.90 | 413. | 414. | 416. | 418. | 419. | 421. | 423. | 424. | 426. | 428. |
| 4.00 | 430. | 431. | 433. | 435. | 437. | 438. | 440. | 442. | 443. | 445. |
| 4.10 | 447. | 449. | 450. | 452. | 454. | 456. | 457. | 459. | 461. | 463. |
| 4.20 | 464. | 466. | 468. | 470. | 472. | 473. | 475. | 477. | 479. | 481. |
| 4.30 | 482. | 484. | 486. | 488. | 490. | 491. | 493. | 495. | 497. | 499. |
| 4.40 | 500. | 502. | 504. | 506. | 508. | 510. | 511. | 513. | 515. | 517. |
| 4.50 | 519. | 521. | 522. | 524. | 526. | 528. | 530. | 532. | 534. | 535. |
| 4.60 | 537. | 539. | 541. | 543. | 545. | 547. | 549. | 550. | 552. | 554. |
| 4.70 | 556. | 558. | 560. | 562. | 564. | 566. | 567. | 569. | 571. | 573. |
| 4.80 | 575. | 577. | 579. | 581. | 583. | 585. | 587. | 589. | 591. | 592. |
| 4.90 | 594. | 596. | 598. | 600. | 602. | 604. | 606. | 608. | 610. | 612. |
| 5.00 | 614. | 616. | 618. | 620. | 622. | 624. | 626. | 628. | 630. | 632. |

**Table A8-15**. Free-flow discharge through 15-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 57.81 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 8.42 | 8.88 | 9.34 | 9.81 | 10.3 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 |
| .40 | 13.3 | 13.9 | 14.4 | 15.0 | 15.5 | 16.1 | 16.7 | 17.3 | 17.9 | 18.5 |
| .50 | 19.1 | 19.7 | 20.3 | 20.9 | 21.6 | 22.2 | 22.9 | 23.5 | 24.2 | 24.9 |
| .60 | 25.5 | 26.2 | 26.9 | 27.6 | 28.3 | 29.0 | 29.7 | 30.5 | 31.2 | 31.9 |
| .70 | 32.7 | 33.4 | 34.2 | 34.9 | 35.7 | 36.5 | 37.3 | 38.1 | 38.8 | 39.6 |
| .80 | 40.5 | 41.3 | 42.1 | 42.9 | 43.7 | 44.6 | 45.4 | 46.3 | 47.1 | 48.0 |
| .90 | 48.8 | 49.7 | 50.6 | 51.5 | 52.4 | 53.3 | 54.2 | 55.1 | 56.0 | 56.9 |
| 1.00 | 57.8 | 58.7 | 59.7 | 60.6 | 61.6 | 62.5 | 63.5 | 64.4 | 65.4 | 66.4 |
| 1.10 | 67.3 | 68.3 | 69.3 | 70.3 | 71.3 | 72.3 | 73.3 | 74.3 | 75.3 | 76.4 |
| 1.20 | 77.4 | 78.4 | 79.5 | 80.5 | 81.6 | 82.6 | 83.7 | 84.7 | 85.8 | 86.9 |
| 1.30 | 88.0 | 89.1 | 90.1 | 91.2 | 92.3 | 93.4 | 94.6 | 95.7 | 96.8 | 97.9 |
| 1.40 | 99.0 | 100. | 101. | 102. | 104. | 105. | 106. | 107. | 108. | 109. |
| 1.50 | 111. | 112. | 113. | 114. | 115. | 117. | 118. | 119. | 120. | 121. |
| 1.60 | 123. | 124. | 125. | 126. | 128. | 129. | 130. | 131. | 133. | 134. |
| 1.70 | 135. | 136. | 138. | 139. | 140. | 142. | 143. | 144. | 145. | 147. |
| 1.80 | 148. | 149. | 151. | 152. | 153. | 155. | 156. | 157. | 159. | 160. |
| 1.90 | 161. | 163. | 164. | 166. | 167. | 168. | 170. | 171. | 172. | 174. |
| 2.00 | 175. | 177. | 178. | 179. | 181. | 182. | 184. | 185. | 187. | 188. |
| 2.10 | 189. | 191. | 192. | 194. | 195. | 197. | 198. | 200. | 201. | 203. |
| 2.20 | 204. | 206. | 207. | 209. | 210. | 212. | 213. | 215. | 216. | 218. |
| 2.30 | 219. | 221. | 222. | 224. | 225. | 227. | 228. | 230. | 231. | 233. |
| 2.40 | 235. | 236. | 238. | 239. | 241. | 242. | 244. | 246. | 247. | 249. |
| 2.50 | 250. | 252. | 254. | 255. | 257. | 259. | 260. | 262. | 263. | 265. |
| 2.60 | 267. | 268. | 270. | 272. | 273. | 275. | 277. | 278. | 280. | 282. |
| 2.70 | 283. | 285. | 287. | 288. | 290. | 292. | 293. | 295. | 297. | 299. |
| 2.80 | 300. | 302. | 304. | 305. | 307. | 309. | 311. | 312. | 314. | 316. |
| 2.90 | 318. | 319. | 321. | 323. | 325. | 326. | 328. | 330. | 332. | 333. |
| 3.00 | 335. | 337. | 339. | 341. | 342. | 344. | 346. | 348. | 350. | 352. |
| 3.10 | 353. | 355. | 357. | 359. | 361. | 362. | 364. | 366. | 368. | 370. |
| 3.20 | 372. | 374. | 375. | 377. | 379. | 381. | 383. | 385. | 387. | 389. |
| 3.30 | 391. | 392. | 394. | 396. | 398. | 400. | 402. | 404. | 406. | 408. |
| 3.40 | 410. | 412. | 413. | 415. | 417. | 419. | 421. | 423. | 425. | 427. |
| 3.50 | 429. | 431. | 433. | 435. | 437. | 439. | 441. | 443. | 445. | 447. |
| 3.60 | 449. | 451. | 453. | 455. | 457. | 459. | 461. | 463. | 465. | 467. |
| 3.70 | 469. | 471. | 473. | 475. | 477. | 479. | 481. | 483. | 485. | 487. |
| 3.80 | 489. | 491. | 494. | 496. | 498. | 500. | 502. | 504. | 506. | 508. |
| 3.90 | 510. | 512. | 514. | 516. | 519. | 521. | 523. | 525. | 527. | 529. |
| 4.00 | 531. | 533. | 536. | 538. | 540. | 542. | 544. | 546. | 548. | 551. |
| 4.10 | 553. | 555. | 557. | 559. | 561. | 563. | 566. | 568. | 570. | 572. |
| 4.20 | 574. | 577. | 579. | 581. | 583. | 585. | 588. | 590. | 592. | 594. |
| 4.30 | 596. | 599. | 601. | 603. | 605. | 608. | 610. | 612. | 614. | 617. |
| 4.40 | 619. | 621. | 623. | 626. | 628. | 630. | 632. | 635. | 637. | 639. |
| 4.50 | 641. | 644. | 646. | 648. | 651. | 653. | 655. | 657. | 660. | 662. |
| 4.60 | 664. | 667. | 669. | 671. | 674. | 676. | 678. | 681. | 683. | 685. |
| 4.70 | 688. | 690. | 692. | 695. | 697. | 699. | 702. | 704. | 706. | 709. |
| 4.80 | 711. | 714. | 716. | 718. | 721. | 723. | 725. | 728. | 730. | 733. |
| 4.90 | 735. | 737. | 740. | 742. | 745. | 747. | 750. | 752. | 754. | 757. |
| 5.00 | 759. | 762. | 764. | 766. | 769. | 771. | 774. | 776. | 779. | 781. |
| 5.10 | 784. | 786. | 789. | 791. | 793. | 796. | 798. | 801. | 803. | 806. |
| 5.20 | 808. | 811. | 813. | 816. | 818. | 821. | 823. | 826. | 828. | 831. |
| 5.30 | 833. | 836. | 838. | 841. | 843. | 846. | 849. | 851. | 854. | 856. |
| 5.40 | 859. | 861. | 864. | 866. | 869. | 871. | 874. | 877. | 879. | 882. |
| 5.50 | 884. | 887. | 889. | 892. | 895. | 897. | 900. | 902. | 905. | 908. |
| 5.60 | 910. | 913. | 915. | 918. | 921. | 923. | 926. | 928. | 931. | 934. |
| 5.70 | 936. | 939. | 942. | 944. | 947. | 949. | 952. | 955. | 957. | 960. |
| 5.80 | 963. | 965. | 968. | 971. | 973. | 976. | 979. | 981. | 984. | 987. |
| 5.90 | 989. | 992. | 995. | 997. | 1000. | 1003. | 1006. | 1008. | 1011. | 1014. |
| 6.00 | 1016. | 1019. | 1022. | 1024. | 1027. | 1030. | 1033. | 1035. | 1038. | 1041. |

**Table A8-16**. Free-flow discharge through 20-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 76.25 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 11.1 | 11.7 | 12.3 | 12.9 | 13.6 | 14.2 | 14.9 | 15.5 | 16.2 | 16.9 |
| .40 | 17.6 | 18.3 | 19.0 | 19.8 | 20.5 | 21.3 | 22.0 | 22.8 | 23.6 | 24.4 |
| .50 | 25.2 | 26.0 | 26.8 | 27.6 | 28.4 | 29.3 | 30.2 | 31.0 | 31.9 | 32.8 |
| .60 | 33.7 | 34.6 | 35.5 | 36.4 | 37.3 | 38.3 | 39.2 | 40.2 | 41.1 | 42.1 |
| .70 | 43.1 | 44.1 | 45.1 | 46.1 | 47.1 | 48.1 | 49.2 | 50.2 | 51.2 | 52.3 |
| .80 | 53.4 | 54.4 | 55.5 | 56.6 | 57.7 | 58.8 | 59.9 | 61.0 | 62.1 | 63.3 |
| .90 | 64.4 | 65.6 | 66.7 | 67.9 | 69.1 | 70.2 | 71.4 | 72.6 | 73.8 | 75.0 |
| 1.00 | 76.3 | 77.5 | 78.7 | 79.9 | 81.2 | 82.4 | 83.7 | 85.0 | 86.2 | 87.5 |
| 1.10 | 88.8 | 90.1 | 91.4 | 92.7 | 94.0 | 95.4 | 96.7 | 98.0 | 99.4 | 101. |
| 1.20 | 102. | 103. | 105. | 106. | 108. | 109. | 110. | 112. | 113. | 115. |
| 1.30 | 116. | 117. | 119. | 120. | 122. | 123. | 125. | 126. | 128. | 129. |
| 1.40 | 131. | 132. | 134. | 135. | 137. | 138. | 140. | 141. | 143. | 144. |
| 1.50 | 146. | 147. | 149. | 151. | 152. | 154. | 155. | 157. | 159. | 160. |
| 1.60 | 162. | 163. | 165. | 167. | 168. | 170. | 172. | 173. | 175. | 177. |
| 1.70 | 178. | 180. | 182. | 183. | 185. | 187. | 188. | 190. | 192. | 194. |
| 1.80 | 195. | 197. | 199. | 201. | 202. | 204. | 206. | 208. | 209. | 211. |
| 1.90 | 213. | 215. | 217. | 218. | 220. | 222. | 224. | 226. | 227. | 229. |
| 2.00 | 231. | 233. | 235. | 237. | 239. | 240. | 242. | 244. | 246. | 248. |
| 2.10 | 250. | 252. | 254. | 256. | 258. | 260. | 261. | 263. | 265. | 267. |
| 2.20 | 269. | 271. | 273. | 275. | 277. | 279. | 281. | 283. | 285. | 287. |
| 2.30 | 289. | 291. | 293. | 295. | 297. | 299. | 301. | 303. | 305. | 307. |
| 2.40 | 309. | 312. | 314. | 316. | 318. | 320. | 322. | 324. | 326. | 328. |
| 2.50 | 330. | 332. | 335. | 337. | 339. | 341. | 343. | 345. | 347. | 350. |
| 2.60 | 352. | 354. | 356. | 358. | 360. | 363. | 365. | 367. | 369. | 371. |
| 2.70 | 374. | 376. | 378. | 380. | 383. | 385. | 387. | 389. | 391. | 394. |
| 2.80 | 396. | 398. | 401. | 403. | 405. | 407. | 410. | 412. | 414. | 417. |
| 2.90 | 419. | 421. | 423. | 426. | 428. | 430. | 433. | 435. | 438. | 440. |
| 3.00 | 442. | 445. | 447. | 449. | 452. | 454. | 456. | 459. | 461. | 464. |
| 3.10 | 466. | 468. | 471. | 473. | 476. | 478. | 481. | 483. | 485. | 488. |
| 3.20 | 490. | 493. | 495. | 498. | 500. | 503. | 505. | 508. | 510. | 513. |
| 3.30 | 515. | 518. | 520. | 523. | 525. | 528. | 530. | 533. | 535. | 538. |
| 3.40 | 540. | 543. | 545. | 548. | 550. | 553. | 556. | 558. | 561. | 563. |
| 3.50 | 566. | 569. | 571. | 574. | 576. | 579. | 582. | 584. | 587. | 589. |
| 3.60 | 592. | 595. | 597. | 600. | 603. | 605. | 608. | 611. | 613. | 616. |
| 3.70 | 619. | 621. | 624. | 627. | 629. | 632. | 635. | 637. | 640. | 643. |
| 3.80 | 645. | 648. | 651. | 654. | 656. | 659. | 662. | 665. | 667. | 670. |
| 3.90 | 673. | 676. | 678. | 681. | 684. | 687. | 690. | 692. | 695. | 698. |
| 4.00 | 701. | 704. | 706. | 709. | 712. | 715. | 718. | 720. | 723. | 726. |
| 4.10 | 729. | 732. | 735. | 737. | 740. | 743. | 746. | 749. | 752. | 755. |
| 4.20 | 758. | 760. | 763. | 766. | 769. | 772. | 775. | 778. | 781. | 784. |
| 4.30 | 787. | 790. | 793. | 795. | 798. | 801. | 804. | 807. | 810. | 813. |
| 4.40 | 816. | 819. | 822. | 825. | 828. | 831. | 834. | 837. | 840. | 843. |
| 4.50 | 846. | 849. | 852. | 855. | 858. | 861. | 864. | 867. | 870. | 873. |
| 4.60 | 876. | 879. | 882. | 885. | 889. | 892. | 895. | 898. | 901. | 904. |
| 4.70 | 907. | 910. | 913. | 916. | 919. | 922. | 926. | 929. | 932. | 935. |
| 4.80 | 938. | 941. | 944. | 947. | 951. | 954. | 957. | 960. | 963. | 966. |
| 4.90 | 970. | 973. | 976. | 979. | 982. | 985. | 989. | 992. | 995. | 998. |
| 5.00 | 1001. | 1005. | 1008. | 1011. | 1014. | 1017. | 1021. | 1024. | 1027. | 1030. |
| 5.10 | 1034. | 1037. | 1040. | 1043. | 1047. | 1050. | 1053. | 1056. | 1060. | 1063. |
| 5.20 | 1066. | 1069. | 1073. | 1076. | 1079. | 1083. | 1086. | 1089. | 1093. | 1096. |
| 5.30 | 1099. | 1103. | 1106. | 1109. | 1113. | 1116. | 1119. | 1123. | 1126. | 1129. |
| 5.40 | 1133. | 1136. | 1139. | 1143. | 1146. | 1149. | 1153. | 1156. | 1160. | 1163. |
| 5.50 | 1166. | 1170. | 1173. | 1177. | 1180. | 1183. | 1187. | 1190. | 1194. | 1197. |
| 5.60 | 1200. | 1204. | 1207. | 1211. | 1214. | 1218. | 1221. | 1225. | 1228. | 1231. |
| 5.70 | 1235. | 1238. | 1242. | 1245. | 1249. | 1252. | 1256. | 1259. | 1263. | 1266. |
| 5.80 | 1270. | 1273. | 1277. | 1280. | 1284. | 1287. | 1291. | 1294. | 1298. | 1301. |
| 5.90 | 1305. | 1309. | 1312. | 1316. | 1319. | 1323. | 1326. | 1330. | 1333. | 1337. |
| 6.00 | 1341. | 1344. | 1348. | 1351. | 1355. | 1358. | 1362. | 1366. | 1369. | 1373. |

**Table A8-17**. Free-flow discharge through 25-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 94.69 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 13.8 | 14.5 | 15.3 | 16.1 | 16.9 | 17.7 | 18.5 | 19.3 | 20.1 | 21.0 |
| .40 | 21.9 | 22.7 | 23.6 | 24.5 | 25.5 | 26.4 | 27.3 | 28.3 | 29.3 | 30.2 |
| .50 | 31.2 | 32.2 | 33.3 | 34.3 | 35.3 | 36.4 | 37.4 | 38.5 | 39.6 | 40.7 |
| .60 | 41.8 | 42.9 | 44.1 | 45.2 | 46.4 | 47.5 | 48.7 | 49.9 | 51.1 | 52.3 |
| .70 | 53.5 | 54.7 | 56.0 | 57.2 | 58.5 | 59.8 | 61.0 | 62.3 | 63.6 | 64.9 |
| .80 | 66.3 | 67.6 | 68.9 | 70.3 | 71.6 | 73.0 | 74.4 | 75.8 | 77.2 | 78.6 |
| .90 | 80.0 | 81.4 | 82.9 | 84.3 | 85.8 | 87.2 | 88.7 | 90.2 | 91.7 | 93.2 |
| 1.00 | 94.7 | 96.2 | 97.7 | 99.3 | 101. | 102. | 104. | 106. | 107. | 109. |
| 1.10 | 110. | 112. | 114. | 115. | 117. | 118. | 120. | 122. | 123. | 125. |
| 1.20 | 127. | 128. | 130. | 132. | 134. | 135. | 137. | 139. | 141. | 142. |
| 1.30 | 144. | 146. | 148. | 149. | 151. | 153. | 155. | 157. | 159. | 160. |
| 1.40 | 162. | 164. | 166. | 168. | 170. | 172. | 173. | 175. | 177. | 179. |
| 1.50 | 181. | 183. | 185. | 187. | 189. | 191. | 193. | 195. | 197. | 199. |
| 1.60 | 201. | 203. | 205. | 207. | 209. | 211. | 213. | 215. | 217. | 219. |
| 1.70 | 221. | 223. | 226. | 228. | 230. | 232. | 234. | 236. | 238. | 240. |
| 1.80 | 243. | 245. | 247. | 249. | 251. | 253. | 256. | 258. | 260. | 262. |
| 1.90 | 264. | 267. | 269. | 271. | 273. | 276. | 278. | 280. | 282. | 285. |
| 2.00 | 287. | 289. | 292. | 294. | 296. | 299. | 301. | 303. | 306. | 308. |
| 2.10 | 310. | 313. | 315. | 317. | 320. | 322. | 325. | 327. | 329. | 332. |
| 2.20 | 334. | 337. | 339. | 342. | 344. | 347. | 349. | 352. | 354. | 356. |
| 2.30 | 359. | 361. | 364. | 366. | 369. | 372. | 374. | 377. | 379. | 382. |
| 2.40 | 384. | 387. | 389. | 392. | 395. | 397. | 400. | 402. | 405. | 408. |
| 2.50 | 410. | 413. | 415. | 418. | 421. | 423. | 426. | 429. | 431. | 434. |
| 2.60 | 437. | 439. | 442. | 445. | 448. | 450. | 453. | 456. | 458. | 461. |
| 2.70 | 464. | 467. | 469. | 472. | 475. | 478. | 481. | 483. | 486. | 489. |
| 2.80 | 492. | 495. | 497. | 500. | 503. | 506. | 509. | 512. | 514. | 517. |
| 2.90 | 520. | 523. | 526. | 529. | 532. | 535. | 537. | 540. | 543. | 546. |
| 3.00 | 549. | 552. | 555. | 558. | 561. | 564. | 567. | 570. | 573. | 576. |
| 3.10 | 579. | 582. | 585. | 588. | 591. | 594. | 597. | 600. | 603. | 606. |
| 3.20 | 609. | 612. | 615. | 618. | 621. | 624. | 627. | 630. | 633. | 637. |
| 3.30 | 640. | 643. | 646. | 649. | 652. | 655. | 658. | 661. | 665. | 668. |
| 3.40 | 671. | 674. | 677. | 680. | 684. | 687. | 690. | 693. | 696. | 700. |
| 3.50 | 703. | 706. | 709. | 712. | 716. | 719. | 722. | 725. | 729. | 732. |
| 3.60 | 735. | 738. | 742. | 745. | 748. | 752. | 755. | 758. | 761. | 765. |
| 3.70 | 768. | 771. | 775. | 778. | 781. | 785. | 788. | 791. | 795. | 798. |
| 3.80 | 802. | 805. | 808. | 812. | 815. | 819. | 822. | 825. | 829. | 832. |
| 3.90 | 836. | 839. | 842. | 846. | 849. | 853. | 856. | 860. | 863. | 867. |
| 4.00 | 870. | 874. | 877. | 881. | 884. | 888. | 891. | 895. | 898. | 902. |
| 4.10 | 905. | 909. | 912. | 916. | 919. | 923. | 927. | 930. | 934. | 937. |
| 4.20 | 941. | 944. | 948. | 952. | 955. | 959. | 962. | 966. | 970. | 973. |
| 4.30 | 977. | 981. | 984. | 988. | 991. | 995. | 999. | 1002. | 1006. | 1010. |
| 4.40 | 1014. | 1017. | 1021. | 1025. | 1028. | 1032. | 1036. | 1039. | 1043. | 1047. |
| 4.50 | 1051. | 1054. | 1058. | 1062. | 1066. | 1069. | 1073. | 1077. | 1081. | 1084. |
| 4.60 | 1088. | 1092. | 1096. | 1100. | 1103. | 1107. | 1111. | 1115. | 1119. | 1122. |
| 4.70 | 1126. | 1130. | 1134. | 1138. | 1142. | 1146. | 1149. | 1153. | 1157. | 1161. |
| 4.80 | 1165. | 1169. | 1173. | 1177. | 1180. | 1184. | 1188. | 1192. | 1196. | 1200. |
| 4.90 | 1204. | 1208. | 1212. | 1216. | 1220. | 1224. | 1228. | 1232. | 1236. | 1240. |
| 5.00 | 1244. | 1248. | 1251. | 1255. | 1259. | 1263. | 1267. | 1272. | 1276. | 1280. |
| 5.10 | 1284. | 1288. | 1292. | 1296. | 1300. | 1304. | 1308. | 1312. | 1316. | 1320. |
| 5.20 | 1324. | 1328. | 1332. | 1336. | 1340. | 1344. | 1349. | 1353. | 1357. | 1361. |
| 5.30 | 1365. | 1369. | 1373. | 1377. | 1382. | 1386. | 1390. | 1394. | 1398. | 1402. |
| 5.40 | 1406. | 1411. | 1415. | 1419. | 1423. | 1427. | 1432. | 1436. | 1440. | 1444. |
| 5.50 | 1448. | 1453. | 1457. | 1461. | 1465. | 1470. | 1474. | 1478. | 1482. | 1486. |
| 5.60 | 1491. | 1495. | 1499. | 1504. | 1508. | 1512. | 1516. | 1521. | 1525. | 1529. |
| 5.70 | 1534. | 1538. | 1542. | 1547. | 1551. | 1555. | 1559. | 1564. | 1568. | 1572. |
| 5.80 | 1577. | 1581. | 1586. | 1590. | 1594. | 1599. | 1603. | 1607. | 1612. | 1616. |
| 5.90 | 1621. | 1625. | 1629. | 1634. | 1638. | 1643. | 1647. | 1651. | 1656. | 1660. |
| 6.00 | 1665. | 1669. | 1674. | 1678. | 1683. | 1687. | 1691. | 1696. | 1700. | 1705. |

**Table A8-18**. Free-flow discharge through 30-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 113.13 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 16.5 | 17.4 | 18.3 | 19.2 | 20.1 | 21.1 | 22.1 | 23.1 | 24.1 | 25.1 |
| .40 | 26.1 | 27.2 | 28.2 | 29.3 | 30.4 | 31.5 | 32.7 | 33.8 | 35.0 | 36.1 |
| .50 | 37.3 | 38.5 | 39.7 | 41.0 | 42.2 | 43.5 | 44.7 | 46.0 | 47.3 | 48.6 |
| .60 | 50.0 | 51.3 | 52.7 | 54.0 | 55.4 | 56.8 | 58.2 | 59.6 | 61.0 | 62.5 |
| .70 | 63.9 | 65.4 | 66.9 | 68.4 | 69.9 | 71.4 | 72.9 | 74.5 | 76.0 | 77.6 |
| .80 | 79.2 | 80.8 | 82.4 | 84.0 | 85.6 | 87.2 | 88.9 | 90.5 | 92.2 | 93.9 |
| .90 | 95.6 | 97.3 | 99.0 | 101. | 102. | 104. | 106. | 108. | 110. | 111. |
| 1.00 | 113. | 115. | 117. | 119. | 120. | 122. | 124. | 126. | 128. | 130. |
| 1.10 | 132. | 134. | 136. | 138. | 140. | 141. | 143. | 145. | 147. | 149. |
| 1.20 | 151. | 153. | 156. | 158. | 160. | 162. | 164. | 166. | 168. | 170. |
| 1.30 | 172. | 174. | 176. | 179. | 181. | 183. | 185. | 187. | 189. | 192. |
| 1.40 | 194. | 196. | 198. | 201. | 203. | 205. | 207. | 210. | 212. | 214. |
| 1.50 | 216. | 219. | 221. | 223. | 226. | 228. | 230. | 233. | 235. | 238. |
| 1.60 | 240. | 242. | 245. | 247. | 250. | 252. | 255. | 257. | 259. | 262. |
| 1.70 | 264. | 267. | 269. | 272. | 274. | 277. | 280. | 282. | 285. | 287. |
| 1.80 | 290. | 292. | 295. | 298. | 300. | 303. | 305. | 308. | 311. | 313. |
| 1.90 | 316. | 319. | 321. | 324. | 327. | 329. | 332. | 335. | 337. | 340. |
| 2.00 | 343. | 346. | 348. | 351. | 354. | 357. | 360. | 362. | 365. | 368. |
| 2.10 | 371. | 374. | 376. | 379. | 382. | 385. | 388. | 391. | 394. | 397. |
| 2.20 | 399. | 402. | 405. | 408. | 411. | 414. | 417. | 420. | 423. | 426. |
| 2.30 | 429. | 432. | 435. | 438. | 441. | 444. | 447. | 450. | 453. | 456. |
| 2.40 | 459. | 462. | 465. | 468. | 471. | 475. | 478. | 481. | 484. | 487. |
| 2.50 | 490. | 493. | 496. | 500. | 503. | 506. | 509. | 512. | 515. | 519. |
| 2.60 | 522. | 525. | 528. | 532. | 535. | 538. | 541. | 544. | 548. | 551. |
| 2.70 | 554. | 558. | 561. | 564. | 568. | 571. | 574. | 577. | 581. | 584. |
| 2.80 | 588. | 591. | 594. | 598. | 601. | 604. | 608. | 611. | 615. | 618. |
| 2.90 | 621. | 625. | 628. | 632. | 635. | 639. | 642. | 646. | 649. | 653. |
| 3.00 | 656. | 660. | 663. | 667. | 670. | 674. | 677. | 681. | 684. | 688. |
| 3.10 | 691. | 695. | 699. | 702. | 706. | 709. | 713. | 717. | 720. | 724. |
| 3.20 | 727. | 731. | 735. | 738. | 742. | 746. | 749. | 753. | 757. | 760. |
| 3.30 | 764. | 768. | 772. | 775. | 779. | 783. | 787. | 790. | 794. | 798. |
| 3.40 | 802. | 805. | 809. | 813. | 817. | 821. | 824. | 828. | 832. | 836. |
| 3.50 | 840. | 843. | 847. | 851. | 855. | 859. | 863. | 867. | 871. | 874. |
| 3.60 | 878. | 882. | 886. | 890. | 894. | 898. | 902. | 906. | 910. | 914. |
| 3.70 | 918. | 922. | 926. | 930. | 934. | 938. | 942. | 946. | 950. | 954. |
| 3.80 | 958. | 962. | 966. | 970. | 974. | 978. | 982. | 986. | 990. | 994. |
| 3.90 | 998. | 1002. | 1007. | 1011. | 1015. | 1019. | 1023. | 1027. | 1031. | 1035. |
| 4.00 | 1040. | 1044. | 1048. | 1052. | 1056. | 1060. | 1065. | 1069. | 1073. | 1077. |
| 4.10 | 1082. | 1086. | 1090. | 1094. | 1098. | 1103. | 1107. | 1111. | 1115. | 1120. |
| 4.20 | 1124. | 1128. | 1133. | 1137. | 1141. | 1146. | 1150. | 1154. | 1158. | 1163. |
| 4.30 | 1167. | 1171. | 1176. | 1180. | 1185. | 1189. | 1193. | 1198. | 1202. | 1206. |
| 4.40 | 1211. | 1215. | 1220. | 1224. | 1229. | 1233. | 1237. | 1242. | 1246. | 1251. |
| 4.50 | 1255. | 1260. | 1264. | 1269. | 1273. | 1278. | 1282. | 1287. | 1291. | 1296. |
| 4.60 | 1300. | 1305. | 1309. | 1314. | 1318. | 1323. | 1327. | 1332. | 1337. | 1341. |
| 4.70 | 1346. | 1350. | 1355. | 1359. | 1364. | 1369. | 1373. | 1378. | 1382. | 1387. |
| 4.80 | 1392. | 1396. | 1401. | 1406. | 1410. | 1415. | 1420. | 1424. | 1429. | 1434. |
| 4.90 | 1438. | 1443. | 1448. | 1453. | 1457. | 1462. | 1467. | 1471. | 1476. | 1481. |
| 5.00 | 1486. | 1490. | 1495. | 1500. | 1505. | 1510. | 1514. | 1519. | 1524. | 1529. |
| 5.10 | 1534. | 1538. | 1543. | 1548. | 1553. | 1558. | 1562. | 1567. | 1572. | 1577. |
| 5.20 | 1582. | 1587. | 1592. | 1597. | 1601. | 1606. | 1611. | 1616. | 1621. | 1626. |
| 5.30 | 1631. | 1636. | 1641. | 1646. | 1651. | 1656. | 1661. | 1665. | 1670. | 1675. |
| 5.40 | 1680. | 1685. | 1690. | 1695. | 1700. | 1705. | 1710. | 1715. | 1720. | 1725. |
| 5.50 | 1730. | 1735. | 1741. | 1746. | 1751. | 1756. | 1761. | 1766. | 1771. | 1776. |
| 5.60 | 1781. | 1786. | 1791. | 1796. | 1801. | 1807. | 1812. | 1817. | 1822. | 1827. |
| 5.70 | 1832. | 1837. | 1843. | 1848. | 1853. | 1858. | 1863. | 1868. | 1874. | 1879. |
| 5.80 | 1884. | 1889. | 1894. | 1900. | 1905. | 1910. | 1915. | 1920. | 1926. | 1931. |
| 5.90 | 1936. | 1941. | 1947. | 1952. | 1957. | 1962. | 1968. | 1973. | 1978. | 1984. |
| 6.00 | 1989. | 1994. | 2000. | 2005. | 2010. | 2016. | 2021. | 2026. | 2032. | 2037. |

**Table A8-19**. Free-flow discharge through 40-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 150.00 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 21.9 | 23.0 | 24.2 | 25.5 | 26.7 | 28.0 | 29.3 | 30.6 | 31.9 | 33.3 |
| .40 | 34.6 | 36.0 | 37.4 | 38.9 | 40.3 | 41.8 | 43.3 | 44.8 | 46.4 | 47.9 |
| .50 | 49.5 | 51.1 | 52.7 | 54.3 | 56.0 | 57.6 | 59.3 | 61.0 | 62.7 | 64.5 |
| .60 | 66.2 | 68.0 | 69.8 | 71.6 | 73.4 | 75.3 | 77.2 | 79.0 | 80.9 | 82.8 |
| .70 | 84.8 | 86.7 | 88.7 | 90.7 | 92.7 | 94.7 | 96.7 | 98.7 | 101. | 103. |
| .80 | 105. | 107. | 109. | 111. | 113. | 116. | 118. | 120. | 122. | 124. |
| .90 | 127. | 129. | 131. | 134. | 136. | 138. | 141. | 143. | 145. | 148. |
| 1.00 | 150. | 152. | 155. | 157. | 160. | 162. | 165. | 167. | 170. | 172. |
| 1.10 | 175. | 177. | 180. | 182. | 185. | 188. | 190. | 193. | 195. | 198. |
| 1.20 | 201. | 203. | 206. | 209. | 212. | 214. | 217. | 220. | 223. | 225. |
| 1.30 | 228. | 231. | 234. | 237. | 240. | 242. | 245. | 248. | 251. | 254. |
| 1.40 | 257. | 260. | 263. | 266. | 269. | 272. | 275. | 278. | 281. | 284. |
| 1.50 | 287. | 290. | 293. | 296. | 299. | 302. | 306. | 309. | 312. | 315. |
| 1.60 | 318. | 321. | 325. | 328. | 331. | 334. | 337. | 341. | 344. | 347. |
| 1.70 | 351. | 354. | 357. | 361. | 364. | 367. | 371. | 374. | 377. | 381. |
| 1.80 | 384. | 388. | 391. | 394. | 398. | 401. | 405. | 408. | 412. | 415. |
| 1.90 | 419. | 422. | 426. | 430. | 433. | 437. | 440. | 444. | 447. | 451. |
| 2.00 | 455. | 458. | 462. | 466. | 469. | 473. | 477. | 480. | 484. | 488. |
| 2.10 | 492. | 495. | 499. | 503. | 507. | 510. | 514. | 518. | 522. | 526. |
| 2.20 | 530. | 533. | 537. | 541. | 545. | 549. | 553. | 557. | 561. | 565. |
| 2.30 | 569. | 573. | 577. | 581. | 585. | 589. | 593. | 597. | 601. | 605. |
| 2.40 | 609. | 613. | 617. | 621. | 625. | 629. | 633. | 637. | 642. | 646. |
| 2.50 | 650. | 654. | 658. | 662. | 667. | 671. | 675. | 679. | 683. | 688. |
| 2.60 | 692. | 696. | 700. | 705. | 709. | 713. | 718. | 722. | 726. | 731. |
| 2.70 | 735. | 739. | 744. | 748. | 752. | 757. | 761. | 766. | 770. | 775. |
| 2.80 | 779. | 783. | 788. | 792. | 797. | 801. | 806. | 810. | 815. | 819. |
| 2.90 | 824. | 829. | 833. | 838. | 842. | 847. | 851. | 856. | 861. | 865. |
| 3.00 | 870. | 875. | 879. | 884. | 889. | 893. | 898. | 903. | 907. | 912. |
| 3.10 | 917. | 922. | 926. | 931. | 936. | 941. | 945. | 950. | 955. | 960. |
| 3.20 | 965. | 969. | 974. | 979. | 984. | 989. | 994. | 999. | 1003. | 1008. |
| 3.30 | 1013. | 1018. | 1023. | 1028. | 1033. | 1038. | 1043. | 1048. | 1053. | 1058. |
| 3.40 | 1063. | 1068. | 1073. | 1078. | 1083. | 1088. | 1093. | 1098. | 1103. | 1108. |
| 3.50 | 1113. | 1118. | 1123. | 1129. | 1134. | 1139. | 1144. | 1149. | 1154. | 1159. |
| 3.60 | 1165. | 1170. | 1175. | 1180. | 1185. | 1191. | 1196. | 1201. | 1206. | 1212. |
| 3.70 | 1217. | 1222. | 1227. | 1233. | 1238. | 1243. | 1249. | 1254. | 1259. | 1264. |
| 3.80 | 1270. | 1275. | 1281. | 1286. | 1291. | 1297. | 1302. | 1307. | 1313. | 1318. |
| 3.90 | 1324. | 1329. | 1335. | 1340. | 1346. | 1351. | 1356. | 1362. | 1367. | 1373. |
| 4.00 | 1378. | 1384. | 1389. | 1395. | 1401. | 1406. | 1412. | 1417. | 1423. | 1428. |
| 4.10 | 1434. | 1440. | 1445. | 1451. | 1456. | 1462. | 1468. | 1473. | 1479. | 1485. |
| 4.20 | 1490. | 1496. | 1502. | 1507. | 1513. | 1519. | 1525. | 1530. | 1536. | 1542. |
| 4.30 | 1548. | 1553. | 1559. | 1565. | 1571. | 1576. | 1582. | 1588. | 1594. | 1600. |
| 4.40 | 1606. | 1611. | 1617. | 1623. | 1629. | 1635. | 1641. | 1647. | 1652. | 1658. |
| 4.50 | 1664. | 1670. | 1676. | 1682. | 1688. | 1694. | 1700. | 1706. | 1712. | 1718. |
| 4.60 | 1724. | 1730. | 1736. | 1742. | 1748. | 1754. | 1760. | 1766. | 1772. | 1778. |
| 4.70 | 1784. | 1790. | 1796. | 1802. | 1809. | 1815. | 1821. | 1827. | 1833. | 1839. |
| 4.80 | 1845. | 1851. | 1858. | 1864. | 1870. | 1876. | 1882. | 1889. | 1895. | 1901. |
| 4.90 | 1907. | 1913. | 1920. | 1926. | 1932. | 1938. | 1945. | 1951. | 1957. | 1964. |
| 5.00 | 1970. | 1976. | 1983. | 1989. | 1995. | 2002. | 2008. | 2014. | 2021. | 2027. |
| 5.10 | 2033. | 2040. | 2046. | 2052. | 2059. | 2065. | 2072. | 2078. | 2085. | 2091. |
| 5.20 | 2097. | 2104. | 2110. | 2117. | 2123. | 2130. | 2136. | 2143. | 2149. | 2156. |
| 5.30 | 2162. | 2169. | 2175. | 2182. | 2189. | 2195. | 2202. | 2208. | 2215. | 2221. |
| 5.40 | 2228. | 2235. | 2241. | 2248. | 2254. | 2261. | 2268. | 2274. | 2281. | 2288. |
| 5.50 | 2294. | 2301. | 2308. | 2314. | 2321. | 2328. | 2335. | 2341. | 2348. | 2355. |
| 5.60 | 2362. | 2368. | 2375. | 2382. | 2389. | 2395. | 2402. | 2409. | 2416. | 2423. |
| 5.70 | 2429. | 2436. | 2443. | 2450. | 2457. | 2464. | 2470. | 2477. | 2484. | 2491. |
| 5.80 | 2498. | 2505. | 2512. | 2519. | 2526. | 2532. | 2539. | 2546. | 2553. | 2560. |
| 5.90 | 2567. | 2574. | 2581. | 2588. | 2595. | 2602. | 2609. | 2616. | 2623. | 2630. |
| 6.00 | 2637. | 2644. | 2651. | 2658. | 2665. | 2672. | 2679. | 2687. | 2694. | 2701. |

**Table A8-20**. Free-flow discharge through 50-ft Parshall measuring flume in $ft^3$/sec. Computed from the formula $Q = 186.88 h_a^{1.6}$.

| Upper Head $h_a$, ft | *Hundredths* 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 27.2 | 28.7 | 30.2 | 31.7 | 33.3 | 34.8 | 36.4 | 38.1 | 39.7 | 41.4 |
| .40 | 43.1 | 44.9 | 46.6 | 48.4 | 50.2 | 52.1 | 53.9 | 55.8 | 57.7 | 59.7 |
| .50 | 61.6 | 63.6 | 65.6 | 67.7 | 69.7 | 71.8 | 73.9 | 76.0 | 78.2 | 80.3 |
| .60 | 82.5 | 84.7 | 87.0 | 89.2 | 91.5 | 93.8 | 96.1 | 98.5 | 101. | 103. |
| .70 | 106. | 108. | 110. | 113. | 115. | 118. | 120. | 123. | 126. | 128. |
| .80 | 131. | 133. | 136. | 139. | 141. | 144. | 147. | 150. | 152. | 155. |
| .90 | 158. | 161. | 164. | 166. | 169. | 172. | 175. | 178. | 181. | 184. |
| 1.00 | 187. | 190. | 193. | 196. | 199. | 202. | 205. | 208. | 211. | 215. |
| 1.10 | 218. | 221. | 224. | 227. | 230. | 234. | 237. | 240. | 244. | 247. |
| 1.20 | 250. | 254. | 257. | 260. | 264. | 267. | 270. | 274. | 277. | 281. |
| 1.30 | 284. | 288. | 291. | 295. | 298. | 302. | 306. | 309. | 313. | 317. |
| 1.40 | 320. | 324. | 328. | 331. | 335. | 339. | 342. | 346. | 350. | 354. |
| 1.50 | 358. | 361. | 365. | 369. | 373. | 377. | 381. | 385. | 389. | 392. |
| 1.60 | 396. | 400. | 404. | 408. | 412. | 416. | 420. | 425. | 429. | 433. |
| 1.70 | 437. | 441. | 445. | 449. | 453. | 458. | 462. | 466. | 470. | 474. |
| 1.80 | 479. | 483. | 487. | 491. | 496. | 500. | 504. | 509. | 513. | 517. |
| 1.90 | 522. | 526. | 531. | 535. | 540. | 544. | 548. | 553. | 557. | 562. |
| 2.00 | 567. | 571. | 576. | 580. | 585. | 589. | 594. | 599. | 603. | 608. |
| 2.10 | 613. | 617. | 622. | 627. | 631. | 636. | 641. | 646. | 650. | 655. |
| 2.20 | 660. | 665. | 669. | 674. | 679. | 684. | 689. | 694. | 699. | 704. |
| 2.30 | 708. | 713. | 718. | 723. | 728. | 733. | 738. | 743. | 748. | 753. |
| 2.40 | 758. | 763. | 769. | 774. | 779. | 784. | 789. | 794. | 799. | 804. |
| 2.50 | 810. | 815. | 820. | 825. | 830. | 836. | 841. | 846. | 851. | 857. |
| 2.60 | 862. | 867. | 873. | 878. | 883. | 889. | 894. | 899. | 905. | 910. |
| 2.70 | 916. | 921. | 927. | 932. | 937. | 943. | 948. | 954. | 959. | 965. |
| 2.80 | 971. | 976. | 982. | 987. | 993. | 998. | 1004. | 1010. | 1015. | 1021. |
| 2.90 | 1027. | 1032. | 1038. | 1044. | 1049. | 1055. | 1061. | 1067. | 1072. | 1078. |
| 3.00 | 1084. | 1090. | 1095. | 1101. | 1107. | 1113. | 1119. | 1125. | 1130. | 1136. |
| 3.10 | 1142. | 1148. | 1154. | 1160. | 1166. | 1172. | 1178. | 1184. | 1190. | 1196. |
| 3.20 | 1202. | 1208. | 1214. | 1220. | 1226. | 1232. | 1238. | 1244. | 1250. | 1256. |
| 3.30 | 1262. | 1268. | 1275. | 1281. | 1287. | 1293. | 1299. | 1305. | 1312. | 1318. |
| 3.40 | 1324. | 1330. | 1337. | 1343. | 1349. | 1355. | 1362. | 1368. | 1374. | 1381. |
| 3.50 | 1387. | 1393. | 1400. | 1406. | 1412. | 1419. | 1425. | 1432. | 1438. | 1444. |
| 3.60 | 1451. | 1457. | 1464. | 1470. | 1477. | 1483. | 1490. | 1496. | 1503. | 1509. |
| 3.70 | 1516. | 1523. | 1529. | 1536. | 1542. | 1549. | 1555. | 1562. | 1569. | 1575. |
| 3.80 | 1582. | 1589. | 1595. | 1602. | 1609. | 1615. | 1622. | 1629. | 1636. | 1642. |
| 3.90 | 1649. | 1656. | 1663. | 1670. | 1676. | 1683. | 1690. | 1697. | 1704. | 1710. |
| 4.00 | 1717. | 1724. | 1731. | 1738. | 1745. | 1752. | 1759. | 1766. | 1773. | 1780. |
| 4.10 | 1787. | 1794. | 1801. | 1808. | 1815. | 1822. | 1829. | 1836. | 1843. | 1850. |
| 4.20 | 1857. | 1864. | 1871. | 1878. | 1885. | 1892. | 1899. | 1907. | 1914. | 1921. |
| 4.30 | 1928. | 1935. | 1942. | 1950. | 1957. | 1964. | 1971. | 1978. | 1986. | 1993. |
| 4.40 | 2000. | 2008. | 2015. | 2022. | 2029. | 2037. | 2044. | 2051. | 2059. | 2066. |
| 4.50 | 2073. | 2081. | 2088. | 2096. | 2103. | 2110. | 2118. | 2125. | 2133. | 2140. |
| 4.60 | 2148. | 2155. | 2163. | 2170. | 2178. | 2185. | 2193. | 2200. | 2208. | 2215. |
| 4.70 | 2223. | 2230. | 2238. | 2246. | 2253. | 2261. | 2268. | 2276. | 2284. | 2291. |
| 4.80 | 2299. | 2307. | 2314. | 2322. | 2330. | 2337. | 2345. | 2353. | 2361. | 2368. |
| 4.90 | 2376. | 2384. | 2392. | 2399. | 2407. | 2415. | 2423. | 2431. | 2439. | 2446. |
| 5.00 | 2454. | 2462. | 2470. | 2478. | 2486. | 2494. | 2502. | 2509. | 2517. | 2525. |
| 5.10 | 2533. | 2541. | 2549. | 2557. | 2565. | 2573. | 2581. | 2589. | 2597. | 2605. |
| 5.20 | 2613. | 2621. | 2629. | 2637. | 2645. | 2653. | 2662. | 2670. | 2678. | 2686. |
| 5.30 | 2694. | 2702. | 2710. | 2718. | 2727. | 2735. | 2743. | 2751. | 2759. | 2768. |
| 5.40 | 2776. | 2784. | 2792. | 2801. | 2809. | 2817. | 2825. | 2834. | 2842. | 2850. |
| 5.50 | 2859. | 2867. | 2875. | 2884. | 2892. | 2900. | 2909. | 2917. | 2925. | 2934. |
| 5.60 | 2942. | 2951. | 2959. | 2967. | 2976. | 2984. | 2993. | 3001. | 3010. | 3018. |
| 5.70 | 3027. | 3035. | 3044. | 3052. | 3061. | 3069. | 3078. | 3086. | 3095. | 3103. |
| 5.80 | 3112. | 3121. | 3129. | 3138. | 3146. | 3155. | 3164. | 3172. | 3181. | 3190. |
| 5.90 | 3198. | 3207. | 3216. | 3224. | 3233. | 3242. | 3251. | 3259. | 3268. | 3277. |
| 6.00 | 3286. | 3294. | 3303. | 3312. | 3321. | 3329. | 3338. | 3347. | 3356. | 3365. |

**Table A9-2**. Discharge of fully contracted standard submerged rectangular orifice in ft$^3$/sec. Computed from the formula $Q = 0.61A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.5 | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 |
| 0.01 | 0.122 | 0.245 | 0.367 | 0.490 | 0.612 | 0.734 | 0.857 | 0.979 |
| .02 | .173 | .346 | .519 | .692 | .865 | 1.04 | 1.21 | 1.38 |
| .03 | .212 | .424 | .636 | .848 | 1.06 | 1.27 | 1.48 | 1.70 |
| .04 | .245 | .490 | .734 | .979 | 1.22 | 1.47 | 1.71 | 1.96 |
| .05 | .274 | .547 | .821 | 1.09 | 1.37 | 1.64 | 1.92 | 2.19 |
| .06 | .300 | .600 | .899 | 1.20 | 1.50 | 1.80 | 2.10 | 2.40 |
| .07 | .324 | .648 | .971 | 1.30 | 1.62 | 1.94 | 2.27 | 2.59 |
| .08 | .346 | .692 | 1.04 | 1.38 | 1.73 | 2.08 | 2.42 | 2.77 |
| .09 | .367 | .734 | 1.10 | 1.47 | 1.84 | 2.20 | 2.57 | 2.94 |
| .10 | .387 | .774 | 1.16 | 1.55 | 1.94 | 2.32 | 2.71 | 3.10 |
| .11 | .406 | .812 | 1.22 | 1.62 | 2.03 | 2.44 | 2.84 | 3.25 |
| .12 | .424 | .848 | 1.27 | 1.70 | 2.12 | 2.54 | 2.97 | 3.39 |
| .13 | .441 | .882 | 1.32 | 1.76 | 2.21 | 2.65 | 3.09 | 3.53 |
| .14 | .458 | .916 | 1.37 | 1.83 | 2.29 | 2.75 | 3.21 | 3.66 |
| .15 | .474 | .948 | 1.42 | 1.90 | 2.37 | 2.84 | 3.32 | 3.79 |
| .16 | .490 | .979 | 1.47 | 1.96 | 2.45 | 2.94 | 3.43 | 3.92 |
| .17 | .505 | 1.01 | 1.51 | 2.02 | 2.52 | 3.03 | 3.53 | 4.04 |
| .18 | .519 | 1.04 | 1.56 | 2.08 | 2.60 | 3.12 | 3.63 | 4.15 |
| .19 | .533 | 1.07 | 1.60 | 2.13 | 2.67 | 3.20 | 3.73 | 4.27 |
| .20 | .547 | 1.09 | 1.64 | 2.19 | 2.74 | 3.28 | 3.83 | 4.38 |
| .21 | .561 | 1.12 | 1.68 | 2.24 | 2.80 | 3.36 | 3.93 | 4.49 |
| .22 | .574 | 1.15 | 1.72 | 2.30 | 2.87 | 3.44 | 4.02 | 4.59 |
| .23 | .587 | 1.17 | 1.76 | 2.35 | 2.93 | 3.52 | 4.11 | 4.70 |
| .24 | .600 | 1.20 | 1.80 | 2.40 | 3.00 | 3.60 | 4.20 | 4.80 |
| .25 | .612 | 1.22 | 1.84 | 2.45 | 3.06 | 3.67 | 4.28 | 4.90 |
| .26 | .624 | 1.25 | 1.87 | 2.50 | 3.12 | 3.74 | 4.37 | 4.99 |
| .27 | .636 | 1.27 | 1.91 | 2.54 | 3.18 | 3.82 | 4.45 | 5.09 |
| .28 | .648 | 1.30 | 1.94 | 2.59 | 3.24 | 3.89 | 4.53 | 5.18 |
| .29 | .659 | 1.32 | 1.98 | 2.64 | 3.30 | 3.95 | 4.61 | 5.27 |
| .30 | .670 | 1.34 | 2.01 | 2.68 | 3.35 | 4.02 | 4.69 | 5.36 |
| .31 | .681 | 1.36 | 2.04 | 2.73 | 3.41 | 4.09 | 4.77 | 5.45 |
| .32 | .692 | 1.38 | 2.08 | 2.77 | 3.46 | 4.15 | 4.85 | 5.54 |
| .33 | .703 | 1.41 | 2.11 | 2.81 | 3.52 | 4.22 | 4.92 | 5.62 |
| .34 | .714 | 1.43 | 2.14 | 2.85 | 3.57 | 4.28 | 5.00 | 5.71 |
| .35 | .724 | 1.45 | 2.17 | 2.90 | 3.62 | 4.34 | 5.07 | 5.79 |
| .36 | .734 | 1.47 | 2.20 | 2.94 | 3.67 | 4.41 | 5.14 | 5.87 |
| .37 | .744 | 1.49 | 2.23 | 2.98 | 3.72 | 4.47 | 5.21 | 5.96 |
| .38 | .754 | 1.51 | 2.26 | 3.02 | 3.77 | 4.53 | 5.28 | 6.04 |
| .39 | .764 | 1.53 | 2.29 | 3.06 | 3.82 | 4.59 | 5.35 | 6.11 |
| .40 | .774 | 1.55 | 2.32 | 3.10 | 3.87 | 4.64 | 5.42 | 6.19 |

**Table A9-2**. Discharge of fully contracted standard submerged rectangular orifice in ft$^3$/sec. Computed from the formula $Q = 0.61A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.5 | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 |
| .41 | 0.784 | 1.57 | 2.35 | 3.13 | 3.92 | 4.70 | 5.49 | 6.27 |
| .42 | .793 | 1.59 | 2.38 | 3.17 | 3.97 | 4.76 | 5.55 | 6.34 |
| .43 | .803 | 1.61 | 2.41 | 3.21 | 4.01 | 4.82 | 5.62 | 6.42 |
| .44 | .812 | 1.62 | 2.44 | 3.25 | 4.06 | 4.87 | 5.68 | 6.49 |
| .45 | .821 | 1.64 | 2.46 | 3.28 | 4.10 | 4.93 | 5.75 | 6.57 |
| .46 | .830 | 1.66 | 2.49 | 3.32 | 4.15 | 4.98 | 5.81 | 6.64 |
| .47 | .839 | 1.68 | 2.52 | 3.36 | 4.19 | 5.03 | 5.87 | 6.71 |
| .48 | .848 | 1.70 | 2.54 | 3.39 | 4.24 | 5.09 | 5.94 | 6.78 |
| .49 | .857 | 1.71 | 2.57 | 3.43 | 4.28 | 5.14 | 6.00 | 6.85 |
| .50 | .865 | 1.73 | 2.60 | 3.46 | 4.33 | 5.19 | 6.06 | 6.92 |
| .51 | .874 | 1.75 | 2.62 | 3.50 | 4.37 | 5.24 | 6.12 | 6.99 |
| .52 | .882 | 1.76 | 2.65 | 3.53 | 4.41 | 5.29 | 6.18 | 7.06 |
| .53 | .891 | 1.78 | 2.67 | 3.56 | 4.45 | 5.35 | 6.24 | 7.13 |
| .54 | .899 | 1.80 | 2.70 | 3.60 | 4.50 | 5.40 | 6.30 | 7.19 |
| .55 | .908 | 1.82 | 2.72 | 3.63 | 4.54 | 5.45 | 6.35 | 7.26 |
| .56 | .916 | 1.83 | 2.75 | 3.66 | 4.58 | 5.49 | 6.41 | 7.33 |
| .57 | .924 | 1.85 | 2.77 | 3.70 | 4.62 | 5.54 | 6.47 | 7.39 |
| .58 | .932 | 1.86 | 2.80 | 3.73 | 4.66 | 5.59 | 6.52 | 7.46 |
| .59 | .940 | 1.88 | 2.82 | 3.76 | 4.70 | 5.64 | 6.58 | 7.52 |
| .60 | .948 | 1.90 | 2.84 | 3.79 | 4.74 | 5.69 | 6.64 | 7.58 |
| .61 | .956 | 1.91 | 2.87 | 3.82 | 4.78 | 5.73 | 6.69 | 7.65 |
| .62 | .964 | 1.93 | 2.89 | 3.85 | 4.82 | 5.78 | 6.75 | 7.71 |
| .63 | .971 | 1.94 | 2.91 | 3.89 | 4.86 | 5.83 | 6.80 | 7.77 |
| .64 | .979 | 1.96 | 2.94 | 3.92 | 4.90 | 5.87 | 6.85 | 7.83 |
| .65 | .987 | 1.97 | 2.96 | 3.95 | 4.93 | 5.92 | 6.91 | 7.89 |
| .66 | .994 | 1.99 | 2.98 | 3.98 | 4.97 | 5.97 | 6.96 | 7.95 |
| .67 | 1.00 | 2.00 | 3.01 | 4.01 | 5.01 | 6.01 | 7.01 | 8.01 |
| .68 | 1.01 | 2.02 | 3.03 | 4.04 | 5.05 | 6.06 | 7.06 | 8.07 |
| .69 | 1.02 | 2.03 | 3.05 | 4.07 | 5.08 | 6.10 | 7.12 | 8.13 |
| .70 | 1.02 | 2.05 | 3.07 | 4.10 | 5.12 | 6.14 | 7.17 | 8.19 |
| .71 | 1.03 | 2.06 | 3.09 | 4.12 | 5.16 | 6.19 | 7.22 | 8.25 |
| .72 | 1.04 | 2.08 | 3.12 | 4.15 | 5.19 | 6.23 | 7.27 | 8.31 |
| .73 | 1.05 | 2.09 | 3.14 | 4.18 | 5.23 | 6.27 | 7.32 | 8.36 |
| .74 | 1.05 | 2.11 | 3.16 | 4.21 | 5.26 | 6.32 | 7.37 | 8.42 |
| .75 | 1.06 | 2.12 | 3.18 | 4.24 | 5.30 | 6.36 | 7.42 | 8.48 |
| .76 | 1.07 | 2.13 | 3.20 | 4.27 | 5.33 | 6.40 | 7.47 | 8.54 |
| .77 | 1.07 | 2.15 | 3.22 | 4.30 | 5.37 | 6.44 | 7.52 | 8.59 |
| .78 | 1.08 | 2.16 | 3.24 | 4.32 | 5.40 | 6.49 | 7.57 | 8.65 |
| .79 | 1.09 | 2.18 | 3.26 | 4.35 | 5.44 | 6.53 | 7.61 | 8.70 |
| .80 | 1.09 | 2.19 | 3.28 | 4.38 | 5.47 | 6.57 | 7.66 | 8.76 |

**Table A9-3**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in $ft^3$/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 5.0 | 6.0 | 7.0 |
| 0.04 | 2.25 | 2.81 | 3.37 | 3.93 | 4.49 | 5.62 | 6.74 | 7.86 |
| .05 | 2.51 | 3.14 | 3.77 | 4.40 | 5.02 | 6.28 | 7.54 | 8.79 |
| .06 | 2.75 | 3.44 | 4.13 | 4.82 | 5.50 | 6.88 | 8.26 | 9.63 |
| .07 | 2.97 | 3.72 | 4.46 | 5.20 | 5.94 | 7.43 | 8.92 | 10.4 |
| .08 | 3.18 | 3.97 | 4.77 | 5.56 | 6.36 | 7.94 | 9.53 | 11.1 |
| .09 | 3.37 | 4.21 | 5.06 | 5.90 | 6.74 | 8.43 | 10.1 | 11.8 |
| .10 | 3.55 | 4.44 | 5.33 | 6.22 | 7.11 | 8.88 | 10.7 | 12.4 |
| .11 | 3.73 | 4.66 | 5.59 | 6.52 | 7.45 | 9.32 | 11.2 | 13.0 |
| .12 | 3.89 | 4.86 | 5.84 | 6.81 | 7.78 | 9.73 | 11.7 | 13.6 |
| .13 | 4.05 | 5.06 | 6.08 | 7.09 | 8.10 | 10.1 | 12.2 | 14.2 |
| .14 | 4.20 | 5.25 | 6.31 | 7.36 | 8.41 | 10.5 | 12.6 | 14.7 |
| .15 | 4.35 | 5.44 | 6.53 | 7.61 | 8.70 | 10.9 | 13.1 | 15.2 |
| .16 | 4.49 | 5.62 | 6.74 | 7.86 | 8.99 | 11.2 | 13.5 | 15.7 |
| .17 | 4.63 | 5.79 | 6.95 | 8.11 | 9.26 | 11.6 | 13.9 | 16.2 |
| .18 | 4.77 | 5.96 | 7.15 | 8.34 | 9.53 | 11.9 | 14.3 | 16.7 |
| .19 | 4.90 | 6.12 | 7.35 | 8.57 | 9.79 | 12.2 | 14.7 | 17.1 |
| .20 | 5.02 | 6.28 | 7.54 | 8.79 | 10.0 | 12.6 | 15.1 | 17.6 |
| .21 | 5.15 | 6.44 | 7.72 | 9.01 | 10.3 | 12.9 | 15.4 | 18.0 |
| .22 | 5.27 | 6.59 | 7.90 | 9.22 | 10.5 | 13.2 | 15.8 | 18.4 |
| .23 | 5.39 | 6.74 | 8.08 | 9.43 | 10.8 | 13.5 | 16.2 | 18.9 |
| .24 | 5.50 | 6.88 | 8.26 | 9.63 | 11.0 | 13.8 | 16.5 | 19.3 |
| .25 | 5.62 | 7.02 | 8.43 | 9.83 | 11.2 | 14.0 | 16.9 | 19.7 |
| .26 | 5.73 | 7.16 | 8.59 | 10.0 | 11.5 | 14.3 | 17.2 | 20.1 |
| .27 | 5.84 | 7.30 | 8.76 | 10.2 | 11.7 | 14.6 | 17.5 | 20.4 |
| .28 | 5.94 | 7.43 | 8.92 | 10.4 | 11.9 | 14.9 | 17.8 | 20.8 |
| .29 | 6.05 | 7.56 | 9.08 | 10.6 | 12.1 | 15.1 | 18.2 | 21.2 |
| .30 | 6.15 | 7.69 | 9.23 | 10.8 | 12.3 | 15.4 | 18.5 | 21.5 |
| .31 | 6.26 | 7.82 | 9.38 | 10.9 | 12.5 | 15.6 | 18.8 | 21.9 |
| .32 | 6.36 | 7.94 | 9.53 | 11.1 | 12.7 | 15.9 | 19.1 | 22.2 |
| .33 | 6.45 | 8.07 | 9.68 | 11.3 | 12.9 | 16.1 | 19.4 | 22.6 |
| .34 | 6.55 | 8.19 | 9.83 | 11.5 | 13.1 | 16.4 | 19.7 | 22.9 |
| .35 | 6.65 | 8.31 | 9.97 | 11.6 | 13.3 | 16.6 | 19.9 | 23.3 |
| .36 | 6.74 | 8.43 | 10.1 | 11.8 | 13.5 | 16.9 | 20.2 | 23.6 |
| .37 | 6.83 | 8.54 | 10.3 | 12.0 | 13.7 | 17.1 | 20.5 | 23.9 |
| .38 | 6.93 | 8.66 | 10.4 | 12.1 | 13.9 | 17.3 | 20.8 | 24.2 |
| .39 | 7.02 | 8.77 | 10.5 | 12.3 | 14.0 | 17.5 | 21.0 | 24.6 |
| .40 | 7.11 | 8.88 | 10.7 | 12.4 | 14.2 | 17.8 | 21.3 | 24.9 |
| .41 | 7.19 | 8.99 | 10.8 | 12.6 | 14.4 | 18.0 | 21.6 | 25.2 |
| .42 | 7.28 | 9.10 | 10.9 | 12.7 | 14.6 | 18.2 | 21.8 | 25.5 |
| .43 | 7.37 | 9.21 | 11.1 | 12.9 | 14.7 | 18.4 | 22.1 | 25.8 |
| .44 | 7.45 | 9.32 | 11.2 | 13.0 | 14.9 | 18.6 | 22.4 | 26.1 |
| .45 | 7.54 | 9.42 | 11.3 | 13.2 | 15.1 | 18.8 | 22.6 | 26.4 |
| .46 | 7.62 | 9.52 | 11.4 | 13.3 | 15.2 | 19.0 | 22.9 | 26.7 |
| .47 | 7.70 | 9.63 | 11.6 | 13.5 | 15.4 | 19.3 | 23.1 | 27.0 |
| .48 | 7.78 | 9.73 | 11.7 | 13.6 | 15.6 | 19.5 | 23.4 | 27.2 |
| .49 | 7.86 | 9.83 | 11.8 | 13.8 | 15.7 | 19.7 | 23.6 | 27.5 |
| .50 | 7.94 | 9.93 | 11.9 | 13.9 | 15.9 | 19.9 | 23.8 | 27.8 |
| .51 | 8.02 | 10.0 | 12.0 | 14.0 | 16.0 | 20.1 | 24.1 | 28.1 |
| .52 | 8.10 | 10.1 | 12.2 | 14.2 | 16.2 | 20.3 | 24.3 | 28.4 |
| .53 | 8.18 | 10.2 | 12.3 | 14.3 | 16.4 | 20.4 | 24.5 | 28.6 |

**Table A9-3 [continued]**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8.0 | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 | 20.0 |
| 0.04 | 8.99 | 11.2 | 13.5 | 15.7 | 18.0 | 20.2 | 22.5 |
| .05 | 10.0 | 12.6 | 15.1 | 17.6 | 20.1 | 22.6 | 25.1 |
| .06 | 11.0 | 13.8 | 16.5 | 19.3 | 22.0 | 24.8 | 27.5 |
| .07 | 11.9 | 14.9 | 17.8 | 20.8 | 23.8 | 26.8 | 29.7 |
| .08 | 12.7 | 15.9 | 19.1 | 22.2 | 25.4 | 28.6 | 31.8 |
| .09 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 | 30.3 | 33.7 |
| .10 | 14.2 | 17.8 | 21.3 | 24.9 | 28.4 | 32.0 | 35.5 |
| .11 | 14.9 | 18.6 | 22.4 | 26.1 | 29.8 | 33.5 | 37.3 |
| .12 | 15.6 | 19.5 | 23.4 | 27.2 | 31.1 | 35.0 | 38.9 |
| .13 | 16.2 | 20.3 | 24.3 | 28.4 | 32.4 | 36.5 | 40.5 |
| .14 | 16.8 | 21.0 | 25.2 | 29.4 | 33.6 | 37.8 | 42.0 |
| .15 | 17.4 | 21.8 | 26.1 | 30.5 | 34.8 | 39.2 | 43.5 |
| .16 | 18.0 | 22.5 | 27.0 | 31.5 | 36.0 | 40.4 | 44.9 |
| .17 | 18.5 | 23.2 | 27.8 | 32.4 | 37.1 | 41.7 | 46.3 |
| .18 | 19.1 | 23.8 | 28.6 | 33.4 | 38.1 | 42.9 | 47.7 |
| .19 | 19.6 | 24.5 | 29.4 | 34.3 | 39.2 | 44.1 | 49.0 |
| .20 | 20.1 | 25.1 | 30.1 | 35.2 | 40.2 | 45.2 | 50.2 |
| .21 | 20.6 | 25.7 | 30.9 | 36.0 | 41.2 | 46.3 | 51.5 |
| .22 | 21.1 | 26.3 | 31.6 | 36.9 | 42.2 | 47.4 | 52.7 |
| .23 | 21.6 | 26.9 | 32.3 | 37.7 | 43.1 | 48.5 | 53.9 |
| .24 | 22.0 | 27.5 | 33.0 | 38.5 | 44.0 | 49.5 | 55.0 |
| .25 | 22.5 | 28.1 | 33.7 | 39.3 | 44.9 | 50.6 | 56.2 |
| .26 | 22.9 | 28.6 | 34.4 | 40.1 | 45.8 | 51.6 | 57.3 |
| .27 | 23.4 | 29.2 | 35.0 | 40.9 | 46.7 | 52.5 | 58.4 |
| .28 | 23.8 | 29.7 | 35.7 | 41.6 | 47.6 | 53.5 | 59.4 |
| .29 | 24.2 | 30.3 | 36.3 | 42.4 | 48.4 | 54.5 | 60.5 |
| .30 | 24.6 | 30.8 | 36.9 | 43.1 | 49.2 | 55.4 | 61.5 |
| .31 | 25.0 | 31.3 | 37.5 | 43.8 | 50.0 | 56.3 | 62.6 |
| .32 | 25.4 | 31.8 | 38.1 | 44.5 | 50.8 | 57.2 | 63.6 |
| .33 | 25.8 | 32.3 | 38.7 | 45.2 | 51.6 | 58.1 | 64.5 |
| .34 | 26.2 | 32.8 | 39.3 | 45.9 | 52.4 | 59.0 | 65.5 |
| .35 | 26.6 | 33.2 | 39.9 | 46.5 | 53.2 | 59.8 | 66.5 |
| .36 | 27.0 | 33.7 | 40.4 | 47.2 | 53.9 | 60.7 | 67.4 |
| .37 | 27.3 | 34.2 | 41.0 | 47.8 | 54.7 | 61.5 | 68.3 |
| .38 | 27.7 | 34.6 | 41.6 | 48.5 | 55.4 | 62.3 | 69.3 |
| .39 | 28.1 | 35.1 | 42.1 | 49.1 | 56.1 | 63.1 | 70.2 |
| .40 | 28.4 | 35.5 | 42.6 | 49.7 | 56.8 | 64.0 | 71.1 |
| .41 | 28.8 | 36.0 | 43.2 | 50.4 | 57.6 | 64.7 | 71.9 |
| .42 | 29.1 | 36.4 | 43.7 | 51.0 | 58.2 | 65.5 | 72.8 |
| .43 | 29.5 | 36.8 | 44.2 | 51.6 | 58.9 | 66.3 | 73.7 |
| .44 | 29.8 | 37.3 | 44.7 | 52.2 | 59.6 | 67.1 | 74.5 |
| .45 | 30.1 | 37.7 | 45.2 | 52.8 | 60.3 | 67.8 | 75.4 |
| .46 | 30.5 | 38.1 | 45.7 | 53.3 | 61.0 | 68.6 | 76.2 |
| .47 | 30.8 | 38.5 | 46.2 | 53.9 | 61.6 | 69.3 | 77.0 |
| .48 | 31.1 | 38.9 | 46.7 | 54.5 | 62.3 | 70.1 | 77.8 |
| .49 | 31.5 | 39.3 | 47.2 | 55.1 | 62.9 | 70.8 | 78.6 |
| .50 | 31.8 | 39.7 | 47.7 | 55.6 | 63.6 | 71.5 | 79.4 |
| .51 | 32.1 | 40.1 | 48.1 | 56.2 | 64.2 | 72.2 | 80.2 |
| .52 | 32.4 | 40.5 | 48.6 | 56.7 | 64.8 | 72.9 | 81.0 |
| .53 | 32.7 | 40.9 | 49.1 | 57.3 | 65.4 | 73.6 | 81.8 |

**Table A9-3 [continued]**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 |
| 0.04 | 24.7 | 27.0 | 29.2 | 31.5 | 33.7 | 36.0 | 38.2 | 40.4 |
| .05 | 27.6 | 30.1 | 32.7 | 35.2 | 37.7 | 40.2 | 42.7 | 45.2 |
| .06 | 30.3 | 33.0 | 35.8 | 38.5 | 41.3 | 44.0 | 46.8 | 49.5 |
| .07 | 32.7 | 35.7 | 38.6 | 41.6 | 44.6 | 47.6 | 50.5 | 53.5 |
| .08 | 35.0 | 38.1 | 41.3 | 44.5 | 47.7 | 50.8 | 54.0 | 57.2 |
| .09 | 37.1 | 40.4 | 43.8 | 47.2 | 50.6 | 53.9 | 57.3 | 60.7 |
| .10 | 39.1 | 42.6 | 46.2 | 49.7 | 53.3 | 56.8 | 60.4 | 64.0 |
| .11 | 41.0 | 44.7 | 48.4 | 52.2 | 55.9 | 59.6 | 63.3 | 67.1 |
| .12 | 42.8 | 46.7 | 50.6 | 54.5 | 58.4 | 62.3 | 66.2 | 70.1 |
| .13 | 44.6 | 48.6 | 52.7 | 56.7 | 60.8 | 64.8 | 68.9 | 72.9 |
| .14 | 46.2 | 50.4 | 54.6 | 58.9 | 63.1 | 67.3 | 71.5 | 75.7 |
| .15 | 47.9 | 52.2 | 56.6 | 60.9 | 65.3 | 69.6 | 74.0 | 78.3 |
| .16 | 49.4 | 53.9 | 58.4 | 62.9 | 67.4 | 71.9 | 76.4 | 80.9 |
| .17 | 51.0 | 55.6 | 60.2 | 64.9 | 69.5 | 74.1 | 78.7 | 83.4 |
| .18 | 52.4 | 57.2 | 62.0 | 66.7 | 71.5 | 76.3 | 81.0 | 85.8 |
| .19 | 53.9 | 58.8 | 63.7 | 68.6 | 73.5 | 78.4 | 83.3 | 88.1 |
| .20 | 55.3 | 60.3 | 65.3 | 70.3 | 75.4 | 80.4 | 85.4 | 90.4 |
| .21 | 56.6 | 61.8 | 66.9 | 72.1 | 77.2 | 82.4 | 87.5 | 92.7 |
| .22 | 58.0 | 63.2 | 68.5 | 73.8 | 79.0 | 84.3 | 89.6 | 94.9 |
| .23 | 59.3 | 64.7 | 70.0 | 75.4 | 80.8 | 86.2 | 91.6 | 97.0 |
| .24 | 60.5 | 66.0 | 71.6 | 77.1 | 82.6 | 88.1 | 93.6 | 99.1 |
| .25 | 61.8 | 67.4 | 73.0 | 78.6 | 84.3 | 89.9 | 95.5 | 101. |
| .26 | 63.0 | 68.7 | 74.5 | 80.2 | 85.9 | 91.7 | 97.4 | 103. |
| .27 | 64.2 | 70.1 | 75.9 | 81.7 | 87.6 | 93.4 | 99.2 | 105. |
| .28 | 65.4 | 71.3 | 77.3 | 83.2 | 89.2 | 95.1 | 101. | 107. |
| .29 | 66.6 | 72.6 | 78.7 | 84.7 | 90.8 | 96.8 | 103. | 109. |
| .30 | 67.7 | 73.8 | 80.0 | 86.2 | 92.3 | 98.5 | 105. | 111. |
| .31 | 68.8 | 75.1 | 81.3 | 87.6 | 93.8 | 100. | 106. | 113. |
| .32 | 69.9 | 76.3 | 82.6 | 89.0 | 95.3 | 102. | 108. | 114. |
| .33 | 71.0 | 77.4 | 83.9 | 90.4 | 96.8 | 103. | 110. | 116. |
| .34 | 72.1 | 78.6 | 85.2 | 91.7 | 98.3 | 105. | 111. | 118. |
| .35 | 73.1 | 79.8 | 86.4 | 93.1 | 99.7 | 106. | 113. | 120. |
| .36 | 74.2 | 80.9 | 87.6 | 94.4 | 101. | 108. | 115. | 121. |
| .37 | 75.2 | 82.0 | 88.8 | 95.7 | 103. | 109. | 116. | 123. |
| .38 | 76.2 | 83.1 | 90.0 | 97.0 | 104. | 111. | 118. | 125. |
| .39 | 77.2 | 84.2 | 91.2 | 98.2 | 105. | 112. | 119. | 126. |
| .40 | 78.2 | 85.3 | 92.4 | 99.5 | 107. | 114. | 121. | 128. |
| .41 | 79.1 | 86.3 | 93.5 | 101. | 108. | 115. | 122. | 129. |
| .42 | 80.1 | 87.4 | 94.7 | 102. | 109. | 116. | 124. | 131. |
| .43 | 81.0 | 88.4 | 95.8 | 103. | 111. | 118. | 125. | 133. |
| .44 | 82.0 | 89.4 | 96.9 | 104. | 112. | 119. | 127. | 134. |
| .45 | 82.9 | 90.4 | 98.0 | 106. | 113. | 121. | 128. | 136. |
| .46 | 83.8 | 91.4 | 99.1 | 107. | 114. | 122. | 130. | 137. |
| .47 | 84.7 | 92.4 | 100. | 108. | 116. | 123. | 131. | 139. |
| .48 | 85.6 | 93.4 | 101. | 109. | 117. | 125. | 132. | 140. |
| .49 | 86.5 | 94.4 | 102. | 110. | 118. | 126. | 134. | 142. |
| .50 | 87.4 | 95.3 | 103. | 111. | 119. | 127. | 135. | 143. |
| .51 | 88.3 | 96.3 | 104. | 112. | 120. | 128. | 136. | 144. |
| .52 | 89.1 | 97.2 | 105. | 113. | 122. | 130. | 138. | 146. |
| .53 | 90.0 | 98.1 | 106. | 115. | 123. | 131. | 139. | 147. |

**Table A9-3 [continued]**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | |
|---|---|---|---|---|---|---|---|
| | 38 | 40 | 42 | 44 | 46 | 48 | 50 |
| 0.04 | 42.7 | 44.9 | 47.2 | 49.4 | 51.7 | 53.9 | 56.2 |
| .05 | 47.7 | 50.2 | 52.8 | 55.3 | 57.8 | 60.3 | 62.8 |
| .06 | 52.3 | 55.0 | 57.8 | 60.5 | 63.3 | 66.0 | 68.8 |
| .07 | 56.5 | 59.4 | 62.4 | 65.4 | 68.4 | 71.3 | 74.3 |
| .08 | 60.4 | 63.6 | 66.7 | 69.9 | 73.1 | 76.3 | 79.4 |
| .09 | 64.0 | 67.4 | 70.8 | 74.2 | 77.5 | 80.9 | 84.3 |
| .10 | 67.5 | 71.1 | 74.6 | 78.2 | 81.7 | 85.3 | 88.8 |
| .11 | 70.8 | 74.5 | 78.3 | 82.0 | 85.7 | 89.4 | 93.2 |
| .12 | 73.9 | 77.8 | 81.7 | 85.6 | 89.5 | 93.4 | 97.3 |
| .13 | 77.0 | 81.0 | 85.1 | 89.1 | 93.2 | 97.2 | 101. |
| .14 | 79.9 | 84.1 | 88.3 | 92.5 | 96.7 | 101. | 105. |
| .15 | 82.7 | 87.0 | 91.4 | 95.7 | 100. | 104. | 109. |
| .16 | 85.4 | 89.9 | 94.4 | 98.9 | 103. | 108. | 112. |
| .17 | 88.0 | 92.6 | 97.3 | 102. | 107. | 111. | 116. |
| .18 | 90.6 | 95.3 | 100. | 105. | 110. | 114. | 119. |
| .19 | 93.0 | 97.9 | 103. | 108. | 113. | 118. | 122. |
| .20 | 95.5 | 100. | 106. | 111. | 116. | 121. | 126. |
| .21 | 97.8 | 103. | 108. | 113. | 118. | 124. | 129. |
| .22 | 100. | 105. | 111. | 116. | 121. | 126. | 132. |
| .23 | 102. | 108. | 113. | 119. | 124. | 129. | 135. |
| .24 | 105. | 110. | 116. | 121. | 127. | 132. | 138. |
| .25 | 107. | 112. | 118. | 124. | 129. | 135. | 140. |
| .26 | 109. | 115. | 120. | 126. | 132. | 137. | 143. |
| .27 | 111. | 117. | 123. | 128. | 134. | 140. | 146. |
| .28 | 113. | 119. | 125. | 131. | 137. | 143. | 149. |
| .29 | 115. | 121. | 127. | 133. | 139. | 145. | 151. |
| .30 | 117. | 123. | 129. | 135. | 142. | 148. | 154. |
| .31 | 119. | 125. | 131. | 138. | 144. | 150. | 156. |
| .32 | 121. | 127. | 133. | 140. | 146. | 153. | 159. |
| .33 | 123. | 129. | 136. | 142. | 148. | 155. | 161. |
| .34 | 124. | 131. | 138. | 144. | 151. | 157. | 164. |
| .35 | 126. | 133. | 140. | 146. | 153. | 160. | 166. |
| .36 | 128. | 135. | 142. | 148. | 155. | 162. | 169. |
| .37 | 130. | 137. | 144. | 150. | 157. | 164. | 171. |
| .38 | 132. | 139. | 145. | 152. | 159. | 166. | 173. |
| .39 | 133. | 140. | 147. | 154. | 161. | 168. | 175. |
| .40 | 135. | 142. | 149. | 156. | 163. | 171. | 178. |
| .41 | 137. | 144. | 151. | 158. | 165. | 173. | 180. |
| .42 | 138. | 146. | 153. | 160. | 167. | 175. | 182. |
| .43 | 140. | 147. | 155. | 162. | 169. | 177. | 184. |
| .44 | 142. | 149. | 157. | 164. | 171. | 179. | 186. |
| .45 | 143. | 151. | 158. | 166. | 173. | 181. | 188. |
| .46 | 145. | 152. | 160. | 168. | 175. | 183. | 190. |
| .47 | 146. | 154. | 162. | 169. | 177. | 185. | 193. |
| .48 | 148. | 156. | 163. | 171. | 179. | 187. | 195. |
| .49 | 149. | 157. | 165. | 173. | 181. | 189. | 197. |
| .50 | 151. | 159. | 167. | 175. | 183. | 191. | 199. |
| .51 | 152. | 160. | 168. | 177. | 185. | 193. | 201. |
| .52 | 154. | 162. | 170. | 178. | 186. | 194. | 203. |
| .53 | 155. | 164. | 172. | 180. | 188. | 196. | 204. |

**Table A9-3 [continued]**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 |
| 0.04 | 61.8 | 67.4 | 73.0 | 78.6 | 84.3 | 89.9 | 95.5 | 101. |
| .05 | 69.1 | 75.4 | 81.6 | 87.9 | 94.2 | 100. | 107. | 113. |
| .06 | 75.7 | 82.6 | 89.4 | 96.3 | 103. | 110. | 117. | 124. |
| .07 | 81.7 | 89.2 | 96.6 | 104. | 111. | 119. | 126. | 134. |
| .08 | 87.4 | 95.3 | 103. | 111. | 119. | 127. | 135. | 143. |
| .09 | 92.7 | 101. | 110. | 118. | 126. | 135. | 143. | 152. |
| .10 | 97.7 | 107. | 115. | 124. | 133. | 142. | 151. | 160. |
| .11 | 102. | 112. | 121. | 130. | 140. | 149. | 158. | 168. |
| .12 | 107. | 117. | 126. | 136. | 146. | 156. | 165. | 175. |
| .13 | 111. | 122. | 132. | 142. | 152. | 162. | 172. | 182. |
| .14 | 116. | 126. | 137. | 147. | 158. | 168. | 179. | 189. |
| .15 | 120. | 131. | 141. | 152. | 163. | 174. | 185. | 196. |
| .16 | 124. | 135. | 146. | 157. | 169. | 180. | 191. | 202. |
| .17 | 127. | 139. | 151. | 162. | 174. | 185. | 197. | 208. |
| .18 | 131. | 143. | 155. | 167. | 179. | 191. | 203. | 214. |
| .19 | 135. | 147. | 159. | 171. | 184. | 196. | 208. | 220. |
| .20 | 138. | 151. | 163. | 176. | 188. | 201. | 214. | 226. |
| .21 | 142. | 154. | 167. | 180. | 193. | 206. | 219. | 232. |
| .22 | 145. | 158. | 171. | 184. | 198. | 211. | 224. | 237. |
| .23 | 148. | 162. | 175. | 189. | 202. | 216. | 229. | 242. |
| .24 | 151. | 165. | 179. | 193. | 206. | 220. | 234. | 248. |
| .25 | 154. | 169. | 183. | 197. | 211. | 225. | 239. | 253. |
| .26 | 158. | 172. | 186. | 201. | 215. | 229. | 243. | 258. |
| .27 | 161. | 175. | 190. | 204. | 219. | 234. | 248. | 263. |
| .28 | 163. | 178. | 193. | 208. | 223. | 238. | 253. | 268. |
| .29 | 166. | 182. | 197. | 212. | 227. | 242. | 257. | 272. |
| .30 | 169. | 185. | 200. | 215. | 231. | 246. | 262. | 277. |
| .31 | 172. | 188. | 203. | 219. | 235. | 250. | 266. | 281. |
| .32 | 175. | 191. | 207. | 222. | 238. | 254. | 270. | 286. |
| .33 | 177. | 194. | 210. | 226. | 242. | 258. | 274. | 290. |
| .34 | 180. | 197. | 213. | 229. | 246. | 262. | 278. | 295. |
| .35 | 183. | 199. | 216. | 233. | 249. | 266. | 282. | 299. |
| .36 | 185. | 202. | 219. | 236. | 253. | 270. | 286. | 303. |
| .37 | 188. | 205. | 222. | 239. | 256. | 273. | 290. | 308. |
| .38 | 190. | 208. | 225. | 242. | 260. | 277. | 294. | 312. |
| .39 | 193. | 210. | 228. | 246. | 263. | 281. | 298. | 316. |
| .40 | 195. | 213. | 231. | 249. | 266. | 284. | 302. | 320. |
| .41 | 198. | 216. | 234. | 252. | 270. | 288. | 306. | 324. |
| .42 | 200. | 218. | 237. | 255. | 273. | 291. | 309. | 328. |
| .43 | 203. | 221. | 239. | 258. | 276. | 295. | 313. | 332. |
| .44 | 205. | 224. | 242. | 261. | 279. | 298. | 317. | 335. |
| .45 | 207. | 226. | 245. | 264. | 283. | 301. | 320. | 339. |
| .46 | 210. | 229. | 248. | 267. | 286. | 305. | 324. | 343. |
| .47 | 212. | 231. | 250. | 270. | 289. | 308. | 327. | 347. |
| .48 | 214. | 234. | 253. | 272. | 292. | 311. | 331. | 350. |
| .49 | 216. | 236. | 256. | 275. | 295. | 315. | 334. | 354. |
| .50 | 218. | 238. | 258. | 278. | 298. | 318. | 338. | 357. |
| .51 | 221. | 241. | 261. | 281. | 301. | 321. | 341. | 361. |
| .52 | 223. | 243. | 263. | 284. | 304. | 324. | 344. | 365. |
| .53 | 225. | 245. | 266. | 286. | 307. | 327. | 348. | 368. |

**Table A9-3 [continued]**. Discharge of rectangular submerged orifices with bottom and side contractions suppressed, in ft3/sec. Computed from the formula $Q = 0.70A\,(2g\,\Delta h)^{0.5}$

| Head $\Delta h$, ft | Cross-sectional area $A$ of orifice, square feet | | | | | | |
|---|---|---|---|---|---|---|---|
| | 95 | 100 | 105 | 110 | 115 | 120 | 125 |
| 0.04 | 107 | 112 | 118 | 124 | 129 | 135 | 140 |
| .05 | 119 | 126 | 132 | 138 | 144 | 151 | 157 |
| .06 | 131 | 138 | 144 | 151 | 158 | 165 | 172 |
| .07 | 141 | 149 | 156 | 163 | 171 | 178 | 186 |
| .08 | 151 | 159 | 167 | 175 | 183 | 191 | 199 |
| .09 | 160 | 169 | 177 | 185 | 194 | 202 | 211 |
| .10 | 169 | 178 | 187 | 195 | 204 | 213 | 222 |
| .11 | 177 | 186 | 196 | 205 | 214 | 224 | 233 |
| .12 | 185 | 195 | 204 | 214 | 224 | 234 | 243 |
| .13 | 192 | 203 | 213 | 223 | 233 | 243 | 253 |
| .14 | 200 | 210 | 221 | 231 | 242 | 252 | 263 |
| .15 | 207 | 218 | 228 | 239 | 250 | 261 | 272 |
| .16 | 213 | 225 | 236 | 247 | 258 | 270 | 281 |
| .17 | 220 | 232 | 243 | 255 | 266 | 278 | 290 |
| .18 | 226 | 238 | 250 | 262 | 274 | 286 | 298 |
| .19 | 233 | 245 | 257 | 269 | 282 | 294 | 306 |
| .20 | 239 | 251 | 264 | 276 | 289 | 301 | 314 |
| .21 | 245 | 257 | 270 | 283 | 296 | 309 | 322 |
| .22 | 250 | 263 | 277 | 290 | 303 | 316 | 329 |
| .23 | 256 | 269 | 283 | 296 | 310 | 323 | 337 |
| .24 | 261 | 275 | 289 | 303 | 316 | 330 | 344 |
| .25 | 267 | 281 | 295 | 309 | 323 | 337 | 351 |
| .26 | 272 | 286 | 301 | 315 | 329 | 344 | 358 |
| .27 | 277 | 292 | 306 | 321 | 336 | 350 | 365 |
| .28 | 282 | 297 | 312 | 327 | 342 | 357 | 372 |
| .29 | 287 | 303 | 318 | 333 | 348 | 363 | 378 |
| .30 | 292 | 308 | 323 | 338 | 354 | 369 | 385 |
| .31 | 297 | 313 | 328 | 344 | 360 | 375 | 391 |
| .32 | 302 | 318 | 334 | 350 | 365 | 381 | 397 |
| .33 | 307 | 323 | 339 | 355 | 371 | 387 | 403 |
| .34 | 311 | 328 | 344 | 360 | 377 | 393 | 409 |
| .35 | 316 | 332 | 349 | 366 | 382 | 399 | 415 |
| .36 | 320 | 337 | 354 | 371 | 388 | 404 | 421 |
| .37 | 325 | 342 | 359 | 376 | 393 | 410 | 427 |
| .38 | 329 | 346 | 364 | 381 | 398 | 416 | 433 |
| .39 | 333 | 351 | 368 | 386 | 403 | 421 | 439 |
| .40 | 338 | 355 | 373 | 391 | 409 | 426 | 444 |
| .41 | 342 | 360 | 378 | 396 | 414 | 432 | 450 |
| .42 | 346 | 364 | 382 | 400 | 419 | 437 | 455 |
| .43 | 350 | 368 | 387 | 405 | 424 | 442 | 460 |
| .44 | 354 | 373 | 391 | 410 | 429 | 447 | 466 |
| .45 | 358 | 377 | 396 | 415 | 433 | 452 | 471 |
| .46 | 362 | 381 | 400 | 419 | 438 | 457 | 476 |
| .47 | 366 | 385 | 404 | 424 | 443 | 462 | 481 |
| .48 | 370 | 389 | 409 | 428 | 448 | 467 | 486 |
| .49 | 374 | 393 | 413 | 433 | 452 | 472 | 492 |
| .50 | 377 | 397 | 417 | 437 | 457 | 477 | 497 |
| .51 | 381 | 401 | 421 | 441 | 461 | 481 | 501 |
| .52 | 385 | 405 | 425 | 446 | 466 | 486 | 506 |
| .53 | 389 | 409 | 429 | 450 | 470 | 491 | 511 |

**Table A9-4**. Discharge of constant-head orifice (CHO) turnout in $ft^3$/sec. Capacity is 20 $ft^3$/sec, gate size is 30 by 24 inches, $\Delta h$ =0.20 feet.

| Discharge | Gate opening in feet | | Discharge | Gate opening in feet | |
|---|---|---|---|---|---|
| *$ft^3$/sec* | 2 gates | 1 gate | *$ft^3$/sec* | 2 gates | 1 gate |
| 0.25 | 0.02 | 0.04 | 10.25 | 0.81 | ----- |
| .50 | .04 | .08 | 10.50 | .83 | ----- |
| .75 | .06 | .12 | 10.75 | .85 | ----- |
| 1.00 | .08 | .16 | 11.00 | .87 | ----- |
| 1.25 | .10 | .20 | 11.25 | .89 | ----- |
| 1.50 | .12 | .24 | 11.50 | .91 | ----- |
| 1.75 | .14 | .28 | 11.75 | .93 | ----- |
| 2.00 | .16 | .32 | 12.00 | .95 | ----- |
| 2.25 | .18 | .36 | 12.25 | .97 | ----- |
| 2.50 | .20 | .40 | 12.50 | .99 | ----- |
| 2.75 | .22 | .44 | 12.75 | 1.01 | ----- |
| 3.00 | .24 | .48 | 13.00 | 1.03 | ----- |
| 3.25 | .26 | .52 | 13.25 | 1.05 | ----- |
| 3.50 | .28 | .56 | 13.50 | 1.07 | ----- |
| 3.75 | .30 | .60 | 13.75 | 1.085 | ----- |
| 4.00 | .32 | .64 | 14.00 | 1.10 | ----- |
| 4.25 | .34 | .68 | 14.25 | 1.12 | ----- |
| 4.50 | .36 | .72 | 14.50 | 1.14 | ----- |
| 4.75 | .38 | .755 | 14.75 | 1.16 | ----- |
| 5.00 | .40 | .79 | 15.00 | 1.18 | ----- |
| 5.25 | .42 | .83 | 15.25 | 1.20 | ----- |
| 5.50 | .44 | .87 | 15.50 | 1.22 | ----- |
| 5.75 | .46 | .91 | 15.75 | 1.24 | ----- |
| 6.00 | .48 | .95 | 16.00 | 1.26 | ----- |
| 6.25 | .50 | .99 | 16.25 | 1.28 | ----- |
| 6.50 | .52 | 1.03 | 16.50 | 1.30 | ----- |
| 6.75 | .54 | 1.065 | 16.75 | 1.32 | ----- |
| 7.00 | .56 | 1.10 | 17.00 | 1.34 | ----- |
| 7.25 | .58 | 1.14 | 17.25 | 1.355 | ----- |
| 7.50 | .60 | 1.18 | 17.50 | 1.37 | ----- |
| 7.75 | .62 | 1.22 | 17.75 | 1.39 | ----- |
| 8.00 | .64 | 1.26 | 18.00 | 1.41 | ----- |
| 8.25 | .66 | 1.30 | 18.25 | 1.43 | ----- |
| 8.50 | .68 | 1.34 | 18.50 | 1.45 | ----- |
| 8.75 | .70 | 1.375 | 18.75 | 1.47 | ----- |
| 9.00 | .72 | 1.41 | 19.00 | 1.49 | ----- |
| 9.25 | .74 | 1.45 | 19.25 | 1.51 | ----- |
| 9.50 | .76 | 1.49 | 19.50 | 1.53 | ----- |
| 9.75 | .775 | 1.525 | 19.75 | 1.545 | ----- |
| 10.00 | .80 | 1.56 | 20.00 | 1.56 | ----- |

**Table A9-5**. Discharge of constant-head orifice (CHO) turnout in $ft^3$/sec. Capacity is 10 $ft^3$/sec, gate size is 24 by 18 inches, $\Delta h$ =0.20 feet.

| Discharge | Gate opening in feet | | Discharge | Gate opening in feet | |
|---|---|---|---|---|---|
| *$ft^3$/sec* | 2 gates | 1 gate | *$ft^3$/sec* | 2 gates | 1 gate |
| 0.25 | 0.025 | 0.05 | 5.25 | 0.525 | ----- |
| .50 | .05 | .10 | 5.50 | .55 | ----- |
| .75 | .075 | .15 | 5.75 | .575 | ----- |
| 1.00 | .10 | .20 | 6.00 | .60 | ----- |
| 1.25 | .125 | .25 | 6.25 | .625 | ----- |
| 1.50 | .15 | .30 | 6.50 | .65 | ----- |
| 1.75 | .175 | .35 | 6.75 | .675 | ----- |
| 2.00 | .20 | .40 | 7.00 | .70 | ----- |
| 2.25 | .225 | .45 | 7.25 | .722 | ----- |
| 2.50 | .25 | .50 | 7.50 | .74 | ----- |
| 2.75 | .275 | .55 | 7.75 | .765 | ----- |
| 3.00 | .30 | .60 | 8.00 | .79 | ----- |
| 3.25 | .325 | .65 | 8.25 | .815 | ----- |
| 3.50 | .35 | .70 | 8.50 | .84 | ----- |
| 3.75 | .375 | .745 | 8.75 | .865 | ----- |
| 4.00 | .40 | .79 | 9.00 | .89 | ----- |
| 4.25 | .425 | .84 | 9.25 | .915 | ----- |
| 4.50 | .45 | .89 | 9.50 | .94 | ----- |
| 4.75 | .475 | .94 | 9.75 | .965 | ----- |
| 5.00 | .50 | .99 | 10.00 | .99 | ----- |

**Table A9-6**. Discharges for standard sized constant-head orifice (CHO) turnouts (Aisenbrey, 1978).

| | Orifice gate openings in feet, for various size turnouts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Gate width | 18 inch | 18 inch | 24 inch | 30 inch | 30 inch | 36 inch | 42 inch | 48 inch | 48 inch |
| Discharge *ft$^3$/sec* | 2-ft$^3$/sec turnout | 4-ft$^3$/sec turnout | 6-ft$^3$/sec turnout | 9-ft$^3$/sec turnout | 12-ft$^3$/sec turnout | 15-ft$^3$/sec turnout | 18-ft$^3$/sec turnout | 24-ft$^3$/sec turnout | 30-ft$^3$/sec turnout |
| 1.0 | 0.27 | 0.27 | 0.20 | 0.16 | 0.16 | 0.13 | 0.11 | 0.10 | 0.10 |
| 2.0 | .53 | .53 | .40 | .32 | .32 | .27 | .23 | .20 | .20 |
| 3.0 | ----- | .80 | .60 | .48 | .48 | .40 | .34 | .30 | .30 |
| 4.0 | ----- | 1.06 | .80 | .64 | .64 | .53 | .46 | .40 | .40 |
| 5.0 | ----- | ----- | .99 | .80 | .80 | .66 | .57 | .50 | .50 |
| 6.0 | ----- | ----- | 1.19 | .96 | .96 | .80 | .68 | .60 | .60 |
| 7.0 | ----- | ----- | ----- | 1.12 | 1.12 | .93 | .80 | .70 | .70 |
| 8.0 | ----- | ----- | ----- | 1.27 | 1.27 | 1.06 | .91 | .80 | .80 |
| 9.0 | ----- | ----- | ----- | 1.43 | 1.43 | 1.19 | 1.02 | .90 | .90 |
| 10.0 | ----- | ----- | ----- | ----- | 1.59 | 1.33 | 1.14 | 1.00 | 1.00 |
| 11.0 | ----- | ----- | ----- | ----- | 1.75 | 1.46 | 1.25 | 1.10 | 1.10 |
| 12.0 | ----- | ----- | ----- | ----- | 1.91 | 1.59 | 1.37 | 1.19 | 1.20 |
| 14.0 | ----- | ----- | ----- | ----- | ----- | 1.86 | 1.59 | 1.39 | 1.39 |
| 15.0 | ----- | ----- | ----- | ----- | ----- | 1.99 | 1.71 | 1.49 | 1.49 |
| 16.0 | ----- | ----- | ----- | ----- | ----- | ----- | 1.82 | 1.59 | 1.59 |
| 18.0 | ----- | ----- | ----- | ----- | ----- | ----- | 2.05 | 1.79 | 1.79 |
| 20.0 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 1.99 | 1.99 |
| 21.0 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 2.09 | 2.09 |
| 22.0 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 2.19 | 2.19 |
| 24.0 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 2.39 | 2.39 |
| 30.0 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 2.99 |

**Appendix E**
Groundwater Elevation Data

**Groundwater Well Elevations, Rico Colorado**

| Date | EB-1 | EB-2 | GW-1 | GW-3 | GW-4 | GW-5 | GW-6 | GW-7 | MW-1 DEEP | MW-1 SHALLOW | MW-2 DEEP | MW-2 SHALLOW | MW-3 DEEP | MW-3 SHALLOW | MW-4 DEEP | MW-4 SHALLOW | MW-5 DEEP | MW-5 SHALLOW | MW-6 DEEP | MW-6 SHALLOW | MW-101 | MW-102 | MW-103 | MW-104 | MW-202 | MW-204 | P13-102 | P13-103 | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Well Casing Elevation | 8839.86 | 8829.84 | 8840.13 | 8836.68 | 8826.79 | 8839.52 | 8837.45 | 8840.00 | 8810.85 | 8810.87 | 8810.21 | 8810.23 | 8819.72 | 8819.57 | 8816.77 | 8816.83 | 8830.73 | 8830.95 | 8830.11 | 8830.58 | 8845.417 | 8841.304 | 8797.799 | 8785.598 | 8859.206 | 8865.954 | 8810.643 | 8811.464 | |
| May-11 | 8820.87 | 8810.38 | CNL | 8825.38 | 8812.73 | 8821.02 | 8818.81 | 8815.85 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Jun-11 | 8820.80 | 8815.41 | 8839.94 | 8825.59 | 8817.63 | 8821.65 | 8817.78 | 8821.95 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Jul-11 | 8819.86 | 8814.31 | 8839.19 | 8824.62 | 8816.8 | 8820.07 | 8816.33 | 8820.14 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Aug-11 | 8818.68 | 8813.65 | 8838.23 | 8824.01 | 8815.98 | 8819.04 | 8815.32 | 8818.93 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Sep-11 | 8817.94 | 8813.45 | 8838.02 | 8823.83 | 8814.88 | 8818.37 | 8814.48 | 8817.89 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Oct-11 | 8818.24 | 8813.59 | 8838.21 | 8823.89 | 8816.01 | 8818.32 | 8816.68 | 8817.38 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Nov-11 | 8818.01 | 8813.40 | 8838.03 | 8823.81 | 8815.94 | 8818.09 | CNO | 8817.41 | 8802.38 | 8804.63 | 8800.12 | CNO | 8809.30 | CNO | 8800.32 | 8800.02 | 8813.67 | 8815.1 | 8807.37 | 8807.74 | | | | | | | | | Obstruction in GW-6, working to remove |
| Dec-11 | 8817.58 | 8813.28 | CNL | 8823.78 | 8815.76 | 8817.65 | CNO | 8817.00 | 8801.86 | 8804.56 | 8800.05 | CNO | 8809.35 | CNO | 8799.89 | 8799.88 | 8813.4 | 8814.76 | 8806.95 | 8807.35 | | | | | | | | | GW-1 buried under snow; GW-6 frozen; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Jan-12 | 8817.36 | 8813.14 | CNO | 8823.68 | CNL | 8817.30 | CNO | 8816.80 | 8801.71 | 8804.49 | 8800.01 | CNO | 8809.35 | CNO | 8799.76 | 8799.76 | 8813.15 | 8814.40 | 8806.72 | 8807.07 | | | | | | | | | GW-1 and GW-4 buried under snow; GW-6 frozen; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Feb-12 | 8817.36 | 8813.23 | CNO | 8823.68 | CNL | 8817.30 | CNO | 8816.80 | 8801.72 | 8804.53 | 8799.99 | CNO | 8809.37 | CNO | 8799.81 | 8799.78 | 8813.12 | 8814.15 | 8806.70 | 8807.09 | | | | | | | | | GW-1 and GW-4 buried under snow; GW-6 frozen; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Mar-12 | 8818.19 | 8813.30 | CNO | 8824.02 | CNL | 8818.22 | CNO | 8817.08 | 8801.99 | 8804.68 | 8800.16 | CNO | 8809.59 | CNO | 8800.23 | 8800.24 | 8813.67 | 8814.24 | CNO | 8807.78 | | | | | | | | | GW-1 and GW-4 buried under snow; GW-6 frozen; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Apr-12 | 8819.32 | 8814.44 | 8839.06 | 8824.33 | 8817.31 | 8819.48 | CNO | 8819.30 | 8802.14 | 8804.71 | 8800.37 | 8800.24 | 8809.90 | CNO | 8800.51 | 8798.54 | 8814.54 | 8816.03 | 8808.30 | 8808.93 | | | | | | | | | GW-6 obstructed; MW-3 SHALLOW dry |
| May-12 | 8818.75 | 8813.87 | 8839.70 | 8823.00 | 8816.75 | 8818.85 | CNO | 8820.48 | 8802.40 | 8804.72 | 8800.45 | CNO | 8809.95 | CNO | 8800.40 | 8800.42 | 8814.19 | 8815.59 | 8807.74 | 8808.23 | | | | | | | | | GW-6 obstructed; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Jun-12 | 8818.19 | 8813.42 | 8838.67 | 8823.87 | 8816.33 | 8818.29 | CNO | 8817.79 | 8801.91 | 8804.68 | 8800.23 | 8800.26 | 8809.66 | 8810.38 | 8799.98 | 8800.00 | 8813.78 | 8815.20 | 8807.27 | 8807.72 | | | | | | | | | GW-6 obstructed |
| Jul-12 | 8817.96 | 8813.24 | 8838.08 | 8822.89 | 8815.91 | 8817.95 | CNO | 8817.42 | 8801.86 | 8804.48 | 8800.20 | CNO | 8809.65 | CNO | 8799.95 | 8799.99 | 8813.57 | 8815.05 | 8807.21 | 8807.62 | | | | | | | | | GW-6 obstructed; MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Aug-12 | 8817.56 | 8812.98 | 8837.67 | 8821.82 | 8815.96 | 8817.62 | 8815.98 | 8817.09 | 8801.81 | 8804.23 | 8800.15 | CNO | 8809.46 | CNO | 8799.97 | 8799.98 | 8813.39 | 8814.86 | 8807.13 | 8807.47 | | | | | | | | | MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Sep-12 | 8817.21 | 8812.84 | 8837.47 | 8822.88 | 8815.78 | 8817.28 | 8815.72 | 8816.91 | 8802.44 | 8804.93 | 8800.08 | CNO | 8809.41 | CNO | 8799.76 | 8799.76 | 8813.16 | 8814.57 | 8806.80 | 8807.20 | | | | | | | | | MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Oct-12 | 8818.49 | 8813.47 | 8837.40 | 8823.24 | 8817.02 | 8818.56 | 8816.67 | 8817.09 | 8801.59 | 8804.68 | 8800.09 | CNO | 8809.73 | CNO | 8800.09 | 8800.11 | 8813.84 | 8814.51 | 8807.25 | 8807.68 | | | | | | | | | MW-2 SHALLOW and MW-3 SHALLOW were dry |
| Nov-12 | 8817.89 | 8813.21 | 8837.62 | 8822.86 | 8816.35 | 8818.02 | 8815.24 | 8817.12 | 8800.47 | 8804.27 | 8800.22 | 8800.04 | 8809.61 | 8810.45 | 8799.85 | 8799.85 | 8813.55 | 8814.52 | 8806.55 | 8807.45 | 8818.15 | 8817.50 | 8790.81 | 8781.32 | CNO | 8852.12 | 8800.04 | 8800.58 | MW-202 was dry. MW-2 SHALLOW and MW-3 SHALLOW had less than 1 inch of water. |
| Dec-12 | 8817.29 | 8812.82 | 8837.92 | 8823.70 | 8815.95 | 8817.36 | 8815.77 | 8816.86 | 8801.14 | 8804.30 | 8800.06 | 8800.04 | 8809.67 | CNO | 8799.74 | 8799.75 | 8813.17 | 8813.39 | CNO | 8807.18 | 8817.64 | 8817.05 | 8790.76 | 8781.21 | CNO | 8851.55 | 8799.93 | 8800.45 | MW-3 SHALLOW and MW-202 were dry. MW-2 SHALLOW had less than 1 inch of water. Mw-6 DEEP was frozen and innaccesible. |
| Jan-13 | 8816.88 | 8812.57 | 8837.49 | 8823.59 | 8815.72 | 8816.92 | 8815.43 | - | 8801.09 | 8804.21 | 8800.01 | CNO | 8809.65 | CNO | 8799.62 | 8799.62 | 8812.92 | 8813.99 | 8806.61 | 8806.9 | 8818.32 | 8816.66 | 8790.74 | 8781.22 | CNO | 8851.01 | 8799.83 | 8800.35 | MW-2 SHALLOW, MW-3 SHALLOW, and MW-202 were dry |
| Feb-13 | 8816.89 | 8812.59 | 8838.05 | 8823.71 | 8815.83 | 8817.00 | CNO | 8816.59 | 8801.10 | 8804.22 | 8800.02 | - | 8809.68 | - | 8799.61 | 8799.61 | 8812.94 | 8813.83 | 8806.51 | 8806.75 | 8817.02 | 8816.67 | 8790.81 | 8781.26 | CNO | 8851.28 | 8799.85 | 8800.36 | MW-2 SHALLOW, MW-3 SHALLOW, and MW-202 were dry. GW-6 was frozen under ice and could not be accessed. |
| Mar-13 | 8816.67 | 8812.45 | 8837.84 | 8823.65 | 8815.9 | 8817.07 | CNO | 8816.49 | 8801.53 | 8803.89 | 8800.1 | CNO | 8809.79 | CNO | 8799.66 | 8799.64 | 8812.89 | 8813.65 | 8806.57 | 8806.86 | 8817.137 | 8816.494 | 8790.809 | 8781.228 | CNO | 8850.544 | 8799.893 | 8800.394 | |
| Apr-13 | 8818.78 | 8813.71 | 8838.67 | 8824.17 | 8816.68 | 8817.92 | 8816.91 | 8817.11 | 8801.96 | 8804.3 | 8800.36 | 8800.24 | 8810.16 | 8810.4 | 8800.44 | 8800.44 | 8813.93 | 8815.17 | 8807.81 | 8808.24 | 8818.417 | 8817.734 | 8791.239 | 8781.768 | 8825.606 | 8850.624 | 8800.523 | 8801.354 | |

*CNL - Could Not Locate, CNO - Could Not Obtain

**Appendix F**

Example Field Water Sampling Forms

# Rico Water Sampling: Sampling Event Main Checklist ***May 2013***

Check off each item as their corresponding forms are completed. An item is **NOT** to be checked off until its cooresponding form is completed in full. If a water sample cannot be completed, its sampling form **must** still be completed, noting reasons for problems, and it still must be checked off on this list.

## Surface Water Samples

*Grab Samples*

- [ ] DR-1
- [ ] DR-2
- [ ] DR-3
- [ ] DR-4
- [ ] DR-5
- [ ] DR-6
- [ ] DR-7
- [ ] DR-4-SW
- [ ] DR-G

*Composite Samples*

- [ ] DR-1 COMPOSITE
- [ ] DR-2 COMPOSITE
- [ ] DR-7 COMPOSITE
- [ ] DR-4-SW COMPOSITE

## Groundwater Samples

- [ ] GW-1
- [ ] GW-3
- [ ] GW-4
- [ ] GW-5
- [ ] GW-6
- [ ] GW-7
- [ ] EB-1
- [ ] EB-2
- [ ] MW-101
- [ ] MW-102
- [ ] MW-103
- [ ] MW-104
- [ ] MW-202
- [ ] MW-204
- [ ] P13-102
- [ ] P13-103
- [ ] MW-1 DEEP
- [ ] MW-1 SHALLOW
- [ ] MW-2 DEEP
- [ ] MW-2 SHALLOW
- [ ] MW-3 DEEP

## Groundwater Samples (cont.)

- [ ] MW-3 SHALLOW
- [ ] MW-4 DEEP
- [ ] MW-4 SHALLOW
- [ ] MW-5 DEEP
- [ ] MW-5 SHALLOW
- [ ] MW-6 DEEP
- [ ] MW-6 SHALLOW
- [ ] CHV-101 S

## Other Samples

- [ ] AT-2
- [ ] BAH-01

## Quality Control Samples

*Blind Duplicates*

- [ ] DR-8
- [ ] DR-9
- [ ] DR-10
- [ ] DR-11
- [ ] DR-12

*Field Blanks*

- [ ] FB-LAB
- [ ] FB-FIELD

## Flowrate Measurements

- [ ] DR-1
- [ ] DR-2
- [ ] DR-7
- [ ] DR-4-SW
- [ ] DR-G
- [ ] DR-1A
- [ ] DR-2A
- [ ] DR-3A

## Additional Tasks

- [ ] Pond inspection completed
- [ ] Pond water levels measured

Rico Water Sampling Form: *Calibration Information*

Name of instrument:

Perfom calibrations in order listed below. Check off if calibration is successful:

- [ ] Electrical Conductivity
- [ ] pH
- [ ] Dissolved Oxygen
- [ ] ORP

Calibration Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-1**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Picture taken of cross section? ☐ Yes

By whom?

***Email photo to mdefriez@andersoneng.com**

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-1_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-1_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-1_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-1_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-1_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-1_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-1_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-1_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-2**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Picture taken of cross section? ☐ Yes

By whom?

***Email photo to mdefriez@andersoneng.com**

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-2_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-2_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-2_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-2_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-2_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-2_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-2_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-2_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-3** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV | Manual Flume Water Depth Measurement, ft |
|---|---|---|---|---|---|
| | | | | | |

*Data downloaded from transducer?* ☐ Yes ☐ No
*Has transducer been cleaned and recalibrated?* ☐ Yes ☐ No

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-3_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-3_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-3_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-3_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-3_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-3_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-3_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-3_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

☒ Surface Water ☐ Groundwater ☐ Other

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

| | |
|---|---|
| Sample Location: | **DR-4** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

| Discharge Pipe Flowrates | | | |
|---|---|---|---|
| Upper Pipe | | Lower Pipe | |
| Depth | Velocity | Depth | Velocity |
| | | | |

*If measuring pipe discharge by other means, describe in "Notes" section

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-4_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-4_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-4_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-4_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-4_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-4_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-4_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-4_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

☒ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-5** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

| | |
|---|---|
| Benchmark Elevation: | |
| Spillway Water Elevation: | |

☐ East to West
☐ West to East

| Velocity (ft/sec) | | Depth (ft) | |
|---|---|---|---|
| 1 | 4 | 1 | 4 |
| 2 | 5 | 2 | 5 |
| 3 | 6 | 3 | 6 |

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

Picture taken of cross section? ☐
By whom?

***Email photo to mdefriez@andersoneng.com**

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-5_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-5_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-5_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-5_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-5_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-5_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-5_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-5_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-6**
Date(s) of Sample Collection:
Time(s) of Sample Collection:
Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV | Manual Flume Water Depth Measurement, ft |
|---|---|---|---|---|---|
| | | | | | |

*Data downloaded from transducer?* ☐ Yes ☐ No
*Has transducer been cleaned and recalibrated?* ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-6_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-6_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-6_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-6_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-6_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-6_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-6_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-6_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

☒ Surface Water ☐ Groundwater ☐ Other

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

Sample Location: **DR-7**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Picture taken of cross section? ☐ Yes

By whom?

***Email photo to mdefriez@andersoneng.com**

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-7_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-7_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-7_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-7_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-7_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-7_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-7_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-7_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-4-SW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Picture taken of cross section? ☐ Yes

By whom?

***Email photo to mdefriez@andersoneng.com**

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-4-SW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-4-SW_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-4-SW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-4-SW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-4-SW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-G**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Picture taken of cross section? ☐ Yes

By whom?

***Email photo to mdefriez@andersoneng.com**

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-G_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-G_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-G_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-G_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-G_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-G_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-G_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-G_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-1 COMPOSITE**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Collected:
☐ East to West
☐ West to East

## *FIELD PARAMETERS / MEASUREMENTS*

| Compartment Number | Compartment Width, ft | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|
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| Total Composite | Total Width*: | | | | | |

*Width here must match width on corresponding flow measurement sheet from Stream Flow Measurements Form

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-1 COMPOSITE_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-1 COMPOSITE_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-1 COMPOSITE_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-1 COMPOSITE_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-1 COMPOSITE_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-1 COMPOSITE_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-1 COMPOSITE_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-1 COMPOSITE_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*Collect composite sample, grab sample, and flow measurements at the same time (not on different days).

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-2 COMPOSITE**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Collected:
☐ East to West
☐ West to East

## *FIELD PARAMETERS / MEASUREMENTS*

| Compartment Number | Compartment Width, ft | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|
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| Total Composite | Total Width*: | | | | | |

*Width here must match width on corresponding flow measurement sheet from Stream Flow Measurements Form

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-2 COMPOSITE_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-2 COMPOSITE_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-2 COMPOSITE_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-2 COMPOSITE_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-2 COMPOSITE_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-2 COMPOSITE_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-2 COMPOSITE_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-2 COMPOSITE_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*Collect composite sample, grab sample, and flow measurements at the same time (not on different days).

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-7 COMPOSITE**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Collected:
☐ East to West
☐ West to East

## *FIELD PARAMETERS / MEASUREMENTS*

| Compartment Number | Compartment Width, ft | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|
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| | | | | | | |
| Total Composite | Total Width*: | | | | | |

*Width here must match width on corresponding flow measurement sheet from Stream Flow Measurements Form

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-7 COMPOSITE_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-7 COMPOSITE_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-7 COMPOSITE_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-7 COMPOSITE_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-7 COMPOSITE_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-7 COMPOSITE_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-7 COMPOSITE_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-7 COMPOSITE_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*Collect composite sample, grab sample, and flow measurements at the same time (not on different days).

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

Sample Location: **DR-4-SW COMPOSITE**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

Collected:
☐ East to West
☐ West to East

## *FIELD PARAMETERS / MEASUREMENTS*

| Compartment Number | Compartment Width, ft | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
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| | | | | | | |
| | | | | | | |
| Total Composite | Total Width*: | | | | | |

*Width here must match width on corresponding flow measurement sheet from Stream Flow Measurements Form

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-4-SW COMPOSITE_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW COMPOSITE_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW COMPOSITE_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-4-SW COMPOSITE_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-4-SW COMPOSITE_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-4-SW COMPOSITE_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-4-SW COMPOSITE_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-4-SW COMPOSITE_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*Collect composite sample, grab sample, and flow measurements at the same time (not on different days).

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-1**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-1_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-1_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-1_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-1_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-1_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 0.00 | 1.70 | 5.10 |
| 0.25 | 1.66 | 4.97 |
| 0.50 | 1.61 | 4.84 |
| 0.75 | 1.57 | 4.71 |
| 1.00 | 1.53 | 4.58 |
| 1.25 | 1.48 | 4.44 |
| 1.50 | 1.44 | 4.31 |
| 1.75 | 1.39 | 4.18 |
| 2.00 | 1.35 | 4.05 |
| 2.25 | 1.31 | 3.92 |
| 2.50 | 1.26 | 3.79 |
| 2.75 | 1.22 | 3.66 |
| 3.00 | 1.18 | 3.53 |
| 3.25 | 1.13 | 3.40 |
| 3.50 | 1.09 | 3.27 |
| 3.75 | 1.05 | 3.14 |
| 4.00 | 1.00 | 3.01 |
| 4.25 | 0.96 | 2.88 |
| 4.50 | 0.92 | 2.75 |
| 4.75 | 0.87 | 2.61 |
| 5.00 | 0.83 | 2.48 |
| 5.25 | 0.78 | 2.35 |
| 5.50 | 0.74 | 2.22 |
| 5.75 | 0.70 | 2.09 |
| 6.00 | 0.65 | 1.96 |
| 6.25 | 0.61 | 1.83 |
| 6.50 | 0.57 | 1.70 |
| 6.75 | 0.52 | 1.57 |
| 7.00 | 0.48 | 1.44 |
| 7.25 | 0.44 | 1.31 |
| 7.50 | 0.39 | 1.18 |
| 7.75 | 0.35 | 1.05 |
| 8.00 | 0.31 | 0.92 |
| 8.25 | 0.26 | 0.78 |
| 8.50 | 0.22 | 0.65 |
| 8.75 | 0.17 | 0.52 |
| 9.00 | 0.13 | 0.39 |
| 9.25 | 0.09 | 0.26 |
| 9.50 | 0.04 | 0.13 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-3**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-3_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-3_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-3_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-3_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-3_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-3_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-3_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-3_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 5.75 | 1.66 | 4.99 |
| 6.00 | 1.62 | 4.86 |
| 6.25 | 1.58 | 4.73 |
| 6.50 | 1.53 | 4.60 |
| 6.75 | 1.49 | 4.47 |
| 7.00 | 1.45 | 4.34 |
| 7.25 | 1.40 | 4.21 |
| 7.50 | 1.36 | 4.08 |
| 7.75 | 1.32 | 3.95 |
| 8.00 | 1.27 | 3.82 |
| 8.25 | 1.23 | 3.69 |
| 8.50 | 1.19 | 3.56 |
| 8.75 | 1.14 | 3.43 |
| 9.00 | 1.10 | 3.29 |
| 9.25 | 1.05 | 3.16 |
| 9.50 | 1.01 | 3.03 |
| 9.75 | 0.97 | 2.90 |
| 10.00 | 0.92 | 2.77 |
| 10.25 | 0.88 | 2.64 |
| 10.50 | 0.84 | 2.51 |
| 10.75 | 0.79 | 2.38 |
| 11.00 | 0.75 | 2.25 |
| 11.25 | 0.71 | 2.12 |
| 11.50 | 0.66 | 1.99 |
| 11.75 | 0.62 | 1.86 |
| 12.00 | 0.58 | 1.73 |
| 12.25 | 0.53 | 1.59 |
| 12.50 | 0.49 | 1.46 |
| 12.75 | 0.44 | 1.33 |
| 13.00 | 0.40 | 1.20 |
| 13.25 | 0.36 | 1.07 |
| 13.50 | 0.31 | 0.94 |
| 13.75 | 0.27 | 0.81 |
| 14.00 | 0.23 | 0.68 |
| 14.25 | 0.18 | 0.55 |
| 14.50 | 0.14 | 0.42 |
| 14.75 | 0.10 | 0.29 |
| 15.00 | 0.05 | 0.16 |
| 15.25 | 0.01 | 0.03 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-4**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-4_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-4_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-4_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-4_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-4_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-4_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-4_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-4_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 5.50 | 1.68 | 5.05 |
| 5.75 | 1.64 | 4.92 |
| 6.00 | 1.59 | 4.78 |
| 6.25 | 1.55 | 4.65 |
| 6.50 | 1.51 | 4.52 |
| 6.75 | 1.46 | 4.39 |
| 7.00 | 1.42 | 4.26 |
| 7.25 | 1.38 | 4.13 |
| 7.50 | 1.33 | 4.00 |
| 7.75 | 1.29 | 3.87 |
| 8.00 | 1.25 | 3.74 |
| 8.25 | 1.20 | 3.61 |
| 8.50 | 1.16 | 3.48 |
| 8.75 | 1.12 | 3.35 |
| 9.00 | 1.07 | 3.22 |
| 9.25 | 1.03 | 3.09 |
| 9.50 | 0.98 | 2.95 |
| 9.75 | 0.94 | 2.82 |
| 10.00 | 0.90 | 2.69 |
| 10.25 | 0.85 | 2.56 |
| 10.50 | 0.81 | 2.43 |
| 10.75 | 0.77 | 2.30 |
| 11.00 | 0.72 | 2.17 |
| 11.25 | 0.68 | 2.04 |
| 11.50 | 0.64 | 1.91 |
| 11.75 | 0.59 | 1.78 |
| 12.00 | 0.55 | 1.65 |
| 12.25 | 0.51 | 1.52 |
| 12.50 | 0.46 | 1.39 |
| 12.75 | 0.42 | 1.25 |
| 13.00 | 0.37 | 1.12 |
| 13.25 | 0.33 | 0.99 |
| 13.50 | 0.29 | 0.86 |
| 13.75 | 0.24 | 0.73 |
| 14.00 | 0.20 | 0.60 |
| 14.25 | 0.16 | 0.47 |
| 14.50 | 0.11 | 0.34 |
| 14.75 | 0.07 | 0.21 |
| 15.00 | 0.03 | 0.08 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-5**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-5_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-5_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-5_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-5_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-5_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-5_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-5_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-5_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 15.00 | 1.66 | 4.97 |
| 15.25 | 1.61 | 4.84 |
| 15.50 | 1.57 | 4.71 |
| 15.75 | 1.53 | 4.58 |
| 16.00 | 1.48 | 4.44 |
| 16.25 | 1.44 | 4.31 |
| 16.50 | 1.39 | 4.18 |
| 16.75 | 1.35 | 4.05 |
| 17.00 | 1.31 | 3.92 |
| 17.25 | 1.26 | 3.79 |
| 17.50 | 1.22 | 3.66 |
| 17.75 | 1.18 | 3.53 |
| 18.00 | 1.13 | 3.40 |
| 18.25 | 1.09 | 3.27 |
| 18.50 | 1.05 | 3.14 |
| 18.75 | 1.00 | 3.01 |
| 19.00 | 0.96 | 2.88 |
| 19.25 | 0.92 | 2.75 |
| 19.50 | 0.87 | 2.61 |
| 19.75 | 0.83 | 2.48 |
| 20.00 | 0.78 | 2.35 |
| 20.25 | 0.74 | 2.22 |
| 20.50 | 0.70 | 2.09 |
| 20.75 | 0.65 | 1.96 |
| 21.00 | 0.61 | 1.83 |
| 21.25 | 0.57 | 1.70 |
| 21.50 | 0.52 | 1.57 |
| 21.75 | 0.48 | 1.44 |
| 22.00 | 0.44 | 1.31 |
| 22.25 | 0.39 | 1.18 |
| 22.50 | 0.35 | 1.05 |
| 22.75 | 0.31 | 0.92 |
| 23.00 | 0.26 | 0.78 |
| 23.25 | 0.22 | 0.65 |
| 23.50 | 0.17 | 0.52 |
| 23.75 | 0.13 | 0.39 |
| 24.00 | 0.09 | 0.26 |
| 24.25 | 0.04 | 0.13 |
| 24.50 | 0.00 | 0.00 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-6**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-6_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-6_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-6_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-6_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-6_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-6_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-6_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-6_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 17.25 | 1.68 | 5.03 |
| 17.50 | 1.63 | 4.89 |
| 17.75 | 1.59 | 4.76 |
| 18.00 | 1.54 | 4.63 |
| 18.25 | 1.50 | 4.50 |
| 18.50 | 1.46 | 4.37 |
| 18.75 | 1.41 | 4.24 |
| 19.00 | 1.37 | 4.11 |
| 19.25 | 1.33 | 3.98 |
| 19.50 | 1.28 | 3.85 |
| 19.75 | 1.24 | 3.72 |
| 20.00 | 1.20 | 3.59 |
| 20.25 | 1.15 | 3.46 |
| 20.50 | 1.11 | 3.33 |
| 20.75 | 1.07 | 3.20 |
| 21.00 | 1.02 | 3.06 |
| 21.25 | 0.98 | 2.93 |
| 21.50 | 0.93 | 2.80 |
| 21.75 | 0.89 | 2.67 |
| 22.00 | 0.85 | 2.54 |
| 22.25 | 0.80 | 2.41 |
| 22.50 | 0.76 | 2.28 |
| 22.75 | 0.72 | 2.15 |
| 23.00 | 0.67 | 2.02 |
| 23.25 | 0.63 | 1.89 |
| 23.50 | 0.59 | 1.76 |
| 23.75 | 0.54 | 1.63 |
| 24.00 | 0.50 | 1.50 |
| 24.25 | 0.45 | 1.36 |
| 24.50 | 0.41 | 1.23 |
| 24.75 | 0.37 | 1.10 |
| 25.00 | 0.32 | 0.97 |
| 25.25 | 0.28 | 0.84 |
| 25.50 | 0.24 | 0.71 |
| 25.75 | 0.19 | 0.58 |
| 26.00 | 0.15 | 0.45 |
| 26.25 | 0.11 | 0.32 |
| 26.50 | 0.06 | 0.19 |
| 26.75 | 0.02 | 0.06 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **GW-7**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-7_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-7_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-7_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-7_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-7_201305 | | Salinity | 250 mL / HDPE / None |
| | GW-7_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-7_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-7_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 15.25 | 1.76 | 5.28 |
| 15.50 | 1.72 | 5.15 |
| 15.75 | 1.67 | 5.01 |
| 16.00 | 1.63 | 4.88 |
| 16.25 | 1.58 | 4.75 |
| 16.50 | 1.54 | 4.62 |
| 16.75 | 1.50 | 4.49 |
| 17.00 | 1.45 | 4.36 |
| 17.25 | 1.41 | 4.23 |
| 17.50 | 1.37 | 4.10 |
| 17.75 | 1.32 | 3.97 |
| 18.00 | 1.28 | 3.84 |
| 18.25 | 1.24 | 3.71 |
| 18.50 | 1.19 | 3.58 |
| 18.75 | 1.15 | 3.45 |
| 19.00 | 1.11 | 3.32 |
| 19.25 | 1.06 | 3.18 |
| 19.50 | 1.02 | 3.05 |
| 19.75 | 0.97 | 2.92 |
| 20.00 | 0.93 | 2.79 |
| 20.25 | 0.89 | 2.66 |
| 20.50 | 0.84 | 2.53 |
| 20.75 | 0.80 | 2.40 |
| 21.00 | 0.76 | 2.27 |
| 21.25 | 0.71 | 2.14 |
| 21.50 | 0.67 | 2.01 |
| 21.75 | 0.63 | 1.88 |
| 22.00 | 0.58 | 1.75 |
| 22.25 | 0.54 | 1.62 |
| 22.50 | 0.50 | 1.49 |
| 22.75 | 0.45 | 1.35 |
| 23.00 | 0.41 | 1.22 |
| 23.25 | 0.36 | 1.09 |
| 23.50 | 0.32 | 0.96 |
| 23.75 | 0.28 | 0.83 |
| 24.00 | 0.23 | 0.70 |
| 24.25 | 0.19 | 0.57 |
| 24.50 | 0.15 | 0.44 |
| 24.75 | 0.10 | 0.31 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **EB-1**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | EB-1_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | EB-1_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | EB-1_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | EB-1_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | EB-1_201305 | | Salinity | 250 mL / HDPE / None |
| | EB-1_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | EB-1_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | EB-1_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 19.00 | 2.85 | 8.55 |
| 19.25 | 2.81 | 8.42 |
| 19.50 | 2.76 | 8.29 |
| 19.75 | 2.72 | 8.16 |
| 20.00 | 2.68 | 8.03 |
| 20.25 | 2.63 | 7.90 |
| 20.50 | 2.59 | 7.77 |
| 20.75 | 2.54 | 7.63 |
| 21.00 | 2.50 | 7.50 |
| 21.25 | 2.46 | 7.37 |
| 21.50 | 2.41 | 7.24 |
| 21.75 | 2.37 | 7.11 |
| 22.00 | 2.33 | 6.98 |
| 22.25 | 2.28 | 6.85 |
| 22.50 | 2.24 | 6.72 |
| 22.75 | 2.20 | 6.59 |
| 23.00 | 2.15 | 6.46 |
| 23.25 | 2.11 | 6.33 |
| 23.50 | 2.07 | 6.20 |
| 23.75 | 2.02 | 6.07 |
| 24.00 | 1.98 | 5.94 |
| 24.25 | 1.93 | 5.80 |
| 24.50 | 1.89 | 5.67 |
| 24.75 | 1.85 | 5.54 |
| 25.00 | 1.80 | 5.41 |
| 25.25 | 1.76 | 5.28 |
| 25.50 | 1.72 | 5.15 |
| 25.75 | 1.67 | 5.02 |
| 26.00 | 1.63 | 4.89 |
| 26.25 | 1.59 | 4.76 |
| 26.50 | 1.54 | 4.63 |
| 26.75 | 1.50 | 4.50 |
| 27.00 | 1.46 | 4.37 |
| 27.25 | 1.41 | 4.24 |
| 27.50 | 1.37 | 4.10 |
| 27.75 | 1.32 | 3.97 |
| 28.00 | 1.28 | 3.84 |
| 28.25 | 1.24 | 3.71 |
| 28.50 | 1.19 | 3.58 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **EB-2**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | EB-2_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | EB-2_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | EB-2_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | EB-2_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | EB-2_201305 | | Salinity | 250 mL / HDPE / None |
| | EB-2_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | EB-2_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | EB-2_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 14.00 | 2.18 | 6.54 |
| 14.25 | 2.14 | 6.41 |
| 14.50 | 2.09 | 6.27 |
| 14.75 | 2.05 | 6.14 |
| 15.00 | 2.00 | 6.01 |
| 15.25 | 1.96 | 5.88 |
| 15.50 | 1.92 | 5.75 |
| 15.75 | 1.87 | 5.62 |
| 16.00 | 1.83 | 5.49 |
| 16.25 | 1.79 | 5.36 |
| 16.50 | 1.74 | 5.23 |
| 16.75 | 1.70 | 5.10 |
| 17.00 | 1.66 | 4.97 |
| 17.25 | 1.61 | 4.84 |
| 17.50 | 1.57 | 4.71 |
| 17.75 | 1.53 | 4.58 |
| 18.00 | 1.48 | 4.44 |
| 18.25 | 1.44 | 4.31 |
| 18.50 | 1.39 | 4.18 |
| 18.75 | 1.35 | 4.05 |
| 19.00 | 1.31 | 3.92 |
| 19.25 | 1.26 | 3.79 |
| 19.50 | 1.22 | 3.66 |
| 19.75 | 1.18 | 3.53 |
| 20.00 | 1.13 | 3.40 |
| 20.25 | 1.09 | 3.27 |
| 20.50 | 1.05 | 3.14 |
| 20.75 | 1.00 | 3.01 |
| 21.00 | 0.96 | 2.88 |
| 21.25 | 0.92 | 2.75 |
| 21.50 | 0.87 | 2.61 |
| 21.75 | 0.83 | 2.48 |
| 22.00 | 0.78 | 2.35 |
| 22.25 | 0.74 | 2.22 |
| 22.50 | 0.70 | 2.09 |
| 22.75 | 0.65 | 1.96 |
| 23.00 | 0.61 | 1.83 |
| 23.25 | 0.57 | 1.70 |
| 23.50 | 0.52 | 1.57 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-101**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-101_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-101_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-101_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-101_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-101_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-101_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-101_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-101_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 23.00 | 2.55 | 7.64 |
| 23.25 | 2.50 | 7.51 |
| 23.50 | 2.46 | 7.38 |
| 23.75 | 2.42 | 7.25 |
| 24.00 | 2.37 | 7.12 |
| 24.25 | 2.33 | 6.98 |
| 24.50 | 2.28 | 6.85 |
| 24.75 | 2.24 | 6.72 |
| 25.00 | 2.20 | 6.59 |
| 25.25 | 2.15 | 6.46 |
| 25.50 | 2.11 | 6.33 |
| 25.75 | 2.07 | 6.20 |
| 26.00 | 2.02 | 6.07 |
| 26.25 | 1.98 | 5.94 |
| 26.50 | 1.94 | 5.81 |
| 26.75 | 1.89 | 5.68 |
| 27.00 | 1.85 | 5.55 |
| 27.25 | 1.81 | 5.42 |
| 27.50 | 1.76 | 5.29 |
| 27.75 | 1.72 | 5.15 |
| 28.00 | 1.67 | 5.02 |
| 28.25 | 1.63 | 4.89 |
| 28.50 | 1.59 | 4.76 |
| 28.75 | 1.54 | 4.63 |
| 29.00 | 1.50 | 4.50 |
| 29.25 | 1.46 | 4.37 |
| 29.50 | 1.41 | 4.24 |
| 29.75 | 1.37 | 4.11 |
| 30.00 | 1.33 | 3.98 |
| 30.25 | 1.28 | 3.85 |
| 30.50 | 1.24 | 3.72 |
| 30.75 | 1.20 | 3.59 |
| 31.00 | 1.15 | 3.45 |
| 31.25 | 1.11 | 3.32 |
| 31.50 | 1.06 | 3.19 |
| 31.75 | 1.02 | 3.06 |
| 32.00 | 0.98 | 2.93 |
| 32.25 | 0.93 | 2.80 |
| 32.50 | 0.89 | 2.67 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-102**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-102_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-102_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-102_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-102_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-102_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-102_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-102_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-102_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 21.50 | 1.66 | 4.99 |
| 21.75 | 1.62 | 4.86 |
| 22.00 | 1.58 | 4.73 |
| 22.25 | 1.53 | 4.60 |
| 22.50 | 1.49 | 4.47 |
| 22.75 | 1.45 | 4.34 |
| 23.00 | 1.40 | 4.21 |
| 23.25 | 1.36 | 4.08 |
| 23.50 | 1.31 | 3.94 |
| 23.75 | 1.27 | 3.81 |
| 24.00 | 1.23 | 3.68 |
| 24.25 | 1.18 | 3.55 |
| 24.50 | 1.14 | 3.42 |
| 24.75 | 1.10 | 3.29 |
| 25.00 | 1.05 | 3.16 |
| 25.25 | 1.01 | 3.03 |
| 25.50 | 0.97 | 2.90 |
| 25.75 | 0.92 | 2.77 |
| 26.00 | 0.88 | 2.64 |
| 26.25 | 0.84 | 2.51 |
| 26.50 | 0.79 | 2.38 |
| 26.75 | 0.75 | 2.25 |
| 27.00 | 0.70 | 2.11 |
| 27.25 | 0.66 | 1.98 |
| 27.50 | 0.62 | 1.85 |
| 27.75 | 0.57 | 1.72 |
| 28.00 | 0.53 | 1.59 |
| 28.25 | 0.49 | 1.46 |
| 28.50 | 0.44 | 1.33 |
| 28.75 | 0.40 | 1.20 |
| 29.00 | 0.36 | 1.07 |
| 29.25 | 0.31 | 0.94 |
| 29.50 | 0.27 | 0.81 |
| 29.75 | 0.23 | 0.68 |
| 30.00 | 0.18 | 0.55 |
| 30.25 | 0.14 | 0.42 |
| 30.50 | 0.09 | 0.28 |
| 30.75 | 0.05 | 0.15 |
| 31.00 | 0.01 | 0.02 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-103**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-103_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-103_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-103_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-103_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-103_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-103_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-103_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-103_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 3.00 | 2.94 | 8.82 |
| 3.25 | 2.90 | 8.69 |
| 3.50 | 2.85 | 8.55 |
| 3.75 | 2.81 | 8.42 |
| 4.00 | 2.76 | 8.29 |
| 4.25 | 2.72 | 8.16 |
| 4.50 | 2.68 | 8.03 |
| 4.75 | 2.63 | 7.90 |
| 5.00 | 2.59 | 7.77 |
| 5.25 | 2.55 | 7.64 |
| 5.50 | 2.50 | 7.51 |
| 5.75 | 2.46 | 7.38 |
| 6.00 | 2.42 | 7.25 |
| 6.25 | 2.37 | 7.12 |
| 6.50 | 2.33 | 6.99 |
| 6.75 | 2.28 | 6.85 |
| 7.00 | 2.24 | 6.72 |
| 7.25 | 2.20 | 6.59 |
| 7.50 | 2.15 | 6.46 |
| 7.75 | 2.11 | 6.33 |
| 8.00 | 2.07 | 6.20 |
| 8.25 | 2.02 | 6.07 |
| 8.50 | 1.98 | 5.94 |
| 8.75 | 1.94 | 5.81 |
| 9.00 | 1.89 | 5.68 |
| 9.25 | 1.85 | 5.55 |
| 9.50 | 1.81 | 5.42 |
| 9.75 | 1.76 | 5.29 |
| 10.00 | 1.72 | 5.16 |
| 10.25 | 1.67 | 5.02 |
| 10.50 | 1.63 | 4.89 |
| 10.75 | 1.59 | 4.76 |
| 11.00 | 1.54 | 4.63 |
| 11.25 | 1.50 | 4.50 |
| 11.50 | 1.46 | 4.37 |
| 11.75 | 1.41 | 4.24 |
| 12.00 | 1.37 | 4.11 |
| 12.25 | 1.33 | 3.98 |
| 12.50 | 1.28 | 3.85 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-104**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-104_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-104_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-104_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-104_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-104_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-104_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-104_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-104_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 0.00 | 3.11 | 9.34 |
| 0.25 | 3.07 | 9.21 |
| 0.50 | 3.03 | 9.08 |
| 0.75 | 2.98 | 8.95 |
| 1.00 | 2.94 | 8.82 |
| 1.25 | 2.89 | 8.68 |
| 1.50 | 2.85 | 8.55 |
| 1.75 | 2.81 | 8.42 |
| 2.00 | 2.76 | 8.29 |
| 2.25 | 2.72 | 8.16 |
| 2.50 | 2.68 | 8.03 |
| 2.75 | 2.63 | 7.90 |
| 3.00 | 2.59 | 7.77 |
| 3.25 | 2.55 | 7.64 |
| 3.50 | 2.50 | 7.51 |
| 3.75 | 2.46 | 7.38 |
| 4.00 | 2.42 | 7.25 |
| 4.25 | 2.37 | 7.12 |
| 4.50 | 2.33 | 6.99 |
| 4.75 | 2.28 | 6.85 |
| 5.00 | 2.24 | 6.72 |
| 5.25 | 2.20 | 6.59 |
| 5.50 | 2.15 | 6.46 |
| 5.75 | 2.11 | 6.33 |
| 6.00 | 2.07 | 6.20 |
| 6.25 | 2.02 | 6.07 |
| 6.50 | 1.98 | 5.94 |
| 6.75 | 1.94 | 5.81 |
| 7.00 | 1.89 | 5.68 |
| 7.25 | 1.85 | 5.55 |
| 7.50 | 1.81 | 5.42 |
| 7.75 | 1.76 | 5.29 |
| 8.00 | 1.72 | 5.15 |
| 8.25 | 1.67 | 5.02 |
| 8.50 | 1.63 | 4.89 |
| 8.75 | 1.59 | 4.76 |
| 9.00 | 1.54 | 4.63 |
| 9.25 | 1.50 | 4.50 |
| 9.50 | 1.46 | 4.37 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-202**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* | |
|---|---|---|
| | 1 | 3 |

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-202_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-202_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-202_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-202_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-202_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-202_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-202_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-202_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-204**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-204_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-204_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-204_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-204_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-204_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-204_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-204_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-204_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 11.00 | 3.09 | 9.26 |
| 11.25 | 3.04 | 9.13 |
| 11.50 | 3.00 | 9.00 |
| 11.75 | 2.96 | 8.87 |
| 12.00 | 2.91 | 8.73 |
| 12.25 | 2.87 | 8.60 |
| 12.50 | 2.82 | 8.47 |
| 12.75 | 2.78 | 8.34 |
| 13.00 | 2.74 | 8.21 |
| 13.25 | 2.69 | 8.08 |
| 13.50 | 2.65 | 7.95 |
| 13.75 | 2.61 | 7.82 |
| 14.00 | 2.56 | 7.69 |
| 14.25 | 2.52 | 7.56 |
| 14.50 | 2.48 | 7.43 |
| 14.75 | 2.43 | 7.30 |
| 15.00 | 2.39 | 7.17 |
| 15.25 | 2.35 | 7.04 |
| 15.50 | 2.30 | 6.90 |
| 15.75 | 2.26 | 6.77 |
| 16.00 | 2.21 | 6.64 |
| 16.25 | 2.17 | 6.51 |
| 16.50 | 2.13 | 6.38 |
| 16.75 | 2.08 | 6.25 |
| 17.00 | 2.04 | 6.12 |
| 17.25 | 2.00 | 5.99 |
| 17.50 | 1.95 | 5.86 |
| 17.75 | 1.91 | 5.73 |
| 18.00 | 1.87 | 5.60 |
| 18.25 | 1.82 | 5.47 |
| 18.50 | 1.78 | 5.34 |
| 18.75 | 1.74 | 5.21 |
| 19.00 | 1.69 | 5.07 |
| 19.25 | 1.65 | 4.94 |
| 19.50 | 1.60 | 4.81 |
| 19.75 | 1.56 | 4.68 |
| 20.00 | 1.52 | 4.55 |
| 20.25 | 1.47 | 4.42 |
| 20.50 | 1.43 | 4.29 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **P13-102**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | P13-102_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | P13-102_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | P13-102_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | P13-102_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | P13-102_201305 | | Salinity | 250 mL / HDPE / None |
| | P13-102_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | P13-102_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | P13-102_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 6.00 | 5.13 | 15.38 |
| 6.25 | 5.08 | 15.25 |
| 6.50 | 5.04 | 15.12 |
| 6.75 | 5.00 | 14.99 |
| 7.00 | 4.95 | 14.86 |
| 7.25 | 4.91 | 14.73 |
| 7.50 | 4.87 | 14.60 |
| 7.75 | 4.82 | 14.47 |
| 8.00 | 4.78 | 14.33 |
| 8.25 | 4.73 | 14.20 |
| 8.50 | 4.69 | 14.07 |
| 8.75 | 4.65 | 13.94 |
| 9.00 | 4.60 | 13.81 |
| 9.25 | 4.56 | 13.68 |
| 9.50 | 4.52 | 13.55 |
| 9.75 | 4.47 | 13.42 |
| 10.00 | 4.43 | 13.29 |
| 10.25 | 4.39 | 13.16 |
| 10.50 | 4.34 | 13.03 |
| 10.75 | 4.30 | 12.90 |
| 11.00 | 4.26 | 12.77 |
| 11.25 | 4.21 | 12.64 |
| 11.50 | 4.17 | 12.50 |
| 11.75 | 4.12 | 12.37 |
| 12.00 | 4.08 | 12.24 |
| 12.25 | 4.04 | 12.11 |
| 12.50 | 3.99 | 11.98 |
| 12.75 | 3.95 | 11.85 |
| 13.00 | 3.91 | 11.72 |
| 13.25 | 3.86 | 11.59 |
| 13.50 | 3.82 | 11.46 |
| 13.75 | 3.78 | 11.33 |
| 14.00 | 3.73 | 11.20 |
| 14.25 | 3.69 | 11.07 |
| 14.50 | 3.65 | 10.94 |
| 14.75 | 3.60 | 10.80 |
| 15.00 | 3.56 | 10.67 |
| 15.25 | 3.51 | 10.54 |
| 15.50 | 3.47 | 10.41 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **P13-103**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | P13-103_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | P13-103_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | P13-103_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | P13-103_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | P13-103_201305 | | Salinity | 250 mL / HDPE / None |
| | P13-103_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | P13-103_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | P13-103_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 6.00 | 2.50 | 7.50 |
| 6.25 | 2.45 | 7.36 |
| 6.50 | 2.41 | 7.23 |
| 6.75 | 2.37 | 7.10 |
| 7.00 | 2.32 | 6.97 |
| 7.25 | 2.28 | 6.84 |
| 7.50 | 2.24 | 6.71 |
| 7.75 | 2.19 | 6.58 |
| 8.00 | 2.15 | 6.45 |
| 8.25 | 2.11 | 6.32 |
| 8.50 | 2.06 | 6.19 |
| 8.75 | 2.02 | 6.06 |
| 9.00 | 1.98 | 5.93 |
| 9.25 | 1.93 | 5.80 |
| 9.50 | 1.89 | 5.67 |
| 9.75 | 1.84 | 5.53 |
| 10.00 | 1.80 | 5.40 |
| 10.25 | 1.76 | 5.27 |
| 10.50 | 1.71 | 5.14 |
| 10.75 | 1.67 | 5.01 |
| 11.00 | 1.63 | 4.88 |
| 11.25 | 1.58 | 4.75 |
| 11.50 | 1.54 | 4.62 |
| 11.75 | 1.50 | 4.49 |
| 12.00 | 1.45 | 4.36 |
| 12.25 | 1.41 | 4.23 |
| 12.50 | 1.37 | 4.10 |
| 12.75 | 1.32 | 3.97 |
| 13.00 | 1.28 | 3.84 |
| 13.25 | 1.23 | 3.70 |
| 13.50 | 1.19 | 3.57 |
| 13.75 | 1.15 | 3.44 |
| 14.00 | 1.10 | 3.31 |
| 14.25 | 1.06 | 3.18 |
| 14.50 | 1.02 | 3.05 |
| 14.75 | 0.97 | 2.92 |
| 15.00 | 0.93 | 2.79 |
| 15.25 | 0.89 | 2.66 |
| 15.50 | 0.84 | 2.53 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-1 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-1 DEEP_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 DEEP_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 DEEP_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 DEEP_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-1 DEEP_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-1 DEEP_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-1 DEEP_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-1 DEEP_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 6.00 | 3.32 | 9.97 |
| 6.25 | 3.28 | 9.84 |
| 6.50 | 3.24 | 9.71 |
| 6.75 | 3.19 | 9.58 |
| 7.00 | 3.15 | 9.45 |
| 7.25 | 3.11 | 9.32 |
| 7.50 | 3.06 | 9.19 |
| 7.75 | 3.02 | 9.06 |
| 8.00 | 2.98 | 8.93 |
| 8.25 | 2.93 | 8.80 |
| 8.50 | 2.89 | 8.66 |
| 8.75 | 2.84 | 8.53 |
| 9.00 | 2.80 | 8.40 |
| 9.25 | 2.76 | 8.27 |
| 9.50 | 2.71 | 8.14 |
| 9.75 | 2.67 | 8.01 |
| 10.00 | 2.63 | 7.88 |
| 10.25 | 2.58 | 7.75 |
| 10.50 | 2.54 | 7.62 |
| 10.75 | 2.50 | 7.49 |
| 11.00 | 2.45 | 7.36 |
| 11.25 | 2.41 | 7.23 |
| 11.50 | 2.37 | 7.10 |
| 11.75 | 2.32 | 6.97 |
| 12.00 | 2.28 | 6.83 |
| 12.25 | 2.23 | 6.70 |
| 12.50 | 2.19 | 6.57 |
| 12.75 | 2.15 | 6.44 |
| 13.00 | 2.10 | 6.31 |
| 13.25 | 2.06 | 6.18 |
| 13.50 | 2.02 | 6.05 |
| 13.75 | 1.97 | 5.92 |
| 14.00 | 1.93 | 5.79 |
| 14.25 | 1.89 | 5.66 |
| 14.50 | 1.84 | 5.53 |
| 14.75 | 1.80 | 5.40 |
| 15.00 | 1.76 | 5.27 |
| 15.25 | 1.71 | 5.14 |
| 15.50 | 1.67 | 5.00 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-1 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-1 SHALLOW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 SHALLOW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 SHALLOW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-1 SHALLOW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-1 SHALLOW_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-1 SHALLOW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-1 SHALLOW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-1 SHALLOW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 0.75 | 1.66 | 4.99 |
| 1.00 | 1.62 | 4.86 |
| 1.25 | 1.58 | 4.73 |
| 1.50 | 1.53 | 4.60 |
| 1.75 | 1.49 | 4.47 |
| 2.00 | 1.44 | 4.33 |
| 2.25 | 1.40 | 4.20 |
| 2.50 | 1.36 | 4.07 |
| 2.75 | 1.31 | 3.94 |
| 3.00 | 1.27 | 3.81 |
| 3.25 | 1.23 | 3.68 |
| 3.50 | 1.18 | 3.55 |
| 3.75 | 1.14 | 3.42 |
| 4.00 | 1.10 | 3.29 |
| 4.25 | 1.05 | 3.16 |
| 4.50 | 1.01 | 3.03 |
| 4.75 | 0.97 | 2.90 |
| 5.00 | 0.92 | 2.77 |
| 5.25 | 0.88 | 2.64 |
| 5.50 | 0.83 | 2.50 |
| 5.75 | 0.79 | 2.37 |
| 6.00 | 0.75 | 2.24 |
| 6.25 | 0.70 | 2.11 |
| 6.50 | 0.66 | 1.98 |
| 6.75 | 0.62 | 1.85 |
| 7.00 | 0.57 | 1.72 |
| 7.25 | 0.53 | 1.59 |
| 7.50 | 0.49 | 1.46 |
| 7.75 | 0.44 | 1.33 |
| 8.00 | 0.40 | 1.20 |
| 8.25 | 0.36 | 1.07 |
| 8.50 | 0.31 | 0.94 |
| 8.75 | 0.27 | 0.81 |
| 9.00 | 0.22 | 0.67 |
| 9.25 | 0.18 | 0.54 |
| 9.50 | 0.14 | 0.41 |
| 9.75 | 0.09 | 0.28 |
| 10.00 | 0.05 | 0.15 |
| 10.25 | 0.01 | 0.02 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-2 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-2 DEEP_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 DEEP_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 DEEP_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 DEEP_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-2 DEEP_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-2 DEEP_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-2 DEEP_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-2 DEEP_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 6.00 | 2.97 | 8.92 |
| 6.25 | 2.93 | 8.78 |
| 6.50 | 2.88 | 8.65 |
| 6.75 | 2.84 | 8.52 |
| 7.00 | 2.80 | 8.39 |
| 7.25 | 2.75 | 8.26 |
| 7.50 | 2.71 | 8.13 |
| 7.75 | 2.67 | 8.00 |
| 8.00 | 2.62 | 7.87 |
| 8.25 | 2.58 | 7.74 |
| 8.50 | 2.54 | 7.61 |
| 8.75 | 2.49 | 7.48 |
| 9.00 | 2.45 | 7.35 |
| 9.25 | 2.41 | 7.22 |
| 9.50 | 2.36 | 7.09 |
| 9.75 | 2.32 | 6.95 |
| 10.00 | 2.27 | 6.82 |
| 10.25 | 2.23 | 6.69 |
| 10.50 | 2.19 | 6.56 |
| 10.75 | 2.14 | 6.43 |
| 11.00 | 2.10 | 6.30 |
| 11.25 | 2.06 | 6.17 |
| 11.50 | 2.01 | 6.04 |
| 11.75 | 1.97 | 5.91 |
| 12.00 | 1.93 | 5.78 |
| 12.25 | 1.88 | 5.65 |
| 12.50 | 1.84 | 5.52 |
| 12.75 | 1.80 | 5.39 |
| 13.00 | 1.75 | 5.26 |
| 13.25 | 1.71 | 5.12 |
| 13.50 | 1.66 | 4.99 |
| 13.75 | 1.62 | 4.86 |
| 14.00 | 1.58 | 4.73 |
| 14.25 | 1.53 | 4.60 |
| 14.50 | 1.49 | 4.47 |
| 14.75 | 1.45 | 4.34 |
| 15.00 | 1.40 | 4.21 |
| 15.25 | 1.36 | 4.08 |
| 15.50 | 1.32 | 3.95 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-2 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* | |
|---|---|---|
| | 1 | 3 |

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-2 SHALLOW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 SHALLOW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 SHALLOW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-2 SHALLOW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-2 SHALLOW_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-2 SHALLOW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-2 SHALLOW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-2 SHALLOW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-3 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-3 DEEP_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 DEEP_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 DEEP_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 DEEP_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-3 DEEP_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-3 DEEP_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-3 DEEP_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-3 DEEP_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 6.00 | 3.01 | 9.04 |
| 6.25 | 2.97 | 8.91 |
| 6.50 | 2.93 | 8.78 |
| 6.75 | 2.88 | 8.65 |
| 7.00 | 2.84 | 8.52 |
| 7.25 | 2.80 | 8.39 |
| 7.50 | 2.75 | 8.26 |
| 7.75 | 2.71 | 8.13 |
| 8.00 | 2.67 | 8.00 |
| 8.25 | 2.62 | 7.86 |
| 8.50 | 2.58 | 7.73 |
| 8.75 | 2.53 | 7.60 |
| 9.00 | 2.49 | 7.47 |
| 9.25 | 2.45 | 7.34 |
| 9.50 | 2.40 | 7.21 |
| 9.75 | 2.36 | 7.08 |
| 10.00 | 2.32 | 6.95 |
| 10.25 | 2.27 | 6.82 |
| 10.50 | 2.23 | 6.69 |
| 10.75 | 2.19 | 6.56 |
| 11.00 | 2.14 | 6.43 |
| 11.25 | 2.10 | 6.30 |
| 11.50 | 2.06 | 6.17 |
| 11.75 | 2.01 | 6.03 |
| 12.00 | 1.97 | 5.90 |
| 12.25 | 1.92 | 5.77 |
| 12.50 | 1.88 | 5.64 |
| 12.75 | 1.84 | 5.51 |
| 13.00 | 1.79 | 5.38 |
| 13.25 | 1.75 | 5.25 |
| 13.50 | 1.71 | 5.12 |
| 13.75 | 1.66 | 4.99 |
| 14.00 | 1.62 | 4.86 |
| 14.25 | 1.58 | 4.73 |
| 14.50 | 1.53 | 4.60 |
| 14.75 | 1.49 | 4.47 |
| 15.00 | 1.44 | 4.33 |
| 15.25 | 1.40 | 4.20 |
| 15.50 | 1.36 | 4.07 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-3 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* | |
|---|---|---|
| | 1 | 3 |

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-3 SHALLOW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 SHALLOW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 SHALLOW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-3 SHALLOW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-3 SHALLOW_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-3 SHALLOW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-3 SHALLOW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-3 SHALLOW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-4 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-4 DEEP_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 DEEP_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 DEEP_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 DEEP_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-4 DEEP_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-4 DEEP_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-4 DEEP_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-4 DEEP_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 13.00 | 3.18 | 9.54 |
| 13.25 | 3.14 | 9.41 |
| 13.50 | 3.09 | 9.28 |
| 13.75 | 3.05 | 9.15 |
| 14.00 | 3.01 | 9.02 |
| 14.25 | 2.96 | 8.88 |
| 14.50 | 2.92 | 8.75 |
| 14.75 | 2.87 | 8.62 |
| 15.00 | 2.83 | 8.49 |
| 15.25 | 2.79 | 8.36 |
| 15.50 | 2.74 | 8.23 |
| 15.75 | 2.70 | 8.10 |
| 16.00 | 2.66 | 7.97 |
| 16.25 | 2.61 | 7.84 |
| 16.50 | 2.57 | 7.71 |
| 16.75 | 2.53 | 7.58 |
| 17.00 | 2.48 | 7.45 |
| 17.25 | 2.44 | 7.32 |
| 17.50 | 2.39 | 7.18 |
| 17.75 | 2.35 | 7.05 |
| 18.00 | 2.31 | 6.92 |
| 18.25 | 2.26 | 6.79 |
| 18.50 | 2.22 | 6.66 |
| 18.75 | 2.18 | 6.53 |
| 19.00 | 2.13 | 6.40 |
| 19.25 | 2.09 | 6.27 |
| 19.50 | 2.05 | 6.14 |
| 19.75 | 2.00 | 6.01 |
| 20.00 | 1.96 | 5.88 |
| 20.25 | 1.92 | 5.75 |
| 20.50 | 1.87 | 5.62 |
| 20.75 | 1.83 | 5.49 |
| 21.00 | 1.78 | 5.35 |
| 21.25 | 1.74 | 5.22 |
| 21.50 | 1.70 | 5.09 |
| 21.75 | 1.65 | 4.96 |
| 22.00 | 1.61 | 4.83 |
| 22.25 | 1.57 | 4.70 |
| 22.50 | 1.52 | 4.57 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-4 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-4 SHALLOW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 SHALLOW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 SHALLOW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-4 SHALLOW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-4 SHALLOW_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-4 SHALLOW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-4 SHALLOW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-4 SHALLOW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 8.75 | 1.68 | 5.04 |
| 9.00 | 1.64 | 4.91 |
| 9.25 | 1.59 | 4.78 |
| 9.50 | 1.55 | 4.65 |
| 9.75 | 1.51 | 4.52 |
| 10.00 | 1.46 | 4.39 |
| 10.25 | 1.42 | 4.26 |
| 10.50 | 1.38 | 4.13 |
| 10.75 | 1.33 | 4.00 |
| 11.00 | 1.29 | 3.86 |
| 11.25 | 1.24 | 3.73 |
| 11.50 | 1.20 | 3.60 |
| 11.75 | 1.16 | 3.47 |
| 12.00 | 1.11 | 3.34 |
| 12.25 | 1.07 | 3.21 |
| 12.50 | 1.03 | 3.08 |
| 12.75 | 0.98 | 2.95 |
| 13.00 | 0.94 | 2.82 |
| 13.25 | 0.90 | 2.69 |
| 13.50 | 0.85 | 2.56 |
| 13.75 | 0.81 | 2.43 |
| 14.00 | 0.77 | 2.30 |
| 14.25 | 0.72 | 2.16 |
| 14.50 | 0.68 | 2.03 |
| 14.75 | 0.63 | 1.90 |
| 15.00 | 0.59 | 1.77 |
| 15.25 | 0.55 | 1.64 |
| 15.50 | 0.50 | 1.51 |
| 15.75 | 0.46 | 1.38 |
| 16.00 | 0.42 | 1.25 |
| 16.25 | 0.37 | 1.12 |
| 16.50 | 0.33 | 0.99 |
| 16.75 | 0.29 | 0.86 |
| 17.00 | 0.24 | 0.73 |
| 17.25 | 0.20 | 0.60 |
| 17.50 | 0.16 | 0.47 |
| 17.75 | 0.11 | 0.33 |
| 18.00 | 0.07 | 0.20 |
| 18.25 | 0.02 | 0.07 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-5 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-5 DEEP_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 DEEP_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 DEEP_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 DEEP_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-5 DEEP_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-5 DEEP_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-5 DEEP_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-5 DEEP_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 14.00 | 3.52 | 10.56 |
| 14.25 | 3.48 | 10.43 |
| 14.50 | 3.43 | 10.30 |
| 14.75 | 3.39 | 10.17 |
| 15.00 | 3.35 | 10.04 |
| 15.25 | 3.30 | 9.91 |
| 15.50 | 3.26 | 9.78 |
| 15.75 | 3.22 | 9.65 |
| 16.00 | 3.17 | 9.52 |
| 16.25 | 3.13 | 9.39 |
| 16.50 | 3.09 | 9.26 |
| 16.75 | 3.04 | 9.12 |
| 17.00 | 3.00 | 8.99 |
| 17.25 | 2.95 | 8.86 |
| 17.50 | 2.91 | 8.73 |
| 17.75 | 2.87 | 8.60 |
| 18.00 | 2.82 | 8.47 |
| 18.25 | 2.78 | 8.34 |
| 18.50 | 2.74 | 8.21 |
| 18.75 | 2.69 | 8.08 |
| 19.00 | 2.65 | 7.95 |
| 19.25 | 2.61 | 7.82 |
| 19.50 | 2.56 | 7.69 |
| 19.75 | 2.52 | 7.56 |
| 20.00 | 2.48 | 7.43 |
| 20.25 | 2.43 | 7.29 |
| 20.50 | 2.39 | 7.16 |
| 20.75 | 2.34 | 7.03 |
| 21.00 | 2.30 | 6.90 |
| 21.25 | 2.26 | 6.77 |
| 21.50 | 2.21 | 6.64 |
| 21.75 | 2.17 | 6.51 |
| 22.00 | 2.13 | 6.38 |
| 22.25 | 2.08 | 6.25 |
| 22.50 | 2.04 | 6.12 |
| 22.75 | 2.00 | 5.99 |
| 23.00 | 1.95 | 5.86 |
| 23.25 | 1.91 | 5.73 |
| 23.50 | 1.87 | 5.60 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-5 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-5 SHALLOW_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 SHALLOW_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 SHALLOW_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-5 SHALLOW_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-5 SHALLOW_201305 | | Salinity | 250 mL / HDPE / None |
| | MW-5 SHALLOW_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-5 SHALLOW_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-5 SHALLOW_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 11.50 | 1.66 | 4.98 |
| 11.75 | 1.62 | 4.85 |
| 12.00 | 1.57 | 4.72 |
| 12.25 | 1.53 | 4.59 |
| 12.50 | 1.49 | 4.46 |
| 12.75 | 1.44 | 4.32 |
| 13.00 | 1.40 | 4.19 |
| 13.25 | 1.35 | 4.06 |
| 13.50 | 1.31 | 3.93 |
| 13.75 | 1.27 | 3.80 |
| 14.00 | 1.22 | 3.67 |
| 14.25 | 1.18 | 3.54 |
| 14.50 | 1.14 | 3.41 |
| 14.75 | 1.09 | 3.28 |
| 15.00 | 1.05 | 3.15 |
| 15.25 | 1.01 | 3.02 |
| 15.50 | 0.96 | 2.89 |
| 15.75 | 0.92 | 2.76 |
| 16.00 | 0.88 | 2.63 |
| 16.25 | 0.83 | 2.49 |
| 16.50 | 0.79 | 2.36 |
| 16.75 | 0.74 | 2.23 |
| 17.00 | 0.70 | 2.10 |
| 17.25 | 0.66 | 1.97 |
| 17.50 | 0.61 | 1.84 |
| 17.75 | 0.57 | 1.71 |
| 18.00 | 0.53 | 1.58 |
| 18.25 | 0.48 | 1.45 |
| 18.50 | 0.44 | 1.32 |
| 18.75 | 0.40 | 1.19 |
| 19.00 | 0.35 | 1.06 |
| 19.25 | 0.31 | 0.93 |
| 19.50 | 0.26 | 0.79 |
| 19.75 | 0.22 | 0.66 |
| 20.00 | 0.18 | 0.53 |
| 20.25 | 0.13 | 0.40 |
| 20.50 | 0.09 | 0.27 |
| 20.75 | 0.05 | 0.14 |
| 21.00 | 0.00 | 0.01 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-6 DEEP**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | MW-6 DEEP_201304 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | MW-6 DEEP_201304 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | MW-6 DEEP_201304 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | MW-6 DEEP_201304 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | MW-6 DEEP_201304 | | Salinity | 250 mL / HDPE / None |
| | MW-6 DEEP_201304 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | MW-6 DEEP_201304 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | MW-6 DEEP_201304 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 19.00 | 3.71 | 11.14 |
| 19.25 | 3.67 | 11.01 |
| 19.50 | 3.63 | 10.88 |
| 19.75 | 3.58 | 10.75 |
| 20.00 | 3.54 | 10.62 |
| 20.25 | 3.49 | 10.48 |
| 20.50 | 3.45 | 10.35 |
| 20.75 | 3.41 | 10.22 |
| 21.00 | 3.36 | 10.09 |
| 21.25 | 3.32 | 9.96 |
| 21.50 | 3.28 | 9.83 |
| 21.75 | 3.23 | 9.70 |
| 22.00 | 3.19 | 9.57 |
| 22.25 | 3.15 | 9.44 |
| 22.50 | 3.10 | 9.31 |
| 22.75 | 3.06 | 9.18 |
| 23.00 | 3.02 | 9.05 |
| 23.25 | 2.97 | 8.92 |
| 23.50 | 2.93 | 8.78 |
| 23.75 | 2.88 | 8.65 |
| 24.00 | 2.84 | 8.52 |
| 24.25 | 2.80 | 8.39 |
| 24.50 | 2.75 | 8.26 |
| 24.75 | 2.71 | 8.13 |
| 25.00 | 2.67 | 8.00 |
| 25.25 | 2.62 | 7.87 |
| 25.50 | 2.58 | 7.74 |
| 25.75 | 2.54 | 7.61 |
| 26.00 | 2.49 | 7.48 |
| 26.25 | 2.45 | 7.35 |
| 26.50 | 2.41 | 7.22 |
| 26.75 | 2.36 | 7.09 |
| 27.00 | 2.32 | 6.95 |
| 27.25 | 2.27 | 6.82 |
| 27.50 | 2.23 | 6.69 |
| 27.75 | 2.19 | 6.56 |
| 28.00 | 2.14 | 6.43 |
| 28.25 | 2.10 | 6.30 |
| 28.50 | 2.06 | 6.17 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **MW-6 SHALLOW**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-1_201304 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-1_201304 | | Salinity | 250 mL / HDPE / None |
| | GW-1_201304 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-1_201304 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-1_201304 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 17.50 | 1.70 | 5.09 |
| 17.75 | 1.65 | 4.96 |
| 18.00 | 1.61 | 4.83 |
| 18.25 | 1.57 | 4.70 |
| 18.50 | 1.52 | 4.57 |
| 18.75 | 1.48 | 4.44 |
| 19.00 | 1.44 | 4.31 |
| 19.25 | 1.39 | 4.18 |
| 19.50 | 1.35 | 4.05 |
| 19.75 | 1.31 | 3.92 |
| 20.00 | 1.26 | 3.79 |
| 20.25 | 1.22 | 3.66 |
| 20.50 | 1.17 | 3.52 |
| 20.75 | 1.13 | 3.39 |
| 21.00 | 1.09 | 3.26 |
| 21.25 | 1.04 | 3.13 |
| 21.50 | 1.00 | 3.00 |
| 21.75 | 0.96 | 2.87 |
| 22.00 | 0.91 | 2.74 |
| 22.25 | 0.87 | 2.61 |
| 22.50 | 0.83 | 2.48 |
| 22.75 | 0.78 | 2.35 |
| 23.00 | 0.74 | 2.22 |
| 23.25 | 0.70 | 2.09 |
| 23.50 | 0.65 | 1.96 |
| 23.75 | 0.61 | 1.82 |
| 24.00 | 0.56 | 1.69 |
| 24.25 | 0.52 | 1.56 |
| 24.50 | 0.48 | 1.43 |
| 24.75 | 0.43 | 1.30 |
| 25.00 | 0.39 | 1.17 |
| 25.25 | 0.35 | 1.04 |
| 25.50 | 0.30 | 0.91 |
| 25.75 | 0.26 | 0.78 |
| 26.00 | 0.22 | 0.65 |
| 26.25 | 0.17 | 0.52 |
| 26.50 | 0.13 | 0.39 |
| 26.75 | 0.09 | 0.26 |
| 27.00 | 0.04 | 0.13 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☒ Groundwater ☐ Other

Sample Location: **CHV-101 S**

Date(s) of Sample Collection:

Time(s) of Sample Collection:

Sampler's Identity:

*FIELD PARAMETERS / MEASUREMENTS*

Measured Depth to Water: ft

| # of Purge Volumes | Time | Cummulative Volume (gal) | pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| Collected Sample Parameters: | | | | | | | |

Well purged dry? ☐ Yes ☐ No

If Yes, did well recover to 80% within 24 hours?** ☐ Yes ☐ No

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | GW-1_201304 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | GW-1_201304 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | GW-1_201304 | | Salinity | 250 mL / HDPE / None |
| | GW-1_201304 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | GW-1_201304 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | GW-1_201304 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

* If conditions significantly change, purge volume can be calculated as follows:

One purge volume = 0.174305 x (Measured Depth to Water - Depth to Well Bottom)

** If "No", well is declared dry for the sampling event.

| Measured Depth to Water (ft) | Quantity (gal) to Purge X Volumes* 1 | 3 |
|---|---|---|
| 33.00 | 5.25 | 15.74 |
| 33.25 | 5.16 | 15.48 |
| 33.50 | 5.07 | 15.22 |
| 33.75 | 4.99 | 14.96 |
| 34.00 | 4.90 | 14.69 |
| 34.25 | 4.81 | 14.43 |
| 34.50 | 4.72 | 14.17 |
| 34.75 | 4.64 | 13.91 |
| 35.00 | 4.55 | 13.65 |
| 35.25 | 4.46 | 13.39 |
| 35.50 | 4.38 | 13.13 |
| 35.75 | 4.29 | 12.86 |
| 36.00 | 4.20 | 12.60 |
| 36.25 | 4.11 | 12.34 |
| 36.50 | 4.03 | 12.08 |
| 36.75 | 3.94 | 11.82 |
| 37.00 | 3.85 | 11.56 |
| 37.25 | 3.76 | 11.29 |
| 37.50 | 3.68 | 11.03 |
| 37.75 | 3.59 | 10.77 |
| 38.00 | 3.50 | 10.51 |
| 38.25 | 3.42 | 10.25 |
| 38.50 | 3.33 | 9.99 |
| 38.75 | 3.24 | 9.73 |
| 39.00 | 3.15 | 9.46 |
| 39.25 | 3.07 | 9.20 |
| 39.50 | 2.98 | 8.94 |
| 39.75 | 2.89 | 8.68 |
| 40.00 | 2.81 | 8.42 |
| 40.25 | 2.72 | 8.16 |
| 40.50 | 2.63 | 7.90 |
| 40.75 | 2.54 | 7.63 |
| 41.00 | 2.46 | 7.37 |
| 41.25 | 2.37 | 7.11 |
| 41.50 | 2.28 | 6.85 |
| 41.75 | 2.20 | 6.59 |
| 42.00 | 2.11 | 6.33 |
| 42.25 | 2.02 | 6.07 |
| 42.50 | 1.93 | 5.80 |

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **AT-2** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV | Depth along angle from casing invert (ft) |
|---|---|---|---|---|---|
| | | | | | |

*Data downloaded from transducer?* ☐ Yes ☐ No
*Has transducer been cleaned and recalibrated?* ☐ Yes ☐ No

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | AT-2_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | AT-2_201305 | | Salinity | 250 mL / HDPE / None |
| | AT-2_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | AT-2_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | AT-2_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☒ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **BAH-01** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |

## *FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV | Depth along angle from casing invert (ft) |
|---|---|---|---|---|---|
| | | | | | |

## *SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | AT-2_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | AT-2_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | AT-2_201305 | | Salinity | 250 mL / HDPE / None |
| | AT-2_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | AT-2_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | AT-2_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-8** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |
| ***Duplicate sample of:** | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-8_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-8_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-8_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-8_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-8_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-8_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-8_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-8_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*This sample is a Blind Duplicate Sample. Collect one blind duplicate sample for every 10 samples collected.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-9** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |
| ***Duplicate sample of:** | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-9_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-9_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-9_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-9_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-9_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-9_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-9_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-9_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*This sample is a Blind Duplicate Sample. Collect one blind duplicate sample for every 10 samples collected.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-10** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |
| ***Duplicate sample of:** | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-10_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-10_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-10_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-10_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-10_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-10_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-10_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-10_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*This sample is a Blind Duplicate Sample. Collect one blind duplicate sample for every 10 samples collected.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☐ Other

| | |
|---|---|
| Sample Location: | **DR-11** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |
| ***Duplicate sample of:** | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-11_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-11_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-11_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-11_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-11_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-11_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-11_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-11_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*This sample is a Blind Duplicate Sample. Collect one blind duplicate sample for every 10 samples collected.

# Rico Water Sampling Form: *Station Information*

☐ Surface Water ☐ Groundwater ☐ Other

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

| | |
|---|---|
| Sample Location: | **DR-12** |
| Date(s) of Sample Collection: | |
| Time(s) of Sample Collection: | |
| Sampler's Identity: | |
| ***Duplicate sample of:*** | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | DR-12_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | DR-12_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | DR-12_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | DR-12_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | DR-12_201305 | | Salinity | 250 mL / HDPE / None |
| | DR-12_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | DR-12_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | DR-12_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:

*This sample is a Blind Duplicate Sample. Collect one blind duplicate sample for every 10 samples collected.

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☒ Other

| | |
|---|---|
| Sample Location: | **FB-LAB** |
| Date of Sample Collection: | |
| Time of Sample Collection: | |
| Sampler's Identity: | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | FB-LAB_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | FB-LAB_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | FB-LAB_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | FB-LAB_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | FB-LAB_201305 | | Salinity | 250 mL / HDPE / None |
| | FB-LAB_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | FB-LAB_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | FB-LAB_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:
*Sample is a Field Blank. Run distilled water through all standard sampling procedures

# Rico Water Sampling Form: *Station Information*

Sampling completed at this location ☐
(Do not check box until **ALL** items have been completed)

☐ Surface Water ☐ Groundwater ☒ Other

| | |
|---|---|
| Sample Location: | **FB-FIELD** |
| Date of Sample Collection: | |
| Time of Sample Collection: | |
| Sampler's Identity: | |

*FIELD PARAMETERS / MEASUREMENTS*

| pH | EC, µS/cm | DO, ppm | Temp, °C | ORP, mV |
|---|---|---|---|---|
| | | | | |

*SAMPLE BOTTLE INFORMATION - Check off each bottle when completed*

| X | Field Sample ID on Bottle | | Analysis | Bottle size/Type/Preservative |
|---|---|---|---|---|
| | FB-FIELD_201305 | | Total Metals, Hardness, Silica | 250 mL / HDPE / HNO3 (RED) |
| | FB-FIELD_201305 | | Dissolved Metals (Field Filtered) | 250 mL / HDPE / HNO3 (RED) |
| | FB-FIELD_201305 | | Potentially Dissolved Metals | 250 mL / HDPE / HNO3 (RED) |
| | FB-FIELD_201305 | | Alkalinity, TSS, TDS, Chloride, Sulfate | 500 mL / HDPE / None |
| | FB-FIELD_201305 | | Salinity | 250 mL / HDPE / None |
| | FB-FIELD_201305 | | Cyanide | 250 mL / HDPE / NaOH (GREEN) |
| | FB-FIELD_201305 | | Sulfide | 250 mL / HDPE / NaOH + Zn Acetate (BLACK) |
| | FB-FIELD_201305 | | Total Organic Carbon, Nitrate | 250 mL / Amber Glass / H2SO4 (YELLOW) |

Notes:
*Sample is a Field Blank. Run distilled water through all standard sampling procedures

Rico Water Sampling Form: *Stream Flow Measurements*



| Location: | DR-1 | | | Location: | DR-2 | | | Location: | DR-7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Benchmark Elevation: | | | | Benchmark Elevation: | | | | Benchmark Elevation: | | | |
| River Water Elevation: | | | | River Water Elevation: | | | | River Water Elevation: | | | |
| ☐ East to West | | | | ☐ East to West | | | | ☐ East to West | | | |
| ☐ West to East | | | | ☐ West to East | | | | ☐ West to East | | | |
| Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | |
| 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 |
| 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 |
| 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 |
| 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 |
| 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 |
| 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 |
| 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 |
| 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 |
| 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 |
| 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 |
| 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 |
| 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 |
| 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 |
| 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 |
| 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 |
| 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 |
| 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 |
| 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 |
| 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 |
| 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 |
| 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 |
| 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 |
| 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 |
| 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 |
| 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 |
| 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 |
| 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 |
| 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 |
| 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 |
| 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 |
| 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 |
| 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 |
| 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 |
| 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 |
| 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 |

NOTE: Each velocity reading must have a corresponding depth reading with matching cell number. Each cell represents a 1-foot subsection. Measurements are to be taken every foot.

Rico Water Sampling Form: *Stream Flow Measurements*



| Location: | DR-4-SW | | | Location: | DR-G | | | Location: | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Benchmark Elevation: | | | | Benchmark Elevation: | | | | Benchmark Elevation: | | | |
| River Water Elevation: | | | | River Water Elevation: | | | | River Water Elevation: | | | |
| ☐ East to West | | | | ☐ East to West | | | | ☐ East to West | | | |
| ☐ West to East | | | | ☐ West to East | | | | ☐ West to East | | | |
| Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | |
| 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 |
| 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 |
| 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 |
| 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 |
| 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 |
| 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 |
| 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 |
| 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 |
| 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 |
| 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 |
| 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 |
| 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 |
| 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 |
| 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 |
| 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 |
| 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 |
| 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 |
| 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 |
| 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 |
| 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 |
| 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 |
| 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 |
| 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 |
| 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 |
| 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 |
| 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 |
| 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 |
| 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 |
| 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 |
| 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 |
| 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 |
| 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 |
| 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 |
| 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 |
| 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 |

NOTE: Each velocity reading must have a corresponding depth reading with matching cell number. Each cell represents a 1-foot subsection. Measurements are to be taken every foot.

Rico Water Sampling Form: *Stream Flow Measurements*



| Location: | DR-1A | | | Location: | DR-2A | | | Location: | DR-3A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Benchmark Elevation: | | | | Benchmark Elevation: | | | | Benchmark Elevation: | | | |
| River Water Elevation: | | | | River Water Elevation: | | | | River Water Elevation: | | | |
| ☐ East to West | | | | ☐ East to West | | | | ☐ East to West | | | |
| ☐ West to East | | | | ☐ West to East | | | | ☐ West to East | | | |
| Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | | Velocity (ft/sec) | | Depth (ft) | |
| 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 | 1 | 36 |
| 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 | 2 | 37 |
| 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 | 3 | 38 |
| 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 | 4 | 39 |
| 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 | 5 | 40 |
| 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 | 6 | 41 |
| 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 | 7 | 42 |
| 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 | 8 | 43 |
| 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 | 9 | 44 |
| 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 | 10 | 45 |
| 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 | 11 | 46 |
| 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 | 12 | 47 |
| 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 | 13 | 48 |
| 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 | 14 | 49 |
| 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 | 15 | 50 |
| 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 | 16 | 51 |
| 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 | 17 | 52 |
| 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 | 18 | 53 |
| 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 | 19 | 54 |
| 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 | 20 | 55 |
| 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 | 21 | 56 |
| 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 | 22 | 57 |
| 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 | 23 | 58 |
| 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 | 24 | 59 |
| 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 | 25 | 60 |
| 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 | 26 | 61 |
| 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 | 27 | 62 |
| 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 | 28 | 63 |
| 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 | 29 | 64 |
| 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 | 30 | 65 |
| 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 | 31 | 66 |
| 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 | 32 | 67 |
| 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 | 33 | 68 |
| 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 34 | 69 |
| 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 | 35 | 70 |

NOTE: Each velocity reading must have a corresponding depth reading with matching cell number. Each cell represents a 1-foot subsection. Measurements are to be taken every foot.

**Appendix G**
Chain of Custody Form

ANDERSON
ENGINEERING COMPANY INC.

977 West 2100 South
Salt Lake City, UT 84119
(801) 972-6222
FAX (801) 972-6235

# CHAIN OF CUSTODY RECORD

COC# _____
Page _____ of _____

Client: _____
Project: _____
_____
AECI Contact _____

Lab Name: _____
Lab Contact: _____
Lab Address: _____
_____

Matrix Codes
(W) Water
(S) Soil
(L) Liquid

QC: (circle one)
I II III IV

| Field Location | Field Sample ID Number | Date | Time | Matrix | No. of Containers | Analysis Requested | | | | | | | | | | COMMENTS |
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**Appendix H**

EPA Guidelines on Measuring River Flow from Surface Velocity

**To measure cross-sectional area:**

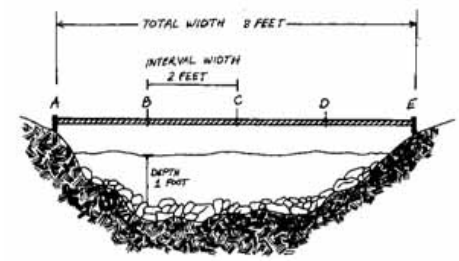


*Figure 5.5*

***A cross section view to measure stream width and depth***

2. Determine the average depth along the transect by marking off equal intervals along the string with the twist ties. The intervals can be one-fourth, one-half, and three-fourths of the distance across the stream. Measure the water's depth at each interval point (Fig. 5.5). To calculate average depth for each transect, divide the total of the three depth measurements by 4. (You divide by 4 instead of 3 because you need to account for the 0 depths that occur at the shores.) In the example shown in Figure 5.6, the average depth of Transect #1 is 0.575 feet and the average depth of Transect #2 is 0.625 feet.
3. Determine the width of each transect by measuring the distance from shoreline to shoreline. Simply add together all the interval widths for each transect to determine its width. In the Figure 5.6 example, the width of Transect #1 is 8 feet and the width of Transect #2 is 10 feet.
4. Calculate the cross-sectional area of each transect by multiplying width times average depth. The example given in Figure 5.6 shows that the average cross-sectional area of Transect #1 is 4.60 square feet and the average cross-sectional area of Transect #2 is 6.25 square feet.
5. To determine the average cross-sectional area of the entire stream reach (A in the formula), add together the average cross-sectional area of each transect and then divide by 2. The average cross-sectional area for the stream reach in Figure 5.6 is 5.42 square feet.

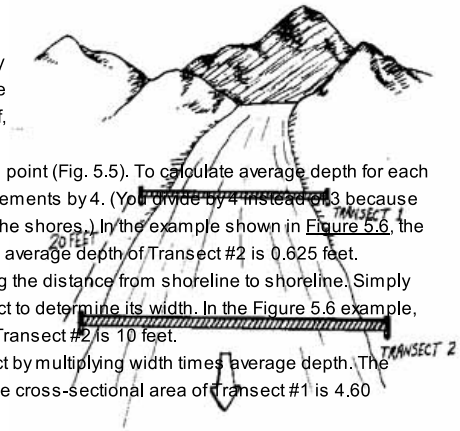


*Figure 5.4*

***A diagram of a 20-foot transect***

## Task 4 Measure travel time

Volunteers should time with a stopwatch how long it takes for an orange (or some other object) to float from the upstream to the downstream transect. An orange is a good object to use because it has enough buoyancy to float just below the water surface. It is at this position that maximum velocity typically occurs.

The volunteer who lets the orange go at the upstream transect should position it so it flows into the fastest current. The clock stops when the orange passes fully under the downstream transect line. Once under the transect line, the orange can be scooped out of the water with the fishing net. This "time of travel" measurement should be conducted at least three times and the results averaged--the more trials you do, the more accurate your results will be. The averaged results are equal to *T* in the formula. It is a good idea to float the orange at different distances from the bank to get various velocity estimates. You should discard any float trials if the object gets hung up in the stream (by cobbles, roots, debris, etc.)

## Task 5 Calculate flow

Recall that flow can be calculated using the equation:

$$\text{Flow} = ALC / T$$

Continuing the example in Fig. 5.6. say the average time of travel for the orange between Transect #1 and #2 is 15 seconds and the stream had a rocky bottom. The calculation of flow would be:

*Where:*

| | | |
|---|---|---|
| A | = | 5.42 ft2 |
| L | = | 20 ft |
| C | = | 0.8 (coefficient for a rocky-bottom stream) |
| T | = | 15 seconds |

$$\text{Flow} = 15 \text{ seconds } (5.42 \text{ ft}^2)\ (20 \text{ ft})\ (0.8) / 15 \text{ sec.}$$
$$\text{Flow} = 86.72 \text{ ft}^3 / 15 \text{ sec.}$$
$$\text{Flow} = 5.78 \text{ ft3/sec.}$$

## Task 6 Record flow on the data form

On the following page is a form volunteers can use to calculate flow of a stream.

## *References*

Adopt-A-Stream Foundation. *Field Guide: Watershed Inventory and Stream Monitoring Methods,* by Tom Murdoch and Martha Cheo. 1996. Everett, WA.

Mitchell, M.K., and W. Stapp. *Field Manual for Water Quality Monitoring.* 5th Edition. Thompson Shore Printers.

Missouri Stream Teams. *Volunteer Water Quality Monitoring.* Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, MO 65102.

*Data Form for Calculating Flow* (PDF, 82.8 KB)

You will need Adobe Acrobat Reader to view the Adobe PDF files on this page. See EPA's PDF page for more information about getting and using the free Acrobat Reader.

Last updated on Tuesday, March 06, 2012

# Appendix E

# Quality Assurance Project Plan for Surface Water and Groundwater (On CD)

Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
Atlantic Richfield Company
May 23, 2013

# Quality Assurance Project Plan For Surface Water and Groundwater

# Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01 Rico, Colorado

Document Control No. 2013-R1-00_

This document is the property of BP – Atlantic Richfield Company and was prepared by Anderson Engineering Company, Inc., and AECOM Technical Services, Inc. It is provided on the condition that it will be used solely for the intended purpose and will be used solely for the execution and review of the engineering, remediation, or construction of the subject project.

| Revision | Prepared By | Reviewed By | Approved By | Date | Pages Affected |
|---|---|---|---|---|---|
| 0 | AECI / AECOM | | | May 23, 2013 | All |
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# Atlantic Richfield Company

**Anthony R. Brown**
Project Manager, Mining

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May 23, 2013

***VIA EMAIL AND OVERNIGHT COURIER***

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
US EPA Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

**Subject: Quality Assurance Project Plan (QAPP) Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01 Rico, Colorado**

Dear Mr. Way,

A digital file in PDF format of the updated *Quality Assurance Project Plan (QAPP) – Rico Tunnels Operable Unit OU01 Rico, Colorado* dated May 23, 2013, is being submitted to you today via email. Three (3) hardcopies of the report will also be sent by overnight courier to your office.

Atlantic Richfield Company (AR) is submitting this updated QAPP responsive to requirements in Section 5.1 of the Removal Action Work Plan accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, Colorado, U.S. EPA Region 8, Docket No. CERCLA-08-2011-0005.

If you have any questions or comments, please feel free to contact me at (714) 228-6770 or via email at Anthony.Brown@bp.com

Sincerely,

Anthony R. Brown

Anthony Brown
Project Manager
Atlantic Richfield Company

Enclosures (Quality Assurance Project Plan, Rico-Argentine Mine Site)

cc: Terry Moore, Atlantic Richfield
Sandy Riese, EnSci
Chris Sanchez, AECI
Dave McCarthy, Copper Environmental
Tom Kreutz, AECOM
Doug Yadon, AECOM
Mark Lombardi, AMEC
Spencer Archer, AMEC

# Executive Summary

The Rico-Argentine Mine Site – Rico Tunnels Operable Unit, OU01, is located just north of the town of Rico, Dolores County, Colorado. Significant mining at the Site began in the early 1900s, and the most recent mining and mineral processing activities ceased in 1976-77. The Site consists of a complex of underground workings and an adit known as the St. Louis Tunnel that drains flows from the underground workings to a series of settling ponds which eventually discharge into the Dolores River. Atlantic Richfield Company (AR) retains responsibility for the Site and is currently operating under EPA Unilateral Administrative Order (UAO) for Removal Action, Rico-Argentine Mine Site, Dolores County, Colorado, U.S. EPA Region 8, Docket No. CERCLA-08-2011-0005, with an effective date of March, 23, 2011.

Under the UAO Remedial Action Work Plan (RAWP), monthly sampling is conducted at the Site to measure selected metals and non-metals concentrations at various points on the system, both in surface water and groundwater. In addition to metals and non-metals concentrations, field parameters (temperature, dissolved oxygen, and electro-conductivity) are measured for each sample, as well as flow rates and groundwater levels. Monthly sampling data are used to track concentrations of metals and other constituents discharged into the Dolores River, evaluate the effectiveness of the St. Louis settling ponds, and assess the possible effects of seasonal variations on the level of metals loading and pond performance.

This Quality Assurance Project Plan (QAPP) describes how AR will collect data to meet the objectives of the water quality sampling and flow and water level monitoring program and activities which occur at the Site. This program will be guided by a separate Sampling and Analysis Plans (SAP) which is a companion document to this QAPP. The SAP covers the monthly routine sampling program. This QAPP discusses how the sampling, analysis, and data management process will be controlled and monitored to ensure that the data are of sufficient quality, quantity, and completeness to meet the user requirements for the project.

# Group A: Project Management

## A1 Title and Approval Sheet

QUALITY ASSURANCE PROJECT PLAN FOR RICO SAMPLING AND ANALYSIS

This Quality Assurance Project Plan has been reviewed and approved by the applicable authority representing the project team. In addition, by signature below, we certify that all personnel working on the project have been trained to this plan:

**Approvals**

**Project Name:** Rico – Argentine Mine Site, Rico Tunnels, Operable Unit OU01
**Location:** Rico, Colorado
**Document Title:** Quality Assurance Project Plan

This plan was prepared through a joint effort of Anderson Engineering Company, Inc. (AECI) and AECOM Technical Services, Inc. (AECOM) on behalf of Atlantic Richfield. The preparer information is as follows:

Jeffrey S. Roehrig
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Steve Szocik
AECOM Quality Assurance Manager
717 17TH Street, Suite 2600
Denver, Colorado 80202
(303) 228-3069
Steve.szocik@aecom.com

I have read and approved this QAPP with respect to quality elements, regulatory requirements, and Contract obligations and procedures.

| | | |
|---|---|---|
| AR Project Manager | Name/Signature | Date |
| Project QA Manager (or Designee dependent upon project requirements) | Name/Signature | Date |

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Appendix B: Training Certification Form
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## ACRONYMS

| | |
|---|---|
| AECI | Anderson Engineering Company, Inc. |
| AECOM | AECOM Technical Services, Inc. |
| AR | Atlantic Richfield Company |
| CDPHE | Colorado Department of Public Health and Environment |
| COC | Chain of Custody |
| CoW | Control of Work |
| DO | Dissolved Oxygen |
| DQO | Data Quality Objectives |
| DVM | Data Validation Manager |
| EDD | Electronic Data Deliverable |
| EPA | United States Environmental Protection Agency |
| HSO | Health, Safety, Security, and Environment Officer |
| HSSE | Health, Safety, Security, and Environment |
| ICB/CVB | Initial Calibration and Calibration Verification Blanks |
| LCS | Laboratory Control Samples |
| LPM | Laboratory Project Manager |
| LQAM | Laboratory Quality Assurance Manager |
| LQM | Laboratory Quality Manual |
| MDL | Method Detection Limits |
| MS | Matrix Spikes |
| MSD | Matrix Spike Duplicate |
| NPDES | National Pollutant Discharge Elimination System |
| ORP | Oxygen Reduction Potential |
| PARCC | Precision, Accuracy, and Bias, Representativeness, Comparability, and Completeness |
| PM | Project Manager |
| PQL | Practical Quantitation Limit |
| RPD | Relative Percent Difference |
| QA | Quality Assurance |
| QAP | Laboratory-Specific Quality Assurance Plan |
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| QCM | Quality Control Manager |
| RAWP | Remedial Action Work Plan |
| SAP | Sampling and Analysis Plan |
| SOP | Standard Operating Procedures |
| SSHASP | Site-Specific Health and Safety Plan |
| STL | Sample Team Leader |
| TSEA | Task Specific Environmental Analysis |
| UAO | Unilateral Administrative Order |
| WQA | Water Quality Assessment |

## A3 Distribution List

The following project personnel have received copies of this document and will be provided with any subsequent revisions to this document:

**Table A3-1: Distribution List**

| QAPP Recipients | Title | Organization | Phone | Fax | Email | Control No. |
|---|---|---|---|---|---|---|
| Stephen Way | EPA On-Scene Coordinator | EPA | 303-886-1640 | 303-312-6071 | way.steven@ epa.gov | 2013-R1-001 |
| Tony Brown | Client Project Manager | AR | 951-265-4277 | 801-972-6235 | anthony.brown@ bp.com | 2013-R1-002 |
| Chris Sanchez | AECI Project Manager | AECI | 801-971-1767 | 801-972-6235 | csanchez@ andersoneng.com | 2013-R1-003 |
| Tom Kreutz | AECOM Project Manager | AECOM | 303-228-3056 | 303-228-3001 | thomas.kreutz@aecom.com | 2013-R1-004 |
| Doug Yadon | Certifying/Design Engineer | AECOM | 303-542-4755 | 303-228-3001 | douglas.yadon@ aecom.com | 2013-R1-005 |
| Steve Szocik | QA Manager | AECOM | 303-228-3069 | 303-228-3001 | steve.szocik@ aecom.com | 2013-R1-006 |
| Jeff Roehrig | QC Manager | AECI | 720-684-9936 | 801-972-6235 | jroehrig@ andersoneng.com | 2013-R1-007 |
| Mark DeFriez | Sample Team Leader | AECI | 801-234-9583 | 801-972-6235 | mdefriez@ andersoneng.com | 2013-R1-008 |

The QA Manager, as listed herein, is ultimately responsible for updates and confirming distribution of any revisions to this plan. Electronic copies of any minor revisions will be sent to the document holders. Any major changes to the plan will be sent via hard copy. Each individual plan holder will be responsible for amending the plan books accordingly with the changes being sent.

## A4 Project and Task Organization

### A4.1 Introduction

The QAPP outlines the requirements for all project personnel to follow in regards to groundwater and surface water sampling and gauging, quality control, and quality assurance inspections, documentation, and testing activities. Oversight of the project will ensure that the final work product meets all project, contract, and regulatory requirements, as well as standard operating procedures (SOPs) and defined practices. Inspections and tests have been identified to confirm that the work product meets these goals, and to provide quantitative criteria of such.

The intent of the QAPP is to provide a process for collecting and managing data that will ensure its quality. This document discusses the data quality process prior to using the data to write reports or make presentations. The project team will use this QAPP as guidance for collecting, analyzing, managing, and validating data. This QAPP should be considered a companion document to the project Work Plans and Sampling and Analysis Plans (SAP).

The organizational structure, management control, functional responsibilities, levels of authority, lines of communication, and interfaces for activities affecting quality are identified and documented in this section. Activities affected by quality include, but are not limited to, training, inspecting, testing, operating, maintaining, repairing, modifying, computer usage and data management, verifying/validating, preparing and reviewing technical calculations, quality records processing, and data collection and analysis.

Figure A4-1 presents the key positions of project organization, including lines of communication. The responsibilities of the key individuals making up the project management, quality management, and field management teams are briefly highlighted below. These descriptions provide all parties a clear understanding of the role that each party plays.

## A4.2 Project Management

### EPA On-Scene Coordinator

The US Environmental Protection Agency (EPA) will be acting as the lead agency in the oversight of this project under the EPA UAO. The EPA On-Scene Coordinator will review draft submittals, receive final reports, and will provide direct communication, on behalf of the EPA, with Atlantic Richfield (AR) and the remainder of the project team.

### Atlantic Richfield Company Project Manager

The AR Project Manager (PM) has ultimate responsibility for all project deliverables, and will interface with the EPA On-Scene Coordinator and consultant PMs concerning project deliverables and other issues pertaining to the project. Other responsibilities include:

- Ensuring that project deliverables are scheduled, budgeted, and prepared
- Ensuring adherence to the quality requirements of the UAO, specific work orders, quality management plans, QAPPs, and SAPs
- Serving as the primary point of contact with the EPA and regulatory agencies
- Communicating with the AECOM PM and AECI PM

### AECOM Project Manager

The AECOM PM is responsible for designing the sampling program and plans in accordance with EPA, Colorado Department of Public Health and Environment (CDPHE), and Colorado Division of Reclamation and Mining Safety (CDRMS) and project requirements, reviewing field data, and reviewing final agency deliverables. AECOM will also provide quality assurance (QA) to the project. The PM is responsible for the quality of work performed by those individuals assigned to them. The PM is responsible for all operations associated with implementation of the QA organization, including, but not limited to:

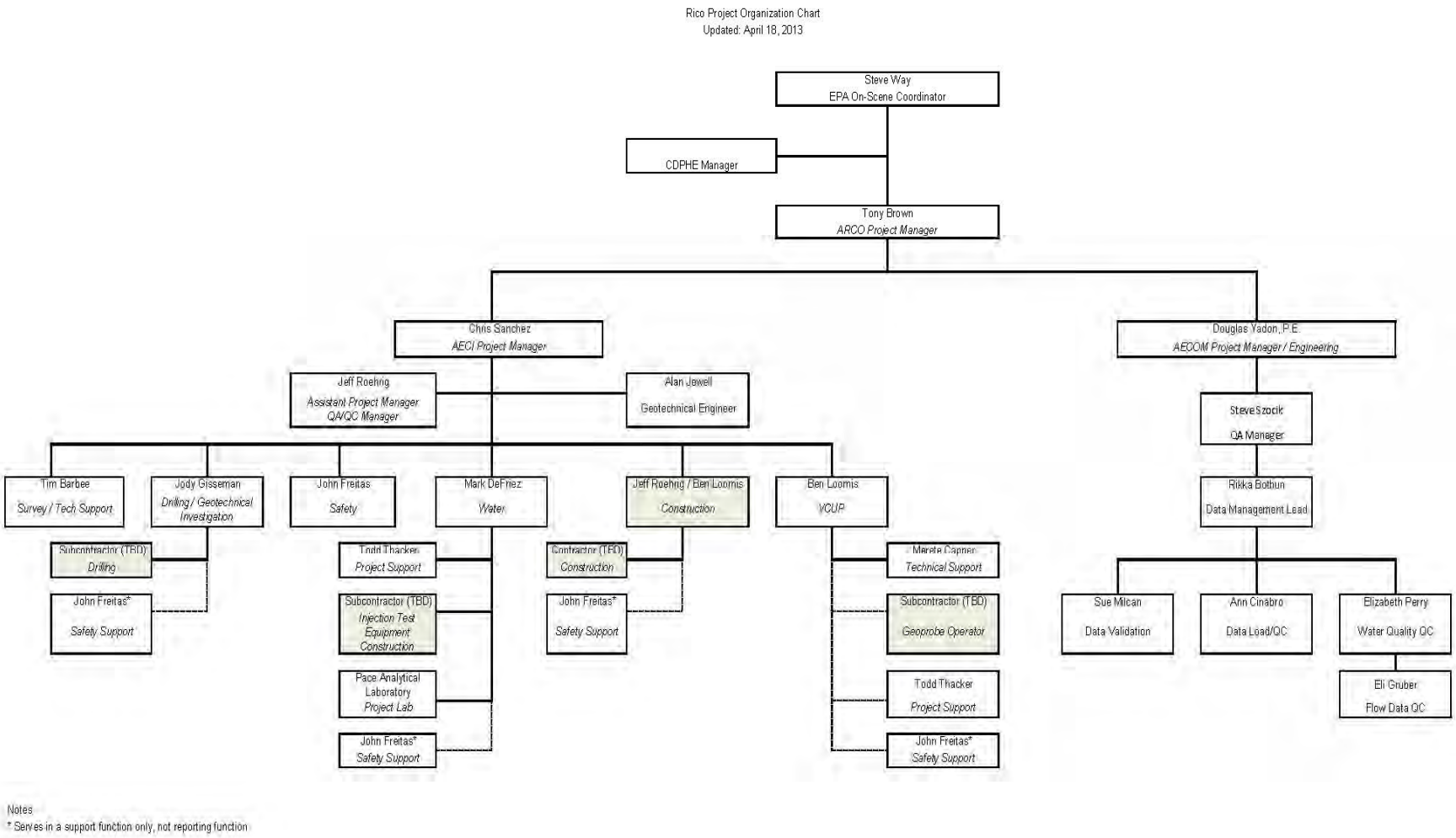
- Managing all aspects of project design and QA oversight and ensuring conformance with project plans and procedures
- Maintaining liaison between QA organization and field sampling organization (AECI)
- Acting as company point of contact with AR PM and AECI PM
- Directing and coordinating updates to AECOM budget and schedule
- Identifying and resolving project issues relating to design and QA functions, and resolving any identified deficiencies or non-conformances
- Identifying and providing resource needs to the project

### Anderson Engineering (AECI) Project Manager

The AECI Project Manager is responsible for implementing the QAPP and other project sampling plans, conducting and reporting investigations, supplying technical support for field personnel, responding to any problems that may arise in the completion of the field tasks, and preparing the draft monthly report for agency delivery. In addition, the AECI Project Manager is also responsible for the following:

- Planning for safe execution of the project from design to completion
- Managing all aspects of project execution involving plan design, sample collection, handling, and processing
- Acting as primary point of contact between AR PM and AECOM PM
- Directing and coordinating updates to AECI budget and schedule
- Identifying and resolving project issues, including all identified deficient and nonconforming work items

**Figure A4-1: Rico Project Organizational Chart**



## A4.3 Quality Assurance / Quality Control Responsibilities

### Quality Assurance Manager (QAM), AECOM

The Quality Assurance Manager (QAM) has overall responsibility for the quality of project data and is not involved in any data generation. The QAM responsibilities are listed below. Additional roles (AECOM QA Supervisor, etc.) are not described in detail in this section, but are shown on the Rico Data Management Procedure and Timeline (Appendix A).

- Maintaining, updating, and distributing the QAPP to applicable project team members
- Coordinating with the AECI QC Manager (QCM) to ensure that appropriate procedures are followed in the field and during data entry/data review, and that QC steps are documented according to requirements in the SAP and QAPP
- Ensuring appropriate QC review is performed on data prior to incorporation into project database and distribution of monthly report, including:
    - Ensuring AECOM Data Manager and AECOM QC Reviewer complete appropriate steps to review the laboratory report, chain of custody forms (COCs), electronic data deliverables (EDDs), and monthly report tables for completeness and accuracy.
    - Ensuring AECOM Data Validation Manager completes validation review of the data and that validation qualifiers are incorporated into the database as appropriate.
    - Coordinating with the AECOM Water Quality QA Reviewer to ensure a geochemical review of the data is completed and any issues are communicated to the appropriate project team members.
    - Coordinating with AECOM Flow QA Reviewer to ensure that review of the hourly and instantaneous flow values is completed. Communicate any potential issues to the AECI QA Reviewer and AECI Sample Team Leader to ensure that any necessary corrective actions are taken.
    - Communicating to AECOM Data Distributor when all required QC reviews have been completed and data and monthly report are ready for delivery to the agency.
- Stopping work if deemed appropriate
- Providing clarification and guidance to project team personnel concerning QA matters
- Evaluating and ensuring the satisfactory performance of the QA personnel and verifying the corrective actions to be taken for significant conditions adverse to quality
- Maintaining programmatic quality records identified in procedures, work plans, or other documents as applicable

### Quality Control Manager (QCM), AECI

The AECI Quality Control Manager, or designee, responsibilities include, but are not limited to, the following:

- Evaluating the quality of work performed by the field implementation team by conducting audits and quality reviews for compliance with requirements specified in the UAO
- Ensuring that any data transcribed from field forms to electronic format is thoroughly reviewed for accuracy before it is submitted for inclusion in the monthly report and project database
- Supervising project QC personnel; or, if no other personnel assigned, performing QC functions on the project. The responsibilities for QC personnel are as follows:
    - Conducting the required inspections and test activities as detailed in work plans, sampling plans, and quality plans
    - Ensuring that further processing, delivery, installation, and use of products or services are controlled in cases where unsatisfactory conditions are known
    - Identifying and reporting deficient and nonconforming items and reviewing the disposition of nonconforming items
    - Ensuring that field changes are implemented and documented according to governing standards, programs, procedures, etc.
    - Monitoring and assessing field activities to ensure the quality of work performed meets specified requirements
    - Preparing nonconformance reports if a characteristic, documentation, or procedure renders the quality of an items or activity unacceptable or indeterminate

- Preparing a field report detailing QC status of the project task or activity observed
- Reporting and communicating any deficient or nonconforming items to the Project and Task Managers, as well as applicable project personnel.
- Developing, implementing, reviewing, and updating project QC procedures
- Forecasting QC personnel staffing levels
- Providing input for the development of project-specific QC objectives
- Reviewing project scope of work, plans, and procedures for discrepancies and impact on the quality program and applicable quality documents, during development and prior to being implemented on the project
- Interfacing with Project and Task Managers on QC issues
- Interfacing with QA Manager regarding project QC issues
- Identifying QC requirements with the project design team
- Performing technical reviews of all prepared plans and reports
- Reviewing all project quality plans and documents

### Laboratory Project Manager (LPM), Pace

The laboratory project manager (LPM) is independent from the daily Site operations. The LPM's responsibilities include:

- Coordinating laboratory analyses
- Supervising in-house COC
- Scheduling sample analyses within required holding times
- Overseeing data review and preparation of analytical reports and (Electronic Data Deliverable) EDD
- Approving final analytical reports and EDDs before submission

### Laboratory QA Manager (LQAM), Pace

The laboratory QA manager (LQAM) is independent from the daily Site operations. The LQAM's responsibilities include:

- Overseeing laboratory data QA and administration of this QAPP
- Communicating data issues through the Laboratory Project Manager (LPM)
- Reviewing and approving laboratory QA/QC procedures
- Reviewing QA documentation
- Conducting compliance review of EDDs to hardcopy data results
- Developing and implementing laboratory corrective actions
- Defining appropriate laboratory QA/QC procedures
- Evaluating effectiveness of the project-specific quality program
- Reviewing and approving laboratory SOPs

### Data Validation Manager (DVM), AECOM

The Data Validation Manager (DVM) is independent from the daily operations of the units generating analytical data. Responsibilities include:

- Communicating any lab issues to the LPM via the AECI Sample Team Leader (STL), as needed
- Scheduling and oversight of, or conducting, data validation; review and submittal of data validation reports in compliance with the QAPP directives
- Reviewing project data QA/QC issues when requested by the QA Manager
- Scheduling and oversight of, or conducting QC review of EDDs of laboratory chemical data, addition of any data validation qualifiers assigned, and import of EDDs to the project database
- Notifying the laboratory and QA Manager of specific laboratory non-conformances and changes as needed

## A4.4 Field Responsibilities

The responsibilities of project field personnel are described in this section.

### Health Safety, Security, and Environment (HSSE) Officer (HSO), AECI

The AECI Health, Safety, Security and Environmental (HSSE) Officer is responsible for the preparation, modification, and implementation of the Site-specific Health and Safety Plan (SSHASP). Any changes to the SSHASP must be approved by the HSSE. The HSSE is the designated regulatory contact on matters related to occupational health and safety.

### Sample Team Leader (STL), AECI

The Sample Team Leader will be responsible for ensuring that the SAP is followed. His or her responsibilities include, but are not limited to, the following:

- Ensuring all sample technicians follow the quality goals set forth in the QAPP, SAP, and other sampling procedural documents
- Ensuring that all sample personnel execute the work safely, in accordance with all safety goals and requirements as outlined in the SSHASP
- Ensuring that an adequate number of sample technicians and field personnel with appropriate skills and training are scheduled for the sampling tasks
- Reporting any deficient or nonconforming work items as identified to the applicable Quality and Project Management staff
- Ensuring that all Control of Work (CoW) items are followed
- Confirming that all sample technicians and other field sampling personnel are properly trained and have the necessary supplies and support to safely execute and perform the assigned tasks
- Communicating with LPM as needed

## A4.5 Lines of Communication

The general lines of communication are presented in the Project Organization Chart in Figure A4-1 above.

# A5 Problem Definition and Background

## A5.1 Problem Definition

Monthly sampling is conducted at the Site as described in the SAP (AECI, 2013) and summarized in Section A6.1. The objective of monthly sampling is to assess the current water quality at and in the proximity of the Rico-Argentine Mine Site (Site) to: a) update the current Water Quality Assessment (WQA, “Water Quality Assessment Mainstem of the Dolores River St. Louis Tunnel Discharge”, Oct. 2008), if necessary, and b) establish receiving water quality to support the preparation of a discharge permit application and associated permit limits, evaluation of this data over an annual cycle, including seasonal low-flow periods. The sampling program also provides discharge water quality data to support system design and implementation of an effective water treatment system for the St. Louis Tunnel discharge including hydraulic controls.

## A5.2 Site Description

The Rico-Argentine Mine Site is defined in the UAO as the complex of tunnels and other facilities at the Rico-Argentine Mine, including the Rico Tunnels Operable Unit, OU01, located just north of the Town of Rico, Dolores County, Colorado. The Rico Tunnels Operable Unit, OU01, is defined in the UAO as the portion of the Site consisting of an adit known as the St. Louis Tunnel, and a series of settling ponds located down-gradient of the St. Louis Tunnel which eventually discharges into the Dolores River. The Site is located approximately 0.75 mile north of the northern boundary of the Town of Rico in Dolores County. This location is in the SW¼ of Section 24 and the NW¼ and SW¼ of Section 25, T40N, R11W, within the USGS

Rico 7.5-minute Topographic Quadrangle.

## A5.3 Site History and Background

A series of significant mining operations have taken place at the Rico-Argentine Mine Site since the early 1900s. The most recent mining activities ceased in 1976-77, while the Site was owned by the Rico-Argentine Mining Company. In 1980, the Anaconda Company (Anaconda) acquired Rico-Argentine Mining Company's surface and mineral properties in the Rico area. As part of the acquisition of Rico-Argentine Mining Company's surface and mineral properties in 1980, a pre-existing National Pollution Discharge Elimination System (NPDES) discharge permit (No. CO-0029793) was transferred to Anaconda. In 1983, water from the Blaine Mine on Silver Creek (outfall 002 under the original NPDES permit) was redirected to the St. Louis Tunnel and the Blaine Tunnel (or adit) became zero discharge. In 1984, Anaconda began operation of a new slaked-lime addition plant to treat mine water discharge from the St. Louis Tunnel as it entered the ponds system. Between 1984 and 1995, slaked lime was added to the tunnel discharge to improve water treatment and solids removal.

AR, a successor to Anaconda, sold its Rico properties to Rico Development Corporation in May 1988. The existing NPDES permit transferred to Rico Development Corporation at that time. Rico Development Corporation then sold/optioned its property holdings and the NPDES permit to others in April 1994. While owned by Rico Development Corporation, it is believed that borrow excavation over the portal area of the St. Louis Tunnel in approximately 1996 resulted in local collapse of the tunnel roof and walls. Around this time, use of the slaked lime system was discontinued and mechanical components were removed (the plant building is still present at the Site). The NPDES permit expired in 1999. In 2001, AR collected the dispersed surface flows from the tunnel portal collapse area into a common channel, diverted the flow through a Parshall flume, and rerouted the flow to Pond 18.

## A5.4 Regulatory Program

A UAO for Removal Action was issued by EPA Region 8, Docket No. CERCLA-08-2011-0005, with an effective date of March, 23, 2011, for the Rico-Argentine Mine Site. Item 32 in the UAO requires implementation of the Removal Action Work Plan (RAWP) issued by the EPA February 25, 2011. Task A in the Work Plan discusses ongoing monthly surface and groundwater sampling and is related to both objectives stated in the Work Plan:

- Reduce the releases of hazardous substances from the St. Louis Tunnel Adit (also referred to in this Work Plan as "adit") and settling ponds into the Dolores River
- Manage the discharge from the St. Louis Tunnel Adit to control and reduce the flow and/or reduce the metals concentrations to levels deemed protective of water quality and aquatic life in the Dolores River

In addition, a WQA issued by the Colorado Department of Public Health and Environment (CDPHE) in 2008, as updated at some point, is expected to be the basis for the water quality discharge permit for the water treatment system (CDPHE, 2008). AR provided input on the preliminary draft, followed by several years of additional watershed sampling, laboratory analysis, and data evaluation that were incorporated into the 2008 WQA. The additional water quality and flow data that is being collected will be utilized in updating the WQA and eventual development of discharge permit limits.

The UAO cites the existence of cadmium, copper, lead, silver, and zinc in the discharge from the adit and in the sediment of the settling ponds as the reason for the Site being considered an actual or potential hazard to human and animal populations and a potential contaminant to drinking water sources. All analytes and laboratory reporting limits for the monitoring program are presented in Table A5.4-1.

**Table A5.4-1: Sampling and Analytical Protocol Information**

| Analyte | Method | MDL | PQL/RL | Container Type | Chemical Preservation | Temperature Preservation | Holding Time |
|---|---|---|---|---|---|---|---|
| **Field Parameters** | | | | | | | |
| Dissolved Oxygen | SM 4500-OG | +/- 1.5% of reading | +/- 1.5% of reading | No Specified Container; Analyzed in Field | None | None | Analyzed Immediately after Collection in Field |
| pH | EPA 120.1 | +/- 0.02 pH units | +/- 0.02 pH units | | | | |
| Temperature (°C) | Standard Method 2550 | +/- 0.15°C | +/- 0.15°C | | | | |
| ORP (Oxidation-Reduction Potential) | Ag/AgCl Probe | +/- 1.0 mV | +/- 1.0 mV | | | | |
| Electrical Conductivity (µmhos/cm) | EPA 120.1 | +/- 1% of reading | +/- 1% of reading | | | | |
| **General Parameters** | | | | | | | |
| Alkalinity (mg/L as CaCO3) | SM 2320B | 1.2 mg/L | 20 mg/L | 500 mL HDPE Bottle | None | 0 - 4 °C | 14 days |
| Chloride | EPA 300.0 | 0.056 mg/L | 1.0 mg/L | 500 mL HDPE Bottle | None | | 28 days |
| Cyanide | EPA 335.4 | 0.005 mg/L | 0.005 mg/L | 250 mL HDPE Bottle | NaOH | | 14 days |
| Hardness | SM 2340 B | 0.5 mg/L | 0.5 mg/L | 250 mL HDPE Bottle | $HNO_3$ | | 6 months |
| Nitrate | EPA 353.2 | 0.022 mg/L | 0.1 mg/L | 250 mL Amber Glass Bottle | $H_2SO_4$ | | 28 days |
| Salinity | SM 2510B (calculated) | None (calculated) | 6 mg/L | 250 mL HDPE Bottle | None | | 28 days |
| Silica | EPA 200.8 | 0.027 mg/L | 0.054 mg/L | 250 mL HDPE Bottle | $HNO_3$ | | 6 months |
| Sulfate (mg/l as SO4) | EPA 300.0 | 1 mg/L | 1 mg/L | 250 mL HDPE Bottle | None | | 28 days |
| Sulfide | 4500-S-2 D | 0.018 mg/L | 0.05 mg/L | 250 mL HDPE Bottle | NaOH and Zn Acetate | | 7 days |
| Total Dissolved Solids (TDS) | SM 2540C | 5.0 mg/L | 5.0 mg/L | 500 mL HDPE Bottle | None | | 7 days |
| Total Organic Carbon (TOC) | SM 5310C | 0.072 mg/L | 0.5 mg/L | 250 mL Amber Glass Bottle | $H_2SO_4$ | | 28 days |
| Total Suspended Solids (TSS) | SM 2540D | 5.0 mg/L | 5.0 mg/L | 500 mL HDPE Bottle | None | | 7 days |
| **Total and Dissolved Metals** | | | | | | | |
| Aluminum (Al) | EPA 200.8 | 2.00 µg/L | 4 µg/L | Two 250 ml HDPE Bottles(One Bottle for Total Metals; One Bottle, Field-Filtered, for Dissolved Metals) | $HNO_3$ | 0 - 4 °C | Mercury: 28 days<br>All Others: 6 months |
| Antimony (Sb) | EPA 200.8 | 0.100 µg/L | 0.5 µg/L | | | | |
| Arsenic (As) | EPA 200.8 | 0.138 µg/L | 0.5 µg/L | | | | |
| Barium (Ba) | EPA 200.8 | 0.150 µg/L | 0.3 µg/L | | | | |
| Beryllium (Be) | EPA 200.8 | 0.092 µg/L | 0.2 µg/L | | | | |
| Cadmium (Cd) | EPA 200.8 | 0.028 µg/L | 0.08 µg/L | | | | |
| Calcium (Ca) | EPA 200.8 | 10.000 µg/L | 20 µg/L | | | | |
| Chromium (Cr) | EPA 200.8 | 0.094 µg/L | 0.5 ug/L | | | | |
| Cobalt (Co) | EPA 200.8 | 0.250 µg/L | 0.5 ug/L | | | | |
| Copper (Cu) | EPA 200.8 | 0.184 µg/L | 0.5 µg/L | | | | |
| Iron (Fe) | EPA 200.8 | 10.00 µg/L | 50 µg/L | | | | |
| Lead (Pb) | EPA 200.8 | 0.018 µg/L | 0.1 µg/L | | | | |

| Analyte | Method | MDL | PQL/RL | Container Type | Chemical Preservation | Temperature Preservation | Holding Time |
|---|---|---|---|---|---|---|---|
| Magnesium (Mg) | EPA 200.8 | 2.31 µg/L | 5 µg/L | | | | |
| Manganese (Mn) | EPA 200.8 | 0.250 µg/L | 0.5 µg/L | | | | |
| Mercury (Hg) | EPA 245.1 | 0.1 µg/L | 0.2 µg/L | | | | |
| Molybdenum (Mo) | EPA 200.8 | 0.069 µg/L | 0.5 ug/L | | | | |
| Nickel (Ni) | EPA 200.8 | 0.151 µg/L | 0.5 ug/L | | | | |
| Potassium (K) | EPA 200.8 | 5.24 µg/L | 20 µg/L | | | | |
| Selenium (Se) | EPA 200.8 | 0.094 µg/L | 0.5 ug/L | | | | |
| Silver (Ag) | EPA 200.8 | 0.040 µg/L | 0.5 ug/L | | | | |
| Sodium (Na) | EPA 200.8 | 10.40 µg/L | 50 µg/L | | | | |
| Thallium (Tl) | EPA 200.8 | 0.019 mg/L | 0.1 µg/L | | | | |
| Vanadium (V) | EPA 200.8 | 0.037 mg/L | 0.1 µg/L | | | | |
| Zinc (Zn) | EPA 200.8 | 1.00 µg/L | 5 µg/L | | | | |
| **Potentially Dissolved Metals** | | | | | | | |
| Aluminum (Al) | EPA 200.8 | 6.35 µg/L | 50 µg/L | 250 ml HDPE Bottle | $HNO_3$ | 0 - 4 °C | Mercury: 28 days<br>All Others: 6 months |
| Antimony (Sb) | EPA 200.8 | 0.03 µg/L | 1 µg/L | | | | |
| Arsenic (As) | EPA 200.8 | 0.05 µg/L | 1 µg/L | | | | |
| Barium (Ba) | EPA 200.8 | 0.08 µg/L | 1 µg/L | | | | |
| Beryllium (Be) | EPA 200.8 | 0.05 µg/L | 0.5 µg/L | | | | |
| Cadmium (Cd) | EPA 200.8 | 0.05 µg/L | 0.5 µg/L | | | | |
| Calcium (Ca) | EPA 200.7 | 10.35 µg/L | 100 µg/L | | | | |
| Chromium (Cr) | EPA 200.8 | 0.07 µg/L | 1 µg/L | | | | |
| Cobalt (Co) | EPA 200.8 | 0.08 µg/L | 1 µg/L | | | | |
| Copper (Cu) | EPA 200.8 | 0.12 µg/L | 1 µg/L | | | | |
| Iron (Fe) | EPA 200.8 | 2.95 µg/L | 50 µg/L | | | | |
| Lead (Pb) | EPA 200.8 | 0.03 µg/L | 1 µg/L | | | | |
| Magnesium (Mg) | EPA 200.7 | 6.48 µg/L | 50 µg/L | | | | |
| Manganese (Mn) | EPA 200.8 | 0.250 µg/L | 1 µg/L | | | | |
| Mercury (Hg) | EPA 245.1 | 0.053 µg/L | 1 µg/L | | | | |
| Molybdenum (Mo) | EPA 200.8 | 0.12 µg/L | 1 µg/L | | | | |
| Nickel (Ni) | EPA 200.8 | 0.07 µg/L | 1 µg/L | | | | |
| Potassium (K) | EPA 200.7 | 44.38 µg/L | 500 µg/L | | | | |
| Selenium (Se) | EPA 200.8 | 0.14 µg/L | 1 µg/L | | | | |
| Silver (Ag) | EPA 200.8 | 0.01 µg/L | 0.5 ug/L | | | | |
| Sodium (Na) | EPA 200.7 | 21.68 µg/L | 500 µg/L | | | | |
| Thallium (Tl) | EPA 200.8 | 0.02 µg/L | 1 µg/L | | | | |
| Vanadium (V) | EPA 200.8 | 0.11 µg/L | 1 ug/L | | | | |
| Zinc (Zn) | EPA 200.8 | 1.04 µg/L | 10 µg/L | | | | |

MDL= Method Detection Limit; PQL = Practical Quantitation Limit; RL = Reporting Limit; HDPE = High Density Polyethylene

# A6 Project/Task Description

## A6.1 Routine Monthly Monitoring

Routine monthly monitoring began at the Site in December 2010. Surface water and groundwater monitoring is conducted at the Site on a monthly basis to monitor water quality and water flow conditions. Sampling locations are shown on Figures 1, 2, and 3 of the SAP.

Field parameters are measured for surface water and groundwater samples. Instantaneous flow rates are measured for surface water samples, and static water levels are measured for groundwater samples. Water samples are also analyzed at an analytical laboratory for metals (total, dissolved, and potentially dissolved fractions) and non-metal inorganic parameters, as shown in Table A5.4-1. In addition, pressure transducers are installed in Parshall flumes to continuously monitor flow at two locations. Additional details about the sampling program can be found in the SAP.

The Rico Data Management Procedure and Timeline included in Appendix A details project data collection and data management and gives the applicable timeline for each task.

# A7 Quality Objectives and Criteria for Measurement Data

## A7.1 Project Data Quality Objectives

Project data quality objectives (DQOs) are used to ensure that environmental data are scientifically valid, defensible, and have an appropriate level of quality given the intended use for the data. The DQOs for this Site are:

- Monitor water quality (with a focus on metals) and flow rates of facility discharge into the Dolores River and of the Dolores River upstream, downstream, and adjacent to the Site to characterize water quality and evaluate effectiveness of St. Louis treatment/settling ponds
- Monitor water quality and water levels in groundwater wells throughout and adjacent to the Site to characterize water movement through the Site
- Monitor conditions throughout the year to assess seasonal variations and possible effects on discharge of contaminants, effectiveness of treatment ponds, etc.
- Ensure that the data collected is of sufficient quantity, quality, and content to accomplish the purposes listed above for all COC

QA objectives for project tasks should, if appropriate, include qualitative guidelines. To obtain high-quality data for the project, this QAPP establishes DQOs and data performance criteria. DQOs reflect the overall degree of data quality or uncertainty that the decision-maker is willing to accept during decision-making.

Data performance criteria discussed in this section quantitatively indicates or measures the data quality objectives.

The quantitative criteria used to evaluate data quality are presented in Table A7.1-1.

**Table A7.1-1: Sampling and Analytical Protocol Information**

| Parameter | Location | QC Program | Evaluation Criteria | QA/QC Goals |
|---|---|---|---|---|
| Precision | Field | Field Duplicate Pairs | Relative Percent Difference (RPD[1]) | RPDs will be ± 30% or results will be +/- the Reporting Limit (RL). |
| Precision | Lab | Lab Duplicate (or Spiked Duplicate) Pairs | Relative Percent Difference (RPD[1]) | RPDs will be ± 20% or results will be within +/- RL. |
| Accuracy | Field | Field Blanks<br>Equipment Blanks | MDL, PQL<br>MDL, PQL | <MDL<br><MDL |
| Accuracy | Lab | Initial Calibration and Calibration Verification Blanks (ICB/CVB) | MDL | <MDL (verified in case narrative) |
| | | Initial Calibration and Continuing Calibration Verification | Percent Recovery | Within method constraints (verified in case narrative). |
| | | Laboratory Control Sample (LCS) | LCS Percent Recovery[2] | Percent Recovery Limit for LCS is 80%-120% for metals; control-charted for general chemistry. |
| | | Matrix Spike / Matrix Spike Duplicate (MS/MSD) | Percent Recovery[3] and RPD | Percent Recovery Limit for MS/MSD is 75%-125% for metals; control-charted for general chemistry. The RPD limit for MS/MSD is ± 20%. |
| Representativeness | Field | Sampling Methods Described in Site Investigation Plan | Were sampling methods adhered to? | All samples collected by described methods. |
| | | Planned, Timely Sample Handling, Prep, and Analysis | Required Holding Times | All laboratory work performed within required holding times. |
| | | Field/Equipment Blanks | MDL, PQL | Results ≤ MDL |
| Comparability | Office | Proposed Consistent Units of Measurement | Are comparable units used in evaluations? | 100% of results reported in the same units. |
| Comparability | Lab | Proposed Analytical Methods | Were approved methods used? | 100% use of approved methods. |
| Comparability | Field | Standardized Sampling Methods | Proposed sampling methods adhered to? | 100% use of proposed (i.e., approved) methods. |
| | | QC samples<br>10% Field Duplicates<br>Field Blanks, 2 per sampling event<br>Lab QA | Were the samples collected as proposed? | Samples were collected as proposed. |
| Completeness | Office | Validation to be performed | Percent valid data | 90% valid data |

### A7.1.1 Choice of Decision Rules

The following paragraphs briefly describe DQOs for the project using the seven-step DQO process described in the USEPA document, “Guidance on Systematic Planning Using the Data Quality Objectives Process” (EPA QA/G-4) (USEPA, 2006b).

### A7.1.2 Data Quality Objectives (DQO) Process

**Step 1. State the Problem.** The problem statement is provided above in Section A5.1.

**Step 2. State the Decision.** State and/or Federal regulatory decisions and orders imposed for this Site are discussed above in Section A5.4.

**Step 3. Inputs to the Decision.** The State and/or Federal regulatory requirements are discussed above in Section A5.4

**Step 4. Define the Site Boundaries.** Site boundaries are presented in Figure 1, 2, and 3 in the SAP.

**Step 5. Decision Rules.** AR shall monitor and maintain the facility to comply with applicable regulatory requirements. All analytes and laboratory reporting limits for the monitoring program are presented in Table A5.4-1. Table A7.1-1 presents QA criteria for the compliance sampling laboratory methods. These criteria will be used to determine if compliance monitoring results meet the data quality objectives listed above.

**Step 6. Establish Decision Error Tolerance Levels.** Laboratory analytical detection limits will be established that meet the objectives of the program. The proposed methodology, reporting limits, and QC samples are adequate to ensure that false positives or negatives will not affect the project. The laboratory documentation will be sufficient to identify any analytical anomalies or outliers. Limited data validation will be used to minimize errors occurring from laboratory data. Project-specific QA objectives are described below in Sections A7.2.1 and A7.2.2.

**Step 7. Optimize the Design for Obtaining Data.** Regulatory oversight agency staff will have an opportunity to review monthly monitoring reports, the work plan, SAP, QAPP, and other applicable project documents, allowing appropriate stakeholders an opportunity to evaluate methods for optimizing the design of the compliance monitoring program.

## A7.2 DQO Discussion

### A7.2.1 Project-Specific QA Objectives

#### Detection Limits

The Method Detection Limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. MDLs are based on analysis of pristine sample matrices. Operationally, MDLs are determined according to protocols given in USEPA 40CFR, Part 136, Appendix B. The analytical laboratory is required to determine MDLs, at least annually, for each parameter required for this program.

The Practical Quantitation Limit (PQL) is the MDL modified to accommodate environmental matrices. PQLs are used as the reporting limit for environmental samples, and are generally three to five times the value of the MDL. Required laboratory PQLs (i.e., reporting limits) are presented in Table A5.4-1.

#### Completeness

Completeness is defined as the percentage of measurements made that are judged to be valid measurements. Overall data set completeness for analytical data will be evaluated during the data validation process. Completeness is defined by the equation below:

$$C\% = \frac{S}{R}(100\%)$$

Where:
*C* = completeness
*S* = number of valid analyses
*R* = number of requested analyses

The completeness goal is essentially the same for all data uses: that a sufficient amount of valid data is generated. It is important that critical samples are identified and plans made to achieve valid data from critical samples. The completeness goals established for both the field and laboratory components are 90 percent.

#### Decision Rule

The target analytes, analytical methods, and laboratory reporting limits for the Site work are presented in Table A5.4-1. Table A7.1-1 presents QA criteria for the laboratory methods. These criteria will be used to measure whether the objectives listed in Section A7.1 are met.

The analytical methods have all been selected such that the PQLs are lower than the applicable regulatory limit for each analyte.

#### Representativeness

Representativeness is the degree to which data accurately and precisely represent a characteristic population, a process control, or an environmental condition. Appropriate sampling procedures are implemented so that the samples are representative of the environmental matrices from which they were obtained. The sampling procedures are described in detail in the SAP and have been designed to ensure an appropriate level of representativeness in the data.

## Comparability

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared to another. Sample data should be comparable with other measurement data for similar samples and sample conditions. This goal is achieved using standard techniques to collect and analyze representative samples and the consistent reporting of analytical results in appropriate units. Comparability is limited by other parameters because the data sets can only be compared with confidence when precision and accuracy are known. For comparability, reporting limits for aqueous sample analyses must achieve the PQL for those samples not subject to dilution or affected by sample matrix. Comparability will be assessed as part of the water quality review conducted each month.

## A7.2.2 Analytical QA Objectives

The data from field samples collected will include laboratory analyses of surface and ground water samples. As part of the QA/QC process, data quality indicators including precision, accuracy and bias, representativeness, comparability, and completeness (PARCC) will be evaluated for both laboratory and field quality control samples. Refer to Table A7-2 for defined control limits applicable to this project.

## Precision

Precision is a measure of the mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. The overall precision of measurement data is a mixture of sampling and analytical factors. Precision is evaluated through field and laboratory duplicate samples. Overall data set precision for analytical data will be evaluated during the data validation process. The precision of analytical data can be evaluated by calculating the relative percent difference (RPD) between duplicate samples. The RPD is calculated using the equation below:

$$RPD = \frac{|C_1 - C_2|}{0.5*(C_1 + C_2)}*100$$

Where:
$C_1$ = the first sample value and
$C_2$ = the duplicate sample value

Laboratory precision will be evaluated through analysis of laboratory duplicates, laboratory control sample duplicates (LCSDs), and/or matrix spike duplicates (MSDs). Laboratory precision should be determined by matrix for each QC batch or for every 20 samples (5 percent), unless an increased frequency is stipulated in laboratory SOPs for individual methods. In general, RPDs of less than 20 percent for laboratory duplicate samples of an aqueous matrix indicate the data are of high precision.

Sampling precision for this program will be evaluated by analysis of field duplicate (DUP) samples from a given location. Field duplicate samples will be collected for analysis at a rate of one sample in 10 (10 percent), or at a minimum of one per sampling event. Field duplicate samples will be analyzed for the same list of analytical parameters as the primary sample. In general, RPDs of less than 30 percent for field duplicate samples of an aqueous matrix indicate the data are of high precision.

Overall data set precision for analytical data will be evaluated during the data validation process.

## Accuracy

Accuracy quantifies the degree of agreement of a measurement with a reference or true value. The accuracy can be evaluated by calculating the percent recovery (%R) of spiked samples.

The %R is calculated using the equation below:

$$\%R = \frac{(C_1 - C_0)}{C_2} \times 100$$

Where:
$C_1$ = the observed concentration of the spiked sample
$C_0$ = the concentration of the unspiked sample
$C_2$ = the theoretical concentration of the spiked sample

Laboratory accuracy for analytical methods will be assessed by spiking samples with known standards and measuring the percent recovery of the spiked analyte. Percent recoveries indicate the actual performance of the analytical method on real world samples. Known standards include matrix spikes (MSs) and laboratory control samples (LCSs). Matrix spikes and LCSs will be submitted for each QC batch or for every 20 samples (5 percent). Control limits for accuracy measurements are listed in Table A7.1-1.

Sampling accuracy will also be assessed by evaluating the results of equipment blanks and field blanks. Samples collected for analysis will be collected in disposable containers. Samples will be accompanied by an equipment blank if decontamination of reusable sampling equipment is practiced (i.e., using a pump to collect filtered samples). Equipment blanks check the adequacy of the decontamination procedures used at the Site. These samples would receive identification numbers similar to actual samples and will be submitted as normal field samples. Blanks will consist of distilled water poured over, or run through, the sampling equipment and collected in a clean sample container, after the equipment has been decontaminated. One equipment blank would be prepared and submitted for the same suite of requested analyses as are applicable for the other samples for each sampling event.

Field blank samples are collected in the field by running distilled water through the same sampling procedure used for all other samples. Field blanks serve to check the following of proper sampling procedures in the field to find out if contamination is being introduced as a result of the procedure. One field blank is collected for each sampling event.

Overall data set accuracy for analytical data will be evaluated during the data validation process.

## A8 Special Training Requirements and Certifications

It is the responsibility of each employer to provide their employees with the required training (e.g., 40-hour OSHA training) and medical monitoring before assigning them to work at the Site. Site-specific training requirements are presented in the Site-Specific Health and Safety Plan (SSHASP). Each employer will provide documentation of current 40-hour OSHA training, medical monitoring, and fit testing to the HSEE Officer before sending their employees to the Site to work. Additionally, personnel will sign the Training Certification Sign-off Sheet (provided as Appendix B) to acknowledge the requirements of this QAPP prior to Site work.

### A8.1 Personnel Training

All Contractors are responsible for providing qualified personnel to perform Site work to ensure compliance with the technical documents. Each individual following requisite training is responsible for the quality of his/her work.

Personnel performing field work will be required to be appropriately trained according to 29 CFR 1910.120. Field personnel will also receive a project-specific review based on anticipated Site responsibilities.

Field sampling and oversight personnel will be trained to the following documents:

- All applicable SOPs
- QAPP
- SAP
- Task Safety Environmental Analysis Risk Assessment (TSEA)

This training will be performed upon start of service by Contractor and personnel. They will be required to be re-trained on an annual basis to the above listed plans and procedures.

A person experienced with field sampling will be assigned to mentor each project person assigned to a field sampling task. The mentor will work with each person until the mentor feels their experience is adequate enough to perform sampling tasks on their own, without direct supervision. At that time, the sample person will complete their in-field training and the mentor will verify their experience, by signing the training form, provided as Appendix B.

An annual update review of all training will be required at the start of each sampling year and with each plan update, with updates to include review of procedures, plan changes, SOPs, and SAPs. The annual update will not require mentor training, only classroom and documented review of the project plans and documents. All training records will be maintained at the project Site for the annual period to which it pertains. All training records will be permanently kept with AECI at their corporate offices in Salt Lake City, Utah, with electronic copies provided to AR as part of annual project closeout.

The QAPP Training Certification Sign-Off Sheet is located in Appendix B.

# A9 Documentation and Records

Project documents will consist primarily of the following: correspondence, deliverables or reports, records (i.e., information used to build documents), and QA/QC documents.

## A9.1 Field Documentation Requirements

The following documents will be generated in completion of all field sampling/measuring/recording actions:

- Field Logbook
- Field Water Sampling Form
- Chain of Custody (COC) Forms
- Calibration Data Sheet
- Daily Field Report

All field documentation generated should follow basic document etiquette, which includes the following techniques:

- All handwritten forms should be legible, correct, and complete.
- Complete handwritten forms using blue or black ink, or indelible marker.
- Write clearly; print if necessary.
- Do not use a highlighter to emphasize important text; underline such text.
- Ensure all forms/records are complete. Do not leave blank spaces; if a section is not applicable, identify it as N/A. All forms or records should be signed and dated.

Corrections/amendments to document information or handwritten entries shall be made as follows:

- Draw one line through the item to be corrected; do NOT use correction fluid/tape.
- Write the correction adjacent to the item.
- Initial and date the correction/amendment next to the correction.

### A9.1.1 Field Documentation Reports and Submittals

The QC and sample technicians will perform applicable inspections as follows:

- Conducting required inspections and records as defined in the Rico Data Management Procedure and Timeline (Appendix A)
- Documenting inspections and test records as defined by applicable SOPs
- Providing internal input to improve quality of work performed (e.g., Field Action Items and Quality Observations)
- Informing project team of all items that, if left uncorrected, would adversely affect the quality of the project
- Stopping work that does not meet quality requirements in project plans, specifications, and contract documents
- Preparing daily reports that identify QA/QC requirements
- Performing routine QC checks of work activities

The following quality inspection and test records will include the following:

- **Daily Field Report –** Detailing QC activities performed for a particular monitoring/sampling activity
- **Field Water Sampling Form –** Depicting monitoring and sampling identification and results for each sampling location
- **Chain of Custody Record –** Documenting custody procedures for each set of samples collected
- **Applicable Field Notes and Photographs –** Depicting each sample or monitoring location

**Field Documentation Records Management and Retention**

All data, reports, and related products generated during field collection of data will be stored in project files maintained by AECI at the project Site. These files will be transferred to AR at the completion of each sampling year. AR will store project data at the Atlantic Richfield office in Butte, Montana. The files will also include original laboratory reports and relevant historical information which has contributed to project decision-making. Readily available public information used during the course of the project may not be included in the project files. An extra set of field data, reports, and related products generated during this project will also be stored on CD media and on backup computer servers at AECI's office in Salt Lake City, Utah.

## A9.2 Analytical Laboratory Documentation Requirements

The laboratory is entrusted to follow all internal quality control procedures (i.e., calibrations, performance checks) as directed in the analytical methods requested. The laboratory is also required to store complete data reports and raw data documentation as required by contract, State, or Federal protocols. Laboratory deliverables for the inorganic and general chemistry methods requested must include:

- Case narrative – include discussion of sample custody, sample condition, and analytical anomalies, and general assessment of internal laboratory QC (calibration, performance check) compliance
- Sample results – include method reference, MDLs, PQLs, units, dilution factors
- Method blank results – include MDLs, PQLs, units
- Laboratory Control Sample (LCS) recoveries
- Matrix Spike (MS) recoveries (reference source sample ID)
- Laboratory Duplicate or Laboratory/Matrix Spiked Duplicate (LCSD or MSD) results
- Laboratory control-charted or referenced QC limits for spikes, duplicates (%Rs, RPDs)
- Batch reference and dates of project and QC sample preparation and analysis, including dilutions
- Signed and dated COC records – include sample receipt temperature
- EQuIS format EDDs of project sample and QC sample results

The laboratory report and EQuIS format EDDs will be provided by the laboratory to AECI. AECI will review the laboratory report and EDDs for completeness. If either deliverable is incomplete, the laboratory will be asked to correct the problem and re-submit the deliverable. When the package is judged by AECI to be complete, the EQuIS-format EDD will be provided to AECOM for additional review and upload to the project EQuIS database. The laboratory report will be included as an attachment to the monthly report that is posted on the project SharePoint site.

## A9.3 Analytical Data Validation Reports

The DVM will review 100 percent of analytical data and provide limited validation of the data presented in the final reports submitted by the analytical laboratory. These reports will include:

- Identification of the laboratory reports and tabulated project samples being evaluated
- Overall data assessments of field and laboratory precision, accuracy, completeness, and laboratory method compliance
- Review of project sample data and field and analytical QC samples to method and QAPP requirements
- Tabulated summary of any qualified data results

## A9.4 Reports to Management

Reports to management will include:

- Monthly Surface and Groundwater Data Summary Report (AECI, with review by AECOM)
- Completed Limited Data Validation Reports (AECOM)

## A9.5 Document Control and Archival

All data, reports, and related products generated during this project will be stored in project files maintained at the AR office in La Palma, California. The files will also include original laboratory reports and relevant historical information which has contributed to project decision-making. Readily available public information used during the course of the project may not be included in the project files. An extra set of field data, reports, and related products generated during this project will also be stored on CD media and on backup computer servers at AECI's office in Salt Lake City, Utah.

Data will be electronically managed using the project EQuIS database. Data are transferred in spreadsheet format as required between AR, AECI, AECOM, and EPA using email or the project SharePoint site. After project closure, all data, files, and other materials to be permanently filed will be inventoried. The files will be maintained by AR in accordance with the requirements of the UAO.

The EQuIS database is maintained by AECOM and is backed up according to AECOM's database management protocols. Electronic backup of other related project documents generated by AECOM or AECI will be performed in accordance with the respective organization's information technology department's electronic file backup protocols.

## A9.6 QAPP Updates and Distribution

The QAPP will be maintained and updated as needed by the QAM. When updated, the QAPP will be distributed to the list identified in Section A3. The QAPP will be distributed via email and will also be posted on the project SharePoint site. Hard copies of the document will not be distributed unless requested.

# Group B: Data Generation and Acquisition

## B1 Sampling Process Design

The sample process was defined during the scoping meeting and subsequent investigation phases of the project that were a result of the UAO. The process includes a multi-type approach to include surface water sites, groundwater wells, flow, and elevation measurements within the non-stagnant water sources and including flumes, rivers, and adits located within the property and as identified by the maps provided with the various SAPs. In addition, this plan will be used to implement quality for all soil and other sampling activities performed at the project. A SAP will be developed for each project and will include the specifics for each sampling program.

Analytical sampling will provide water quality data points, including trace metals and other compounds of concern, in order to evaluate various strategies for addressing the items identified in the UAO. Each project-specific SAP will detail the purpose for the analytical sampling and the process by which the sampling will be completed.

The information that is critical to the success of these sampling programs will also be defined in the specific SAPs for each sampling project. The information that will be collected for background or information only will also be identified (as noted, for example, on Table 2-1 of the Sampling and Analysis Plan for Surface and Groundwater Sampling).

Each SAP will also identify the various pitfalls and sources of variability based upon sample collection methods. Each sample collection method will further discuss how sources of variability will be reconciled and minimized on the project. This information is as presented, for example, in Section 6.0 of the Sampling and Analysis Plan for Surface and Groundwater Sampling.

Analytical sampling will provide water quality data points, including trace metals, in order to prepare and evaluate the Water Quality Assessment for the CDPHE. The purpose of the sampling program is to collect data designed to meet the DQOs defined in Section A7.

## B2 Sampling Method Requirements

### B2.1 Sampling Procedures and Requirements

All sample procedures and requirements are defined in the various Sample and Analysis Plans that have been prepared for the various sampling tasks associated with this project. Each SAP has associated Standard Operating Procedures that define the sample and analysis tasks. The SOPs are typically included as appendices to the SAPs which they support, and include the following:

**Table B2.1-1: Water Sampling Activities Standard Operating Procedures**

| SOP No. | Revision | Date | Matrix | Description | Regulatory Citation | Modifications |
|---|---|---|---|---|---|---|
| 1-6 | 0 | 2007 | GW, SW | Sample Custody and Documentation | Method 1669 | None |
| 1-11 | 0 | 2007 | GW, SW | Packaging and Shipment of Field Samples | Method 1669 | None |
| 2-9 | 0 | 2008 | GW, SW | Field Water Quality Measurement | None | None |
| 3-1 | 0 | 2001 | SW | Surface Water and Sediment Sampling | Method 1669 | None |
| 3-4 | 0 | 2002 | SW | Streamflow Measurement | Method 1669 | None |
| 3-7 | 0 | 2012 | SW | Streamflow Measurement with Ice Present | | None |
| 3-8 | 0 | 2013 | SW | Collection of Cross Channel Surface Water Samples | Method 1669 | None |
| 4-1 | 0 | 2007 | GW | Groundwater Sampling | Method 1669 | None |
| 4-9 | 0 | 2008 | GW | Well Purging | Method 1669 | None |
| E1669 | 0 | 1996 | GW | Sampling Ambient Water for Trace Metals | Method 1669 | None |

## B2.2 Sample Collection Procedures

The sample collection process is as defined by AECI SOP No 3-1, 4-1, and 3-8. It is further guided by EPA Standard Procedure 1669. Both practices are included as Appendices in the SAP. All lead field personnel will be trained and certified as proficient on the applicable procedures prior to performing any field task, as indicated in Section A8 above.

## B2.3 Sample Containers, Volume, and Preservation

The sample containers are provided by the analytical laboratory. They are ordered via a sample order form in advance of the sampling event. Upon receiving the order, the laboratory packages clean sample bottles (including the necessary preservative) and sends them to AECI Rico field office.

The applicable containers (volume, size, and quantity, with the necessary preservative for each analysis) are defined further in Table A5.4-1 above.

## B2.4 Equipment/Sample Containers, Cleaning, and Decontamination

As defined by the SAP, all groundwater sampling is conducted using a dedicated bailer assigned to each well location. The collected water is then transferred to a clean disposable gallon jug and transferred to the lab building where the samples are placed into the analytical containers, logged, and packaged for shipment.

All surface water samples are collected directly into a clean, disposable plastic gallon jug.

All sample packaging and handling is delivered back to the lab building where samples are transferred to the sample containers, final water quality readings collected, and filtration of field-filtered metal samples.

## B2.5 Corrective Actions

Corrective actions are discussed in section C1.3 in this QAPP.

All quality-related items that are identified during sample and field data collection will be reported using a Quality Observation Form. The observations can be identified by any project personnel and will be completed and reviewed at the start of the next project shift during the Daily Toolbox Meeting. The purpose of the Quality Observations is to assist the project with maintenance of the quality objectives.

The Quality Observation Forms will be recorded and, if necessary, tracked until a reported item is closed. It is assumed that most Quality Observations are minor in nature and can be resolved relatively easily at the time of their identification with the field personnel involved.

If a Quality Observation is found to be in violation of project requirements, or if an observation item is not addressed in a timely manner, causing a violation of project requirements, a non-conformance report will be generated detailing the violation and the proposed corrective action for resolution of the violation. All nonconformances will be tracked from the time at which they are issued until they are resolved to the satisfaction of the QAM and PM.

All items identified during field operations will be tracked until resolution and shared with all personnel on the project team.

# B3 Sample Handling and Custody

COC procedures are intended to document sample possession from the time of collection to acceptance by the analytical laboratory.

## B3.1 Sample Collection

Sample collection will be performed according to methods described in the SAP. Sample size, containers, and preservatives to be used are also described Table A5.4-1. For samples with lower concentrations expected, ultra clean procedures will be followed per EPA Method 1669.

## B3.2 Sample Handling

See applicable SAP documents for details on sampling handling.

## B3.3 Sample Delivery

The samples will be delivered to the analytical laboratory via external courier as described in applicable Sample and Analysis Plans for the activity being sampled.

## B3.4 Sample Custody and Documentation

Each individual SAP details sample custody and documentation, including a sample of a chain of custody form. Please refer to each individual SAP for this information.

## B3.5 Sample Collection, Transport, and Custody Documentation

A copy of all field forms to be utilized as part of the sampling tasks for this project, including the Field Sampling Form and Chain of Custody Form, are included as Appendices F and G of the SAP.

# B4 Analytical Methods Requirements

## B4.1 Analytical Methods

Pace Analytical will perform the laboratory analyses for the surface water and groundwater samples that will be collected at the Site. EPA-approved methods will be used in the analysis of the samples collected. Case narratives will be provided with each analytical data package and will discuss details of failures and/or exceptions in maintaining method performance, or other, requirements. Corrective action (e. g., re-analysis or re-calibration) may be required in incidents of unacceptable precision, recovery, instrument calibration, etc. The specific analytical parameters to be tested for this project are presented in Table A5.4-1. Furthermore, Section C1.3 outlines the procedures to follow when failures occur, identifies the person(s) responsible, and defines the appropriate documentation for the corrective action.

Field SOPs related to sample collection are found in the applicable SAP. Refer to the appropriate SAP for a list of and copies of each SOP.

Laboratory SOPs related to sample preparation, analysis, and reporting are provided as reference with this QAPP. The applicable SOPs are as follows:

**Table B4-1: Applicable Laboratory Standard Operating Procedures**

| SOP No. | Revision | Date | Description | Regulatory Citation | Modifications |
|---|---|---|---|---|---|
| S-KS-M-006 | 9 | 12-26-12 | Sample Preparation and Analysis for Mercury | EPA Method 245.1/7470A/7471A/7471B | Not clarified |
| S-KS-M-009 | 3 | 2-4-2013 | Determination of Metals by ICPMS | SW-846/6020A/ EPA 200.8 | Not clarified |
| S-KS-I-050 | 0 | 1-11-2013 | Automated Alkalinity | 2320B | Not clarified |
| S-KS-M-005 | 13 | 2-12-2013 | Determination of Metals by Inductively Coupled Plasma-Atomic Emission Spectrometry | EPA 200.7 / 6010B | Not clarified |
| S-KS-I-043 | 8 | 6-29-2012 | Determination of Inorganic Anions by Ion Chromatography | EPA 300.0, Rev. 2.1, August 1993<br>SW-846, Method 9056A | Not clarified |
| S-KS-I-047 | 1 | 6-29-2012 | Sulfide by Methylene Blue Method | Standard Method 4520-S2-D | Not clarified |
| S-KS-I-039 | 11 | 10-17-2012 | Nitrate-Nitrate by Automated Colorimetry | EPA 353.2 | Not clarified |
| S-KS-I-022 | 11 | 12-14-2012 | Total Suspended Solids | 2540D | Not clarified |
| S-KS-I-036 | 8 | 2-4-2012 | Total, Amenable, and Weak Acid Dissociable Cyanide | 4500-CN E/G | Not clarified |
| S-KS-I-016 | 11 | 3-22-2013 | Total Organic Carbon | Methods 5310C/9060A | Not clarified |
| S-MN-I-338 | 11 | 5-11-2012 | Hardness by Calculation | Method 2340 B | Not clarified |
| S-GB-I-063 | 2 | 9-28-2012 | The Determination of Total Organic Carbon Using the Teledyne Tekmar Fusion | SM 5310C, SW 846 9060A | Not clarified |

| SOP No. | Revision | Date | Description | Regulatory Citation | Modifications |
|---|---|---|---|---|---|
| S-MN-I-359 | 18 | 3-4-2013 | Mercury in Liquid and Solid/Semi-Solid Waste | Method SW-846 7470A/7471/7471B and 245.1 | Not clarified |
| S-MT-I-007 | 4 | 9-25-2012 | Specific Conductivity and Salinity of Aqueous Samples | SM 2510B, SM2520B, ASA 10.3-3 | Not clarified |

## B4.2 Analytical Turnaround Time

The standard turnaround time for Pace Analytical to complete the analysis and reporting requirements is four weeks (28 calendar days) from the time the laboratory receives the samples (see Rico Data Management Procedure and Timeline in Appendix A). In the event a shorter turnaround time is needed, the STL will coordinate with the laboratory project manager to ensure the request is processed accordingly.

## B4.3 Independent Validation of the Analytical Methods

Data validation will be performed on final laboratory analytical data to ensure analytical data meet the DQOs defined in Section A7.2. Data validation is described in Section D1.3.

# B5 Quality Control Requirements

General programmatic requirements for internal QC of laboratory data are established in the SOPs and the EPA-approved methods proposed for analyses. Laboratory-specific SOPs relative to this QAPP are provided separately with the Laboratory Quality Manual (LQM)

## B5.1 Field Quality Control Checks

All field measurements and sampling are performed as specified in the SAP. In addition, measuring and test equipment used during environmental data collection activities will be subject to calibration requirements, as described in Section B6 of the QAPP.

## B5.2 Analytical Laboratory Internal Quality Control

Internal QC procedures are designed to assure the consistency and continuity of data. Internal QC procedures are routinely carried out to assess the accuracy of the data generated, and are documented at the laboratory according to the laboratory QA Manual. Some of the internal QC procedures are as follows:

- Instrument performance checks
- Instrument calibration
- Documentation on the traceability of instrument standards, samples, and data
- Documentation on analytical methodology and QC methodology, including spiked samples, duplicate samples, and split sample use of reference blanks, and checking standards for method accuracy and precision
- Documentation on sample preservation and transport

A routine QA protocol is an essential part of the analytical process. See the Quality System Audits and Review of the Pace Analytical Laboratory Quality Manual (LQM) for a complete discussion of internal QA/QC procedures. The minimum requirements for each analytical run are discussed in the remainder of this section.

### B5.2.1 Initial Calibration and Calibration Verification

Standard calibration curves are composed of a minimum of three to five standards, based upon the method. Typically a second source verification is performed using an Initial Calibration Verification (ICV) immediately after initial calibration. Requirements for initial and continuing calibration are specified in the applicable laboratory SOPs provided with the LQM and listed in Section B.4.1 above. Confirmation of acceptable calibration will be documented in the case narrative comments of the final laboratory reports.

## B5.3 Analytical Quality Control Samples

Generally, quality control in the laboratory is guided by the laboratory-specific Quality Assurance Plan (QAP). Specifically, method blanks, laboratory control standards, matrix spikes, and laboratory duplicates are used, along with data review and documentation, to accomplish QA/QC objectives. In addition, the selected laboratory will use QA/QC procedures routinely used at the laboratory to maintain State of Colorado certification and will use analytical methods and method-specific QA/QC control as described in SW-846.

### B5.3.1 Method Blank Analysis

The method blank is utilized to rule out contamination by reagent or method preparation. The blank is analyzed once with every batch of samples or type of matrix or 20 samples, whichever is more frequent.

### B5.3.2 Matrix Spike and Duplicate Samples

The spike sample analysis provides information about the effect of the sample matrix on the analytical methodology. The percent recovery of the spike is calculated and compared to the criteria given in Table A7.1-1. The relative percent difference of the duplicate spikes or sample duplicates are calculated and compared to the precision criteria given in Table A7.1-1. The formulas for calculating accuracy and precision can be found in Section A7.2. At least one matrix spike sample, and once duplicate sample analysis or one MSD is performed for each batch of samples or every 20 samples, whichever is more frequent.

### B5.3.3 Laboratory Control Samples

The LCS can be purchased from an outside vendor or prepared in the laboratory. The LCS is analyzed with every batch of samples, or after every 20 sample analyses, whichever is more frequent. Results must be within the acceptable range provided by the manufacturer or within control limits established by the laboratory SOPs as presented in Table A7.1-1. A discussion of control limits and formulas for calculating accuracy and precision were presented in Section A7.

# B6 Instrument/Equipment Testing, Inspection, and Maintenance

Periodic preventative maintenance of equipment is required. Instrument manuals are kept on file for reference if equipment needs repair. Troubleshooting sections of manuals are often useful in assisting personnel in performing maintenance tasks. Appropriate and sufficient replacement parts or backup equipment are available so that sampling and monitoring are not substantially impeded or delayed.

## B6.1 Field Instrument Preventative Maintenance

Depending on the media involved and the intended purpose, a wide variety of equipment is available for field sampling and field sampling support activities. Because of the reliance placed on such equipment, all sampling and sampling support equipment, whether electronic, mechanical, chemical, or otherwise, are maintained at a proper functional level, as dictated by the equipment manufacturers' recommendations.

Field sampling equipment is maintained to manufacturer's specifications and in operational condition. Equipment requiring routine maintenance includes water level probes, ultrasonic meters, pumps and tubing, bailers, turbidity meters, and multi-parameter water quality meters (used to measure pH, conductivity, oxidation-reduction potential [ORP], temperature and dissolved oxygen [DO]). Routine preventative maintenance, as well as per-use inspections and checkout, is conducted to assure proper operation of the various pieces of equipment. The objective of the preventative maintenance program for field sampling and field sampling support equipment is to avoid generating erroneous environmental measurements. Preventative maintenance also helps decrease the possibility of equipment failure and delays in scheduled activities.

Each piece of equipment used in activities affecting data quality is maintained according to specifications presented by the manufacturer. The STL has access to tools and spare parts to conduct routine maintenance. A backup instrument is always available during sampling events to account for deficiencies noted or equipment that may not function properly during use. If the equipment or instrument cannot be maintained to manufacturer's specifications or cannot be properly calibrated, it is returned to the manufacturer or other repair facility for proper maintenance and repair. Before being reinstated, the instrument is checked for compliance to project specifications. The maintenance records for field equipment are kept in the same notebook as the calibration data.

Support equipment includes safety devices, storage and transportation containers, wind indicators, cameras, and vehicles that may be required for completing an environmental monitoring or measurement task. Support equipment required to maintain the safety of the project work force is identified in the SSHASP.

## B6.2 Laboratory Instrument Preventative Maintenance

For a complete discussion of preventive maintenance in the laboratory, see Section 6.0 of the Pace Analytical LQM.

# B7 Instrument Calibration and Frequency

This section establishes the procedures for maintaining the accuracy of the field instruments and laboratory equipment used during the project. The responsibility for the calibration of laboratory equipment lies with the analyst. The STL is responsible for the calibration of field equipment.

## B7.1 Field Equipment Calibration, Maintenance, Testing, and Inspection Procedures

Field equipment related to the collection of analytical data will include a thermometer, pH meter, electric conductivity meter, DO meter, and an ORP meter (or a multimeter capable of performing these functions), and decontamination equipment. The equipment will be inspected before each use. Equipment found in disrepair will be repaired according to manufacturer’s guidance or replaced. Equipment decontamination will be performed as described in the SAP.

The water quality meter will be calibrated checked before each use, at a minimum, using standards (pH buffers) recommended by the manufacturer. Acceptable precision for instrument calibration is specified in the user’s manual. Recalibration will be repeated until acceptable calibration is achieved or equipment will be replaced as necessary.

The conductivity meter will be calibrated before each use, at a minimum, using a standard solution recommended by the manufacturer. Proper calibration is considered to be achieved when within 10 percent of the standard concentration. If proper calibration is not achieved, recalibration will be repeated and equipment adjusted/replaced as necessary.

All individual meters and multi-meters will be field-checked for proper calibration before each use. According to the manufacturer's recommendation, daily full calibration is not required on these instruments and leads to an early breakdown in accuracy of the instrument, causing more frequent calibration cycles. If equipment is found to be out of calibration, an evaluation will be made and documented to determine the validity of previous measurements and/or corrective action will be implemented.

## B7.2 Analytical Instrument Calibration, Maintenance, Testing, and Inspection Procedures

Laboratory equipment calibration requirements are specified in the applicable laboratory SOPs and LQM. Inspection and maintenance of laboratory equipment is performed according to the QAP. The laboratory's QAP and any applicable method-specific requirements will guide the QA/QC aspects related to laboratory supplies and consumables.

## B7.3 Preparation of Standards for use with Laboratory Analytical Instruments

The laboratory calibration solutions and standards are further defined in the LQM, Section 6.0.

# B8 Requirements for Supplies and Consumables

## B8.1 Sampling Supply Inspection and Acceptance Procedures

Field supplies and consumables will include calibration fluids, decontamination fluids, water for equipment blanks, disposable gallon containers for initial sample collection, and plastic bags or sheets to keep decontaminated equipment clean before use. Materials that are visibly contaminated will not be used and will be replaced. If contaminated materials are identified, suppliers and/or handling procedures will be re-evaluated as appropriate. At a minimum, distilled water will be used for the preparation of equipment blanks. Purer grades of water may be selected for this purpose. If measurable concentrations of the metals of concern are reported in an equipment blank, the water will be tested, and replaced and the source re-evaluated, as appropriate. The analytical results of the water supply will then be evaluated, and any effect on the integrity of the surface water sample results assessed.

The supplies and consumables used in the field and in the laboratory will be inspected for usability and quality upon receipt. Prior to commencement of the sampling activities, the STL will confirm that all equipment, supplies, and consumables are functional and free of contamination. Materials not meeting acceptance criteria will be returned, replaced, or discarded, as appropriate.

In addition, the STL will track and store all equipment, supplies, and consumables appropriately. If needed, additional items will be replenished or replaced.

# B9 Use of Existing Data (Non-Direct Measurements)

## B9.1 Secondary Data Sources

Monitoring of surface water flow and quality at and in the vicinity of the Rico-Argentine Mine Site has occurred at varying locations and frequencies since 1978. A more regular program of surface water sampling and analysis was implemented in 1999, followed by adoption of a formal, regulatory SAP in 2003. A total of 21 sampling events were conducted from 2001 through 2006 by AR, ranging from a minimum of two to a maximum of eight events per year. The CDPHE conducted groundwater sampling and analysis in 2002 and 2003. AR conducted groundwater monitoring from 2004 to 2007. Data collected prior to December 2010 is referred to as "historical" data and is used as a secondary data source to help guide, develop, and evaluate current sampling operations at the Rico-Argentine Mine Site.

## B9.2 Intended Use of Secondary Data

Currently, historical data can be accessed by internal project team members only. These data are accompanied by variable amounts of documentation describing field and laboratory methods used to collect and analyze the samples. Where such methods are documented, these data are being used to evaluate long-term analytical trends at specific sample locations. In addition, current data is being compared to these trends with consideration of different sampling and analysis methods.

At a future date, secondary data will be made available to all data users and will include qualifiers to inform the user of any uncertainty or anomalous values. Although the quality of the data is thought to be generally good, QA/QC procedures applied to the data are largely unknown, limiting the applicability of these data for regulatory purposes. Any historical data that is distributed will include necessary disclaimers as to their intended and/or recommended use.

## B9.3 Acceptance Criteria

Data consistency will be verified using the current data to flag any anomalous historical results based on a range of expected values. This range will be defined based on statistical analyses performed by AECOM staff with the necessary expertise. Inconsistent data will be qualified appropriately and maintained in the database.

## B9.4 Management of Secondary Data

The secondary data is stored in the project EQuIS database, which is described in more detail in Section B10.1. Future web-based mapping and database tools are planned to make data accessible for a broader project team.

## B9.5 Validity and Applicability of Secondary Data

AECOM staff specializing in statistical analyses and geochemical analysis will be tasked with developing appropriate qualifiers. Users will determine the appropriateness of the data for their purposes based on the qualifiers provided. It is unknown whether the secondary data conforms to the QA/QC procedures defined within this document, and thus is not intended for use in the development of any permit or regulatory criteria.

# B10 Data Management

Data management functions are essential in maintaining project data in a consistent and reliable repository so that it can be used to support project decisions and the DQOs. It is imperative that these functions are performed accurately and that accepted statistical techniques are employed to evaluate the quality and usability of the data. The following sections discuss data reduction, data validation, data reporting, and data management.

## B10.1 Project Database

A relational database management system, EQuIS, will be used to store project data. The database will house water quality data (field parameters and laboratory results) as well as water level data and flow data. Both instantaneous and hourly flow data will be stored in the database.

In addition, the database will store location information for the sample locations. Horizontal coordinates will be expressed in Colorado State Plane coordinates, NAD83 datum, Zone 12, in units of U.S. Survey feet. Elevations, including monitoring well reference point elevations, will be measured relative to the NAVD88 vertical datum, in units of U.S. Survey feet.

Data collected under the current sampling program will be clearly separated from what is considered

"historic" project data (data collected prior to December 2010 under previous sampling programs). Additional types of data may be added to the project database in the future if deemed necessary. The database is managed by AECOM and is currently only available directly to AECOM staff (although exports from the database can be provided). Future plans include web-based access to the project database.

The project database will be protected to prevent unauthorized use and access using standard IT and database management protocols. Database permission levels will be established so that only authorized users will be able to view the contents of the database. Database modifications will only be made by authorized users.

## B10.2 Data Life-Cycle

### B10.2.1 Field Data

Field monitoring information from sampling activities will be transferred by AECI from field sampling forms to a spreadsheet in a format suitable for inclusion in the monthly report. Data entry will be checked for accuracy before the report is sent to AECOM. The AECOM Data Manager will transfer the data electronically from the spreadsheets to the EQuIS database. Data to be transferred in this manner includes field parameters, water levels for monitoring wells, and instantaneous flow rates. Data are reviewed as described in section D1.1.

Continuous depth data will be downloaded from the data loggers by AECI, processed into hourly flow data using the procedures outlined in the SAP, and reviewed for quality and consistency. After review, the hourly flow data and the raw depth data will be transmitted to AECOM in spreadsheet format. This transmittal will occur along with transmittal of the monthly report. AECOM will perform a technical review the flow data to determine if the results conform to the expected range of values and then upload the data to the EQuIS database.

### B10.2.2 Laboratory Data

Laboratory analytical results will be uploaded directly from the EDDs provided by the laboratory. Electronic data transfer reduces the likelihood of transcription errors. The EDDs will be checked against the AECI monthly report, the official laboratory PDF report, and COCs as described in Section D1.3.1. Analytical data from sampling activities will be subjected to independent data validation by the DVM and the database updated as appropriate to include any qualifiers assigned during data validation. Additional data review of water quality will be conducted as described in Section D1.3.2.

### B10.2.3 Retrieval and Transfer of Information

Tables of water quality results, field parameters, and flow rates will be produced using the database software to meet project needs. Data can be provided on computer disk and/or as printed reports. If applicable, data summary tables will be checked for accuracy against final hard-copy laboratory reports.

The monthly report will be prepared by AECI and reviewed by AECOM. The final copy of the report will be made available on the project SharePoint site in PDF format. Supplemental spreadsheets of water quality data, water levels, and flow data can be made available to EPA to allow for easier evaluation of data trends.

# Group C: Assessment and Oversight

## C1 Assessment and Response Actions

Planned and documented performance audits may be conducted to verify compliance with specific project QA/QC program requirements for both laboratory and field activities. These audits will consist, as appropriate, of an evaluation of QA/QC procedures, the effectiveness of the QA/QC implementation, and a review of project documentation. If problems are noted, the QAM or other authorized assessor can stop the work to take corrective measures. The results of all field and laboratory audits will be shared with all parties to enhance the quality of future work.

### C1.1 Field Performance and System Audits

An audit of the field operations may be performed if requested by the QAM. The audit will only be performed if routine review of data (as described in Section B.10) indicates a reason for concern. The field operations audit involves a review of field activities by the QCM with assistance from the STL. Items to be examined will include, as appropriate, the availability and implementation of approved work procedures, sampling procedures, sampling documentation and specifications; calibration and operation of equipment; labeling, packaging, storage, and shipping of samples; performance documentation and checking; and nonconformance documentation. The field SOPs and manufacturer specifications include specific information regarding calibration of specific measuring devices, work procedures, sampling procedures, sample handling, and sample shipment.

The records of field operation will be reviewed to verify that field-related activities are performed in accordance with appropriate project procedures. Items reviewed will include, but will not be limited to, the calibration records of field equipment, field activity logs, data, sample collection and custody forms, and field log books.

### C1.2 Laboratory Performance and System Audits

Audits may be conducted for laboratory operations to assess accuracy of measurement systems and determine effectiveness of QC procedures. The audit will only be performed if routine review of the laboratory data (as described in Section B.10) indicates a reason for concern. If required, the laboratory audit will be performed by the DVM with assistance by the LPM and the LQAM.

Laboratory audits will be conducted internally by the LQAM following the procedures outlined in Section 8.0 – Quality System Audits and Reviews of the Pace Analytical LQM. Follow-up audits may occur to verify implementation of required corrective actions.

Activities selected for audit will be evaluated against specified requirements and will include an objective evaluation of the methodology. Typical items reviewed during a laboratory audit include:

- Documentation of the QA Program
- Results of proficiency testing
- Consistency of test procedures with current methods
- Documentation of approval for all test procedure modification
- Proper storage and labeling of reference standards
- Glassware cleaning procedures
- Documentation of laboratory water purity
- Proper sample storage and COC
- Records of instrument maintenance
- Traceability and supervisor review of data and calculations
- Record retention systems
- Provisions for confidentiality of data

## C1.3 Corrective Action

Corrective action will be undertaken when QC data fail to meet the prescribed limits or when the overall quality of the project is suspect. Corrective actions will be determined based on the nature and severity of the problem. Generally, repeat measurements and/or sample preparation will be required.

Corrective action is dictated by the type and extent of the nonconformance. Corrective action may be initiated and carried out by non-supervisory staff, but final approval and data review by management is necessary before reporting any information. All potentially affected data must be thoroughly reviewed for acceptance or rejection.

Nonconforming items and activities are those that do not meet the project requirements or approved work procedures. Nonconformances may be detected and identified by any of the following groups during the activities indicated:

- **Project Staff –** While conducting field activities and testing, completing audits, and verifying numerical analyses
- **Laboratory Staff –** While preparing for and conducting laboratory testing, calibrating equipment, and carrying out QC activities
- **QA/QC-Staff –** While performing audits

Each nonconformance will be documented by the person identifying or originating it. For this purpose, a variance log, testing procedure record, notice of equipment calibration failure, results of laboratory analysis control tests, post-audit report, internal memorandum, or letter will be used, as appropriate. Documentation will, as necessary, include the following:

- Name(s) of the individual(s) identifying and/or originating the nonconformance
- Description of the nonconformance
- Any required approval signatures
- Method(s) for correcting the nonconformance or description of the variance granted
- Schedule for completing corrective action

Documentation will be made available to project, laboratory, and/or QA management. Appropriate personnel will be notified by the management of any significant nonconformance detected by the project, laboratory, or QA staff. Implementation of corrective actions will be the responsibility of the QCM or LQAM. Any significant recurring nonconformance will be evaluated by project or laboratory personnel to determine its cause. Appropriate changes will then be instituted in project requirements and procedures to prevent future recurrence. When such an evaluation is performed, the results will be documented.

Any major problem identified in the field or laboratory will be brought to the attention of the project managers prior to corrective action being applied. All major problems and corrective actions will be documented in the appropriate project report.

### C1.3.1 Field Activities

Corrective action to be taken as a result of nonconformance during field activities will be situation-dependent. If possible, action will be taken in the field to correct any nonconformance observed during field activities. If necessary and appropriate, corrective action may consist of re-sampling. If implementation of corrective action in the field is not possible, the nonconformance, and its potential impact on data quality, will be discussed in the groundwater monitoring report. All field corrective actions will be recorded in the field log book.

### C1.3.2 Analytical Laboratory

Corrective action procedures within the laboratory are often handled at the bench level by the analyst, who reviews the preparation or extraction procedure for possible errors, checks the instrument calibration, spike

and calibration mixes, instrument sensitivity, and so on. If the problem persists or cannot be identified, the matter is referred to the laboratory technical personnel or group leader, manager, and/or QA department for further investigation. Once the problem is resolved, full documentation of the corrective action procedure is filed with the LQAM by means of a Nonconformance Memo or similar form. Corrective action documentation is routinely reviewed by the LQAM. Nonconformances and corrective actions will be discussed in the report narrative.

The laboratory will be contacted regarding any deviations from the QAPP, and will be asked to provide written justification for deviations. In some instances, the laboratory will be asked to reanalyze the sample(s) in question. Additional details on laboratory corrective actions are found in Section 9.0 of the LQM

## C2 Reports to Management

If the QAM or QCM deems it necessary to conduct a field or laboratory audit, the results of this audit, corrective actions, and follow up will be reported to management. The report will explain the reason for the audit; list who participated in the audit; describe the processes that were inspected and the findings; and explain the corrective actions to be taken and the findings of any follow-up inspections to ensure the recommended corrective actions were implemented. The report will be submitted, as appropriate, to the EPA On-Scene Coordinator, the AR PM, the AECI PM, and the AECOM PM.

# Group D: Data Validation and Usability

## D1 Data Review, Verification, and Validation

The data collection and management process is defined by the Rico Data Management Procedure and Timeline provided as Appendix A to this plan. This procedure and timeline defines the steps followed from sample collection to final submittal of the data. It further defines roles, responsibilities, and schedule for each step of the process.

As discussed in Section B9, any data used from non-direct measurement sources such as computer databases, programs, literature files, and historical databases will be reviewed for representativeness, bias, and precision. Any limitations on the use of the data resulting from uncertainty in its quality will be evaluated. The rationale for the original collection of the data and its relevance to the project will also be addressed. Any historic data incorporated into the EQuIS database will be clearly flagged as being "historic" so it is clear that the data was not necessarily submitted to the same QA/QC reviews as the data collected for the current monitoring program.

Data review, verification, and validation are used to ensure quality from sample planning, sampling, sample shipping, analytical procedures, data review by the laboratory, and consultant independent data validation, through to the final report.

### D1.1 Field Data (AECI)

Field data includes water quality parameters measured in the field, water levels and flow rates, and data collected from pressure transducers. The QCM is responsible for reviewing all field data and for verification of the data obtained from field measurements and calculations used to process data. The data verification will include ensuring that correct codes, units, sample locations, blind duplicate locations, analytical parameters, dates, and times, as well as other pertinent information, are included on the sampling forms, field log books, and custody forms. The QCM will also ensure that field instruments are properly calibrated are maintained, and that all required field QC samples have been analyzed and are within acceptable criteria. Any required corrections to field data will be made by placing a single line through the entry, and initialing and dating the correction. Variations in data that cannot be explained will be assigned a lower level of validity and will be used for limited purposes. The QCM will summarize the data obtained from field measurements and include this information in the sampling field methods portion of the monthly report.

Data will be entered on hard-copy sample forms in the field and transcribed to spreadsheets in the office. The QCM will ensure that this data entry is thoroughly reviewed to check for data-entry errors. The QCM will also ensure that data-reduction calculations performed on pressure transducer data are performed using proper methods and checked for accuracy.

### D1.2 Laboratory Data (Pace)

#### D1.2.1 Data Reduction

For most analyses, laboratory data reduction involves comparing the response of samples to that of standards used to create a standard reference curve. Samples and sample extracts are diluted so that the responses fall within that of the standard curve. The sample response is then multiplied by the appropriate dilution factors to obtain the final result. Results from analyses that do not utilize a standard calibration curve are calculated using the formula given in the method, taking the number of significant figures into account. The equations for data reduction are given in the laboratory SOPs. The laboratories make use of direct upload to transfer reduced data to the LIMS where reports are generated. This significantly reduces the chances for error from manual data entry.

### D1.2.2 Data Verification by the Laboratory

The laboratory project manager and the individual laboratory group leaders will be responsible for verifying data prior to laboratory reporting of results. A 100 percent data review of raw analytical data is performed by a peer or supervisor prior to release to the LPM. Included in this laboratory data verification is an assessment of the acceptability of the data with respect to the following:

- Adherence to required analytical procedures
- Correctness of numerical inputs when computer programs are used (random check)
- Numerical correctness of calculations and formulas (random check)
- Correct interpretation of chromatograms, mass spectra, etc.
- Acceptability of QC data
- Documentation that instruments were operating according to method specifications (calibrations, performance checks, etc.)
- Documentation of dilution factors, standard concentrations, etc.

## D1.3 Data Validation and Technical Review (AECOM)

### D1.3.1 Data Validation

A final independent validation of all laboratory data will be provided by the DVM. This data validation provides an impartial evaluation of the laboratory results by an individual who was not involved with the sample collection or analysis. The data validation process assures technical data quality and method compliance; provides precision, accuracy, and completeness assessments; verifies that adequate analytical documentation was performed and reported; determines whether the analytical data are usable; and helps the data user to determine whether project quality objectives were met.

Data validation will be done on the final reports submitted by the analytical laboratory according to quality directives defined in the *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Superfund Data Review* (NFGs) (EPA, 2010), as applied to the reported methodology and QC criteria defined in this QAPP. The data validation reports and checklists will include assessments of data precision, accuracy, completeness, and method compliance according to the submitted data. Sample results, case narratives, and analytical QC summaries will be reviewed at a frequency of 100 percent. All sample and QC results will be compared to the EDDs at a 100 percent frequency and updated in the project database.

The data validation reports will address the following data measurements as applicable to the reported methodology:

- Overall precision, accuracy, method compliance, and completeness
- Sample custody and integrity
- Case narrative comments
- MDLs, PQLs, and sample quantitation
- Holding time compliance
- Method blanks
- Field-originating blanks
- LCS results
- MS results
- Laboratory duplicate or spiked duplicate results
- Field duplicate results (calculated RPDs)

A summary table of any qualified data will be included in the data validation report, along with qualifier definitions. The data will be qualified as acceptable, estimated, or rejected based upon the requirements given in the validation guidance. An example data validation report is provided in Appendix C.

A list of data validation qualifiers applicable to the proposed methods is given below.

**J** estimated concentration
**J+** estimated concentration, high bias indicated
**J-** estimated concentration, low bias indicated
**R** rejected due to severe QA/QC noncompliance
**U** evaluated to be undetected at the reporting limit/concentration, due to evidence of contamination
**UJ** undetected, reporting limit is estimated

Any rejected data or data that is identified as unacceptable for its intended purpose will either be eliminated from the decision-making process or qualified for limited use (e.g., approximation purposes).

### D1.3.2 Additional Data Review

As described in Section 10.2.2, above, additional data quality reviews will be performed in addition to the independent data validation described above. Reviews will be performed to ensure that the laboratory reports are complete and match the EDDs, that the water quality data are within expected ranges and ratios relative to other parameters, and the flow data calculations and data reductions are performed correctly and are consistent with overall trends for the site.

- The AECOM DVM will compare the EDDs to the official laboratory report to check for completeness (all requested samples and analytes reported) and consistency (reported values on EDD match values in laboratory report).
- The AECOM Water Quality Reviewer will review the water quality data to assess whether data are comparable to the expected ranges and in expected ratios relative to other related parameters.
- The AECOM Flow Data QC Reviewer will check the accuracy of the calculations necessary to transform hourly data from data loggers into flow rates and review overall trends of the flow data.

## D2 Reconciliation of the Data with User Requirements

Limitations on the data will be reported to the data users in the form of data validation qualifiers for laboratory analytical data. The appropriate data validation qualifiers (as described above) will be stored in the EQuIS database along with the laboratory data. Any qualifiers will be reported along with the laboratory analytical data as presented in the monthly report and the spreadsheets generated from the database. Any other limitations on the data identified through the other quality checks described above will be documented in narrative form in the monthly report.

The results of the QA/QC methods implemented during the project will be evaluated and summarized. An assessment of overall data usability will be prepared. The project will be considered successful if the data generated under this QAPP is accurate, precise, comparable, representative, and complete, and sufficient to meet the DQOs.

## References

USEPA, 2010. *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Superfund Data Review*, USEPA-540-R-10-011. United States Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation. January 2010.

USEPA, 2006a. *EPA Requirements for Quality Assurance Projects Plans*. Washington, D.C.: United States Environmental Protection Agency. EPA QA/R-5. 2001, Re-issued, May 2006.

*Surface and Groundwater Sampling and Analysis Plan*. Rico, C.O.; Anderson Engineering Company, May 2013.

*Water Quality Assessment Mainstem of the Dolores River St. Louis Tunnel Discharge.* Appendix A, Water Quality Assessment for the St. Louis Tunnel Discharge. Colorado Department of Public Health and Environment, Water Quality Control Division. October 2008.

**Appendix A**

Rico Data Management Procedure and Timeline

# Rico Data Management Procedure and Timeline

| Time Frame | | | Responsible Party |
|---|---|---|---|
| 1 week prior to sampling | Oversight provided by the **QC Manager** (AECI): Refer to the QAPP for details | Pre-Sampling Event Preparation | AECI Sample Team Leader & AECI Sample Tech |
| Sample Collection | | • Mobilization to site<br>• Prepare access routes and field safety preparation<br>• Purge wells and collect groundwater (GW) samples<br>• Surface water sample collection<br>• Flow/GW level measurements<br>• DR-3/DR-6 flow data upload and manual depth measurement<br>• Chain of custody (COC) preparation and ship samples to laboratory (Pace) | AECI Sample Team Leader & AECI Sample Tech |
| 3 to 5 weeks after sample collection | | • Receive results of laboratory analyses<br>- Confirm lab report is consistent w/ COC documents and Electronic Data Deliverable (EDD)<br>If errors, return to lab for revision and repeat previous step<br>Prepare *Monthly Surface and Groundwater Data Summary Report (Monthly Report)* including entry of field and analytical data to Excel tables and QC of data entry | AECI Rico Staff Engineer |
| 3 weeks after receiving lab reports/EDDs from lab (6-8 weeks after sample collection) | | • Submit the following to AECOM Data Management Lead<br>- *Monthly Report*<br>- EQuIS EDDs for laboratory analysis<br>- Excel tables (from *Monthly Report*) with field parameters, GW levels, sample-day flow data, & hourly/raw flume flow data | AECI Rico Staff Engineer |
| w/in 1-2 weeks of receiving monthly submittal from AECI (7-10 weeks after sample collection) | Oversight provided by the Data Management Lead (AECOM): Refer to the QAPP for details | • Limited data validation and loading of analytical data<br>• Review and loading of field data<br>If errors, return to AECI for revision | AECOM Data Management Lead |
| w/in 1-2 weeks of receiving data from AECOM Data Manager/QC Reviewer (8-12 weeks after sample collection) | | • Data usability assessment<br>• Flow data<br>• Water Quality data<br>Document any issues | AECOM **Data Management Lead** |
| w/in 1-2 week of completion of data QC (9-14 weeks after sample collection) | | AECOM QA Manager<br>• Ensure QA/QC procedures have been completed and documented<br>• Notifies AECOM Data Management Lead to distribute deliverables | AECOM QA Manager |
| **Normal total turn-around time: 9-14 weeks** | | • Export December 2010-present spreadsheets from EQuIS:<br>• Analytical and field parameters (3 format variations)<br>• Monthly flow<br>• GW level measurements<br>• Append hourly flume flow data to master table<br>• Distribute data tables to EPA/URS and post files to SharePoint<br>• Post PDF of *Monthly Report* to SharePoint and notify stakeholders | AECOM **Data Management Lead** |

**Appendix B**

Training Certification Form

Training Record Date:

| Project: |
|---|
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| Topics: |
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| Name (Print) | Signature | Company |
|---|---|---|
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| Trainers | | |
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**Appendix C**

Example of Data Validation Report

Submitted to:

Submitted by:
AECOM

Environment

# Date

# Title

**Prepared By**

## Overview

## List of Submitted Deliverables

## Data Validation Qualifiers Assigned During this Review

## Overall Data Assessment

**Table of Samples Analyzed**
**Title**

| Matrix | Sample ID | Sample Date | Sample Time | Lab SDG | Lab Sample ID |
|---|---|---|---|---|---|
| | | | | | |

# ANALYTICAL LIMITED DATA VALIDATION CHECKLIST

| | |
|---|---|
| Project Name: | Laboratory: |
| Project Reference: | Sample Matrix: |
| AECOM Project No.: | Sample Start Date: |
| Validator/Date Validated: | Sample End Date: |
| Samples Analyzed: | |
| Parameters Reviewed: | |
| Laboratory Project ID/Sample Delivery Group (SDG): | |

| PRECISION, ACCURACY, METHOD COMPLIANCE, AND COMPLETENESS ASSESSMENT | | | | | | |
|---|---|---|---|---|---|---|
| Precision: | | Acceptable | | Unacceptable | | Initials |
| Comments: | | | | | | |
| Accuracy: | | Acceptable | | Unacceptable | | Initials |
| Comments: | | | | | | |
| Method Compliance: | | Acceptable | | Unacceptable | | Initials |
| Comments: | | | | | | |
| Completeness: | | Acceptable | | Unacceptable | | Initials |
| Comments: | | | | | | |

| VALIDATION CRITERIA CHECK | | | | | | |
|---|---|---|---|---|---|---|
| Data validation qualifiers assigned during this review: | | | | | | |
| 1. Did the laboratory identify any non-conformances related to the analytical results? | | Yes | | No | | Initials |
| Comments: | | | | | | |

# ANALYTICAL LIMITED DATA VALIDATION CHECKLIST

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. Were sample Chain-of-Custody forms complete? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 3. Were all the analyses requested for the samples on the COCs completed by the laboratory? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 4. Were samples received in good condition and at the appropriate temperature? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 5. Were the reported analytical methods in compliance with WP/QAPP, permit, or COC? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 6. Were detection limits in accordance with WP/QAPP, permit, or method? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 7. Do the laboratory reports include only those constituents requested to be reported for a specific analytical method? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 8. Were sample holding times met? | | Yes | | No | | Initials |
| Comments: | | | | | | |

# ANALYTICAL LIMITED DATA VALIDATION CHECKLIST

| | | | | | | |
|---|---|---|---|---|---|---|
| 9. Were correct concentration units reported? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 10. Were the reporting requirements for flagged data met? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 11. Were laboratory blank samples free of target analyte contamination? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 12. Were trip blank, field blank, and/or equipment rinse blank samples free of target analyte contamination? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 13. Were instrument calibrations within method or data validation control limits? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 14. Were surrogate recoveries within control limits? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 15. Were laboratory control sample recoveries within control limits? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 16. Were matrix spike recoveries within control limits? | | Yes | | No | | Initials |
| Comments: | | | | | | |

# ANALYTICAL LIMITED DATA VALIDATION CHECKLIST

| | | | | | | |
|---|---|---|---|---|---|---|
| 17. Were duplicate RPDs and/or serial dilution %Ds within control limits? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 18. Were organic system performance criteria met? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 19. Were internal standards within method criteria for GC/MS sample analyses? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 20. Were inorganic system performance criteria met? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 21. Were blind field duplicates collected? If so, discuss the precision (RPD) of the results. | | Yes | | No | | Initials |
| Duplicate Sample No. | | Primary Sample No. | | | | |
| Comments: | | | | | | |

| Method | Units | Analyte | Sample | Sample | RPD | Qualifier |
|---|---|---|---|---|---|---|
| | | | | | | |

# ANALYTICAL LIMITED DATA VALIDATION CHECKLIST

| | | | | | | |
|---|---|---|---|---|---|---|
| 22. Were qualitative criteria for organic target analyte identification met? | | Yes | | No | SM | Initials |
| Comments: | | | | | | |
| 23. Were 100% of the EDD concentrations and reporting limits compared to the hardcopy data reports? | | Yes | | No | | Initials |
| Comments: | | | | | | |
| 24. General Comments: | | | | | | |

**Table of Qualified Analytical Results**
**Title**

| Sample ID | Lab ID | Method | Diln | QC Batch | Analyte | Concentration | Qualifier | Reason Code |
|---|---|---|---|---|---|---|---|---|
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**Reason Codes:**

# Appendix F

# Field Exploration Results

**Field Exploration Results**

From 2011 through 2013, boreholes SSR-1 through -5 and SSR-101 through -104, monitoring wells MW-5S/D, MW-101, MW-102 and MW-202, test pits TP2011-17 through -19 and TP2013-08 through -11, CPT probes CPT-1 through -6, CPT-PDF-03 and CPT-SSR-05, and ReMi lines RM-2 and RM-4 were completed within or near the periphery of the full build-out footprint of the repository as shown on Appendix A, Drawing G-120. The results of these explorations are discussed below.

Earlier explorations in proximity include borings B-1 through B-5, EB-1, EB-2 and EB-2D, DH-11 and DH-12R, monitoring wells GW-5 through GW-8 (some of which no longer exist due to construction of the IDF), test pits TP-13 through -22 and test pits TP B and TPC. The older exploration locations are shown on Drawing G-120 and the logs included in Appendix B but these are not discussed in detail except for clarification of stratigraphy.

*Phase 1 Area*

Borings SSR-3, SSR-101 and SSR-102 were completed near the location of the proposed starter dike. The total depths drilled ranged from 100 to 169.2 feet below ground surface (bgs). Boring SSR-101 was completed as a groundwater monitoring well with screened interval set from 27.9 to 37.9 feet bgs. Boring SSR-102 was originally completed to 35 feet, then due to an out-of-plumb surface casing, was offset 5.5 feet south and completed as SSR-102A. Boring SSR-3 was completed through the remnant floor slab of a prior structure.

Borings SSR-101 and SSR-102 encountered 15.4 to 28.5 feet bgs of variable fill consisting of loose to dense sand, gravel and waste rock, with significant silt and clay fraction. Possible buried topsoil was identified in SSR-101 (28.5 to 31.5 feet bgs), and in SSR-102 (15.4 to 16.5 feet bgs).

Below the fill and buried topsoil, layered, extremely dense to medium dense silty gravels, sands and cobble/boulder layers were observed in SSR-101 (to 56 feet bgs), in SSR-102 (to 39 feet bgs) and in SSR-3 to 58 feet bgs). These strata were in turn underlain by dense to medium dense, silty sands (SP, SP-SM and SM) to 110.5 feet bgs (SSR-101), to 81 feet bgs (SSR-102) and were inter-layered with several well-graded gravel beds (GW) to the maximum depth of exploration (100 feet bgs) in SSR-3.

Below 100 feet in SSR-101, an atypical layer of high plasticity clay was observed from 110.5 to 115 feet bgs, underlain by dense sands and silts to 138.5 feet bgs, then by boulder-sized, weathered Hermosa sandstone to 160.5 feet bgs. Very dense clean gravel was present from 160.5 feet bgs to the top of weathered sandstone bedrock (163.4 feet bgs). Hard unfractured rock was noted by rotary wash cuttings (core not recovered) to the maximum depth of exploration (169.2 feet bgs).

Below 81 feet in SSR-102, medium dense to dense, layered gravel, sand and silt was observed, becoming very dense to extremely dense below 122 feet. Altered Hermosa sandstone was then encountered from 136.3 to 142.6 feet bgs, and intact sandstone bedrock was identified from 146.2 feet bgs to the maximum depth of exploration (150.0 feet bgs).

Borings SSR-1 and SSR-2 were completed at the toe and on the upper eastern hillside of the proposed SSR-A Phase 1 area. Gravelly lean clay with sand, silt, cobbles and boulders was observed from existing grade to 22 feet bgs in SSR-1, and from grade to 23 feet bgs in SSR-2. SPT N-values were typically 10 to 40 blows/feet, with a loose zone identified in SSR-2 at 15 feet bgs.

The upper strata in SSR-1 are underlain by inferred alluvial deposits of gravelly lean clay to 42 feet bgs, then by interlayered sands and gravels (clean and silty/clayey), variably medium dense to extremely dense, to the maximum depth of exploration (100 feet bgs). The upper strata in SSR-2 are underlain by

alluvial clay with gravel to 35 feet bgs, then by interlayered, very dense to extremely dense, clean to silty sands and gravels, to the maximum depth of exploration (also 100 feet bgs).

Test pit exploration confirmed the presence of some buried debris in the proposed Phase 1 area, including some broken brick and part of a PVC pipe (TP2011-18 and -19), steel debris (TP2013-09 and TP-22), and buried concrete foundations (TP2013-08 from 0 to 3 feet and TP-19 at 4.4 feet). In general, the shallow soils on the upper eastern hillside (TP2011-17, -18 and -19) appear to consist of fill and/or colluvium, which typically consist of dark brown clayey and sandy gravels / clayey gravels with cobbles and boulders (up to 24-inch size). The surficial soils of the middle portion of this area consist of clayey sand and gravel fill with some waste rock and calcine lenses based on the logas of earlier TP19 through TP22.

ReMi Line RM-2 identified lower shear wave velocity materials in a range of 1000 to 1300 feet per second within the upper 25 to 30 feet of the ground surface, with higher variability with depth. The highest shear wave velocities were within the northern portion of the array at a depth beginning about 70 feet below grade. The shear wave velocity of this material is lower than expected for intact bedrock, which was confirmed at more than more than 140 feet below grade in SSR-101 and -102. No potentially liquefiable materials were detected in the overburden.

First groundwater is indicated in MW-101 at about 28 feet below surface, El. 8845 ft amsl, and at about 23 feet below surface El. 8839 feet amsl in MW-102. Boring SSR-1 encountered saturated strata at about 44 feet below surface El. 8863 feet amsl, and Boring SSR-2 had saturated strata at about 35 feet below surface El. 8850 feet amsl. These readings correspond to a groundwater elevation ranging from about 8815 to 8819 feet amsl.

*Future Build-Out Area*

The western portion of the SSR-A repository site (covered at present by the IDF consists of 3-4 feet of solids excavated from Pond 18 in 2011, over a variable thickness of calcines. These fill strata are in turn underlain by native alluvium, as discussed below. Borings SSR-4, SSR-5 and PDF-1 through -3 were completed from 31.5 to 100 feet bgs. Due to the soft nature of the solids, all but PDF-2 were completed through the short dikes that separate the various cells of the IDF. For these particular borings, the nomenclature IDF and PDF (Permanent Drying Facility) refer to the same general area at the St. Louis Ponds.

Borings SSR-4 and -5 encountered 4 feet of IDF dike fill at the surface, followed by loose to medium dense, sand and silt-sized calcines to 25 feet bgs (SSR-4), or by waste rock over sand and gravel fill (4-8 feet), underlain by calcine fill (8 to 25.5 feet) in SSR-5. Below the calcines, medium dense to extremely dense, clean and silty sand and gravel alluvium with cobbles was identified in SSR-4 to the depth of exploration (60 feet bgs). In SSR-5, a layer of extremely dense colluvium or waste rock was located below the calcine fill, followed by clean and silty, sand and gravel alluvium to the maximum depth of exploration (61.5 feet bgs).

Borings PDF-1 through -3 encountered 1.5 to 3.5 feet of waste rock or IDF embankment fill, followed by calcines to 22.5 to 27 feet bgs (an additional layer of clayey gravel fill was located below the embankment from 3.5 to 7.5 feet in PDF-3). Below the calcine fill, borings PDF-1 and -2 encountered clean to silty, sand and gravel alluvium with some cobbles, to the maximum depth of exploration (100 feet bgs in PDF-1 and 31.5 feet bgs in PDF-2). In PDF-3, the calcine fill is underlain by loose to medium dense, organic silty sand alluvium (possible remnant of buried overbank deposits within a river meander) from 23 feet to the maximum depth of exploration (31.5 feet bgs).

Probes CPT-1 through CPT-6, CPT-PDF-03 and CPT SSR-05 completed in the former Pond 16/17 area (present-day IDF), identified materials interpreted as thinly-layered sandy silts, clayey silts and silty

sands to refusal depths of 18 to 29 feet bgs. These are likely the calcines (typically sand- and silt-sized fill materials).

Earlier test pits in the future build-out area (TP2004 F, G, H and I - completed before the IDF was constructed), identified 0.5 to 4 feet of surficial granular fill, over calcine fill to the maximum depth explored (12 feet bgs at that time).

ReMi Line RM-4 at the downstream (west toe) of the future build-out area of SSR-A suggests loose to very loose strata within about 30 feet of the ground surface. The shear wave velocities were as low as about 500 feet per second, which suggests that some of these soils have some potential for liquefaction depending on the characteristics of the design earthquake event for the site still under development. With greater depth, soil strata were interpreted to be medium dense to very dense. Based on shear wave velocity, denser strata were detected at about 70 to 80 feet bgs within the central to northern portion of the array.

In 2011, first groundwater was indicated in SSR-5 at 15.5 feet below grade, and in PDF-1, -2 and -3 at 14.5, 18 and 14 feet bgs. Based on the surface grades at those locations, the readings correspond to a groundwater El. 8817 to 8821 feet msl.

# Appendix G

# Design Calculations

# Drainage Layer Filter Calculations

AECOM

JOB TITLE Rico - Repository Design
JOB NO. 60306858 CALCULATION NO.
ORIGINATOR EED DATE 10-23-13
REVIEWER DATE
SCALE SHEET NO. 1 OF 7

Filter Criteria - Oxyhydroxide solids (Ref. Ch26 National Engr. Handbook)

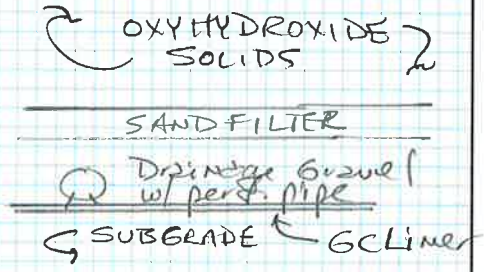
1) Average gradation curve - 100% passes #4 so no correction

2) % - #200 ≈ 58% ⇒ Category 2

3) Max $D_{15} \leq 0.7$ mm (Category 2)

4) Min $D_{15} \geq 4 d_{15}$ and $\geq 0.1$ mm
uncorrected

$\geq 4(0.004\text{ mm}) = 0.016\text{ mm} < 0.1$, so use 0.1 mm
avg. g.s. curve




5) Width of band @ any % passing ≤ 60% should be ≤ 5

$$\frac{D_{15_{max}}}{D_{15_{min}}} = \frac{0.7\text{ mm}}{0.1\text{ mm}} = 7 > 5$$

Assuming filtration is primary req. (rel. little leachate drainage expected), so keep $D_{15_{min}} = 0.1$ mm; use $D_{15_{max}} = 5(0.1) = 0.5$ mm

6) Keep $C_u \leq 6 = D_{60}/D_{10}$

$D_{10_{max}} \approx D_{15_{max}}/1.2 = \frac{0.5}{1.2} = 0.42$; ⇒ $D_{60_{max}} = 6 D_{10_{max}} = 2.5$ mm

$D_{60_{min}} = D_{60_{max}}/5 = 0.5$ mm

7) $D_5 \geq$ #200 $\geq 0.074$ mm

$D_{100} \leq$ 3 inch

8) $D_{10_{min}} = D_{15_{min}}/1.2 = 0.1/1.2 = 0.083$ mm $< 0.5$, so $D_{90_{max}} = 20$ mm
T26-6

$D_{90_{min}} = 20/5 = 4$ mm

9) From Results, coarse end of ASTM C33 Fine Aggregate is an acceptable filter between the oxyhydroxide solids and the underlying drainage gravel. Since coarse vs. fine end of gradation is slightly out, accept C33 FA range as-is.

Grid: 10x10 = 1"

AECOM

JOB TITLE Reco – Repository Design
JOB NO. 60306858 CALCULATION NO.
ORIGINATOR ESD DATE 10-23-13
REVIEWER DATE
SCALE SHEET NO. 2 OF 7

FILTER CRITERIA – FILTER SAND TO Drainage Gravel
Ref: Ch26, Nat'l Engr. Handbook

1) Avg curve for C33 Fine Agg (SAND) is < #4 so no curve corr. reqd.

2) % – #200 ≈ 3% ⇒ Category 4

3) $D_{15\,max} \le 4 d_{85\,\text{sand after corr.}} \le 4(1.9\,mm) \le 7.6\,mm$

4) $D_{15\,min} \ge 4 d_{15\,\text{sand before corr}} \ge 4(0.25) \ge 1.0\,mm$ and $\ge 0.1\,mm$ ✓

5) $\frac{D_{15\,max}}{D_{15\,min}} = \frac{7.6}{1.0} = 7.6 > 5$, so assuming primary function of gravel is drainage, keep $D_{15\,max}$ & raise $D_{15\,min} = 7.6/5 = 1.5\,mm$.

6) $D_{10\,max} \approx \frac{D_{15\,max}}{1.2} = 7.6/1.2 = 6.3\,mm \Rightarrow D_{60\,max} = D_{10\,max} \times 6 = 37.8\,mm$

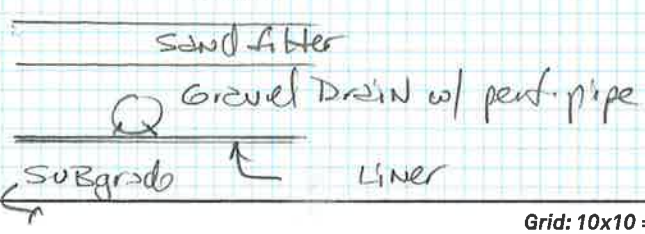
$D_{60\,min} = D_{60\,max}/5 = 7.6\,mm$

7) $D_5 \ge \#200 = 0.071\,mm$
$D_{100} \le 3\,inch = 76\,mm$

8) $D_{10\,min} \approx D_{15\,min}/1.2 = 1.5/1.2 = 1.25\,mm \Rightarrow D_{90\,max} = 30\,mm$ (T26-6) $\Rightarrow D_{90\,min} = 30/5 = 6\,mm$

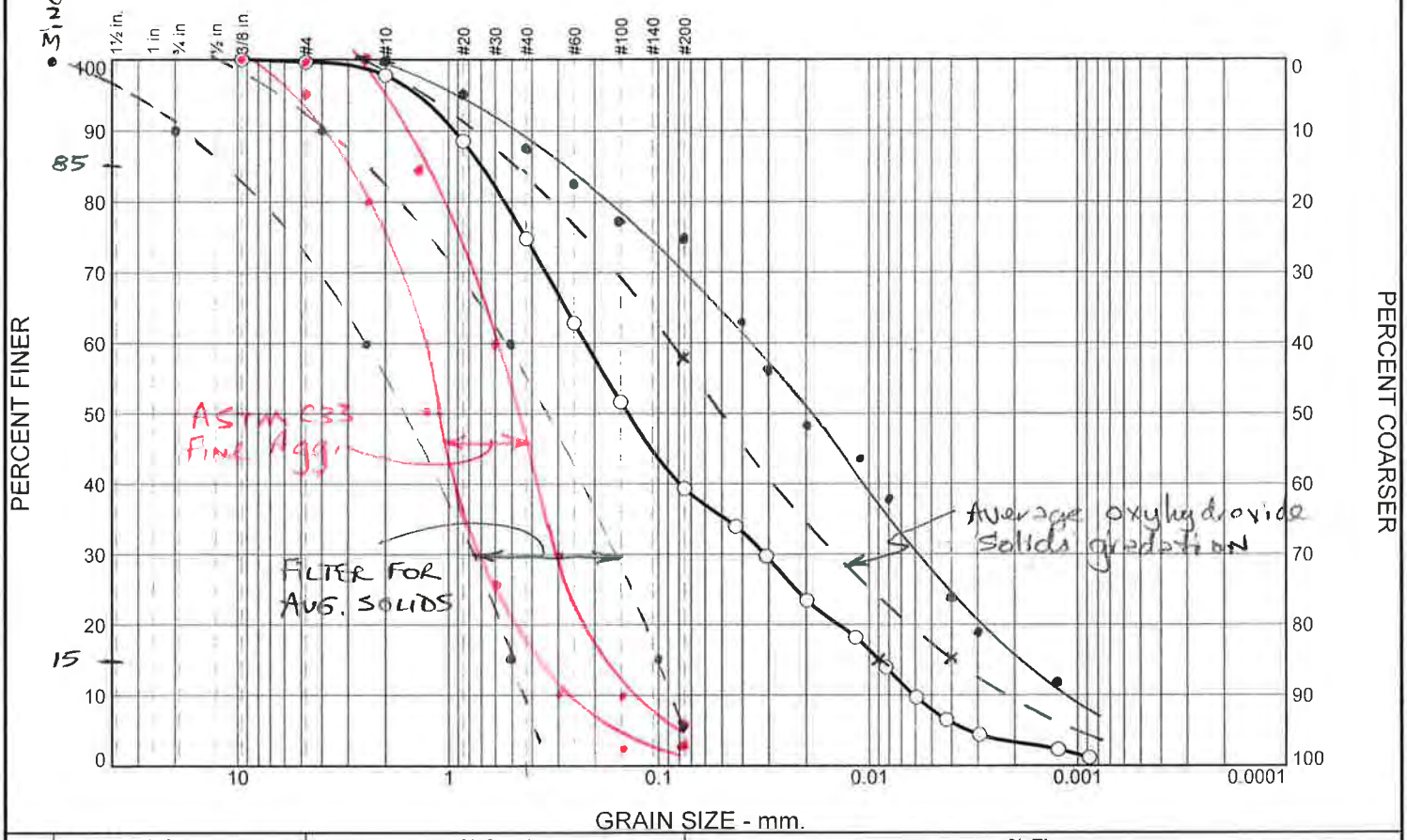
9) For gravel w/ perf. pipe, $D_{85} \ge$ perf. size
perf size $\le D_{85\,gravel\,min} \le 3/8''$

ASTM C33 Coarse aggregate Gr. 57 as drainage layer meets filter criteria with sand filter




Grid: 10x10 = 1"

# PARTICLE SIZE ANALYSIS OF SOILS ASTM D422




| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 0.4 | 1.8 | 23.0 | 35.5 | 31.4 | 7.9 |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| .375 | 100.0 | | |
| #4 | 99.6 | | |
| #10 | 97.8 | | |
| #20 | 88.5 | | |
| #40 | 74.8 | | |
| #60 | 62.8 | | |
| #100 | 51.6 | | |
| #200 | 39.3 | | |

* (no specification provided)

**Material Description**

OXYHYDROXIDE SOLIDS - REDDISH BROWN

**Atterberg Limits**

PL= 88 LL= 88 PI= NP

**Coefficients**

$D_{90}$= 0.9353 $D_{85}$= 0.6968 $D_{60}$= 0.2205
$D_{50}$= 0.1388 $D_{30}$= 0.0313 $D_{15}$= 0.0090
$D_{10}$= 0.0061 $C_u$= 36.14 $C_c$= 0.73

**Classification**

USCS= AASHTO= A-5(0)

**Remarks**

o FROM POND 15 DREDGED INTO POND 13
F.M.=1.08
• POND 18 SOLIDS (sampled in IDF Oct 2011)

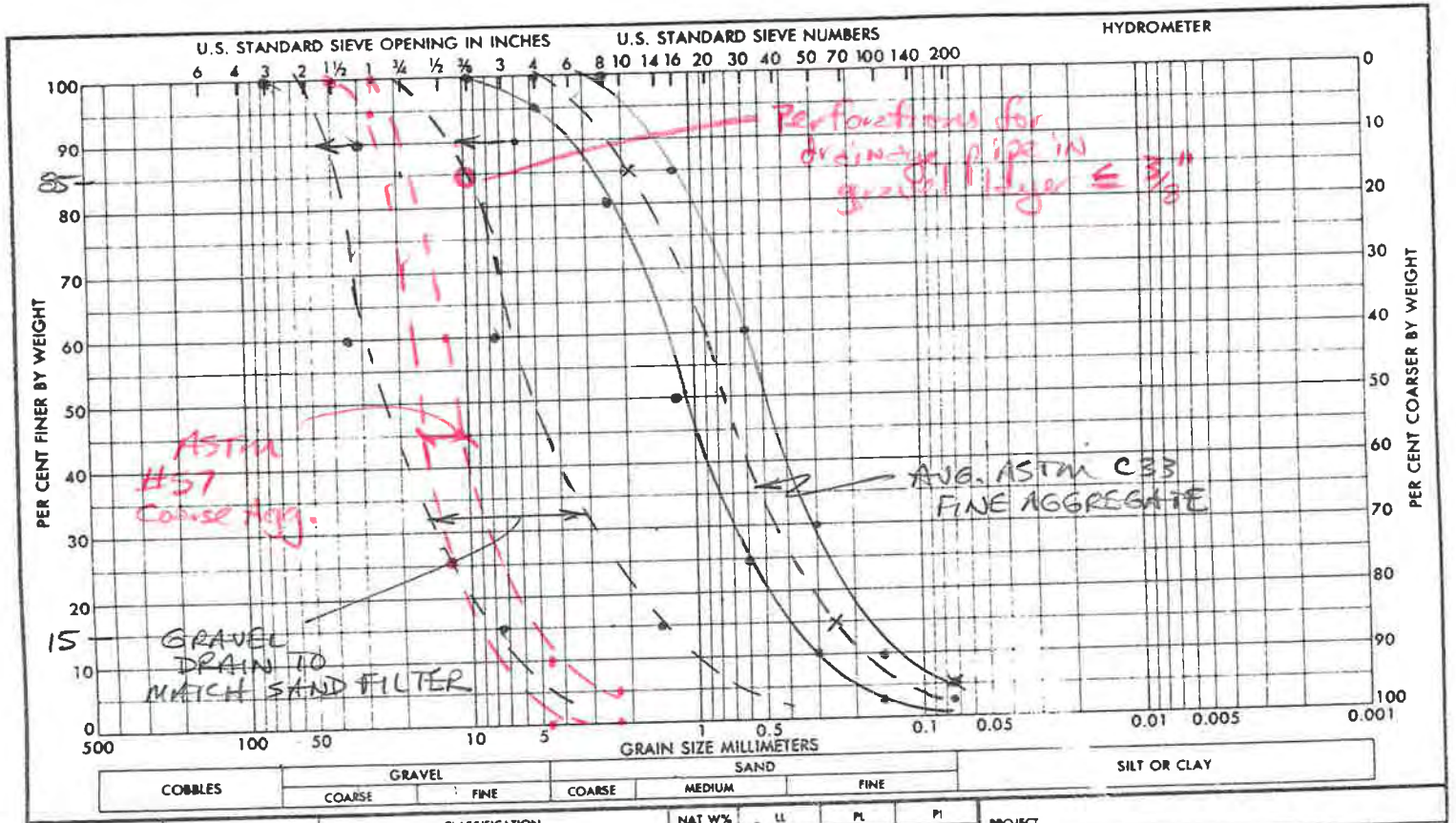
**Source of Sample:** 9-6-2013 **Depth:** 0.0'-1.5'
**Sample Number:** P13 ST-1

**Date:** 10/21/13

AECOM

**Client:** BP
**Project:** BP RICO 2013 SOLIDS PROJECT
**Project No:** 60301339

**Tested By:** BCM **Checked By:** WPQ




| SAMPLE NO | ELEV OR DEPTH | CLASSIFICATION | NAT W% | LL | PL | PI |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

PROJECT

AREA

BORING NO

DATE

**GRADATION CURVES**

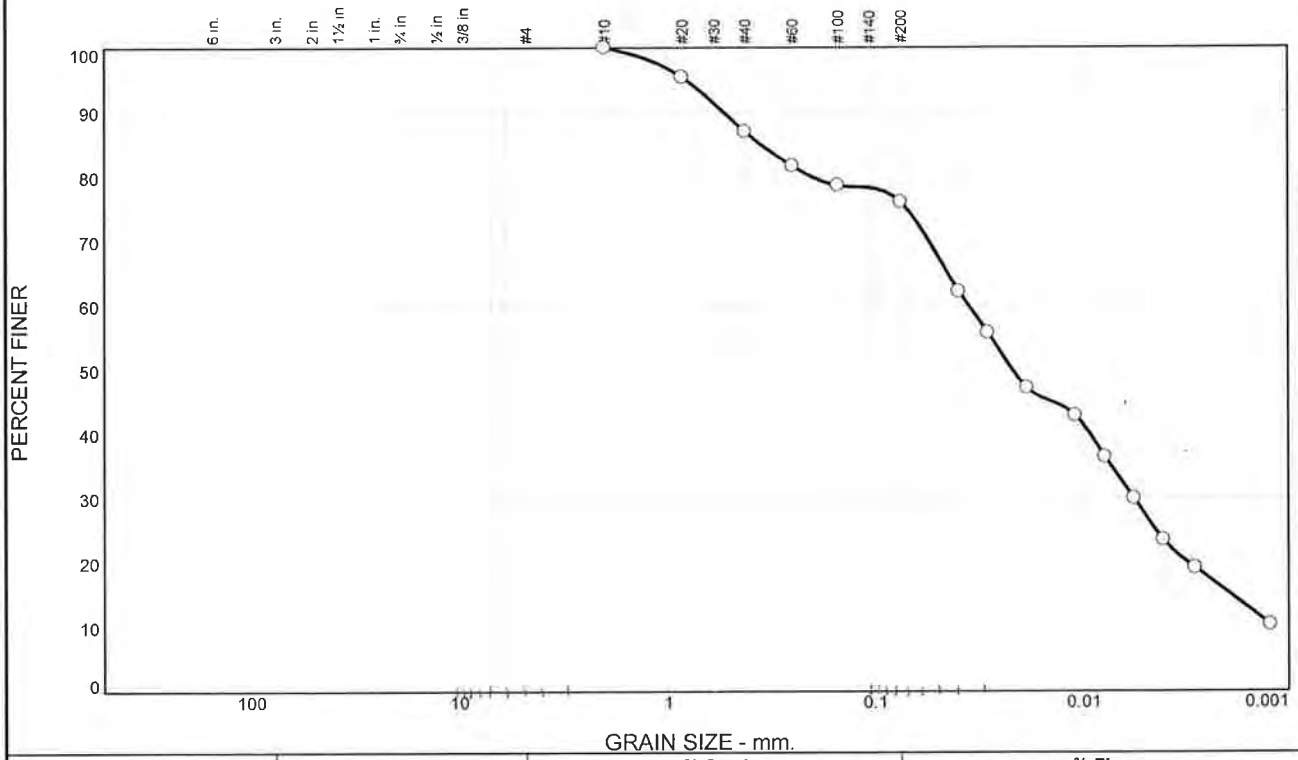
ENG FORM 1 MAY 63 2087

PLATE V-2



4/7

# PARTICLE SIZE ANALYSIS OF SOILS ASTM D422




| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 0.0 | 0.0 | 13.0 | 10.9 | 48.8 | 27.3 |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| #10 | 100.0 | | |
| #20 | 95.5 | | |
| #40 | 87.0 | | |
| #60 | 81.7 | | |
| #100 | 78.6 | | |
| #200 | 76.1 | | |

* (no specification provided)

**Material Description**

LIME TREATMENT SOLIDS - POND 18 - REDDISH BROWN

**Atterberg Limits**

PL= 79 LL= 83 PI= 4

**Coefficients**

$D_{90}$= 0.5391 $D_{85}$= 0.3556 $D_{60}$= 0.0355
$D_{50}$= 0.0220 $D_{30}$= 0.0057 $D_{15}$= 0.0019
$D_{10}$= $C_u$= $C_c$=

**Classification**

USCS= AASHTO= A-5(13)

**Remarks**

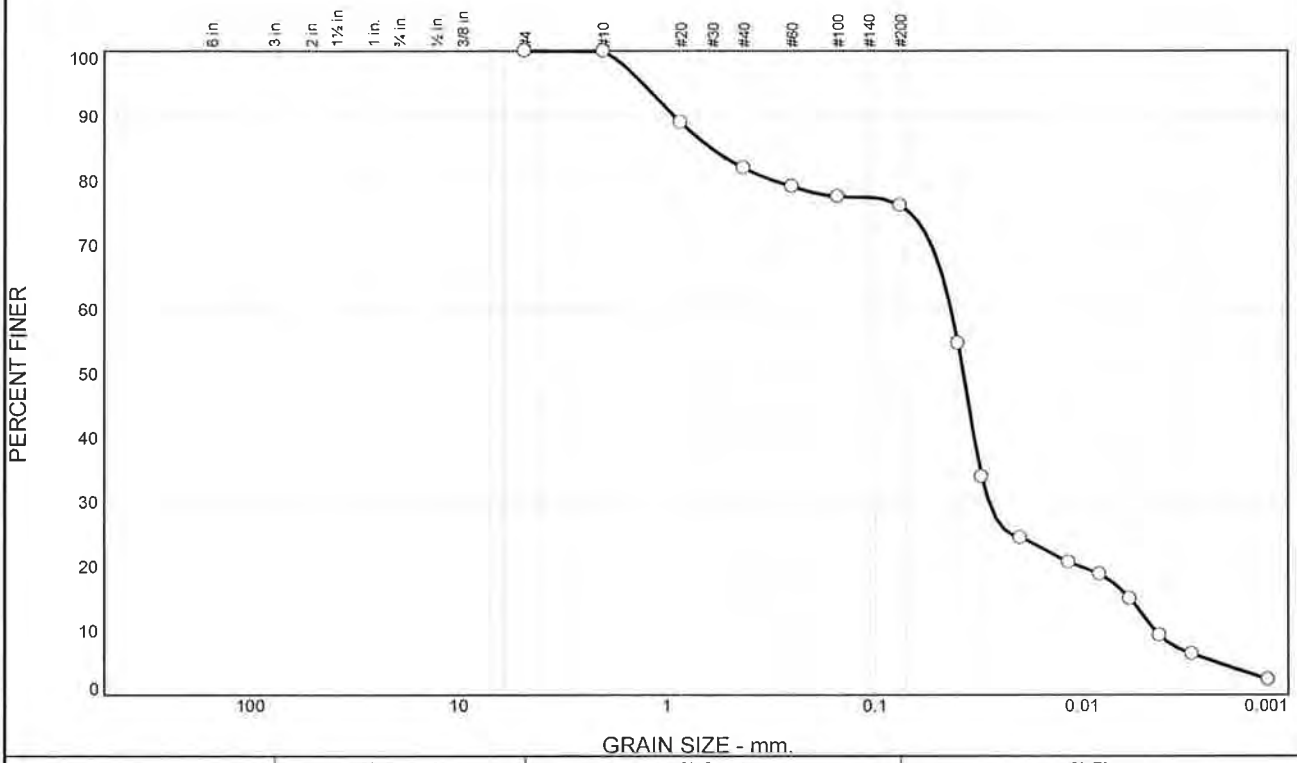
**Source of Sample:** B-ST18-2 **Depth:** 0.0"-30.0"
**Sample Number:** ST18-2 **Date:** 10/27/2011

AECOM

**Client:** BP
**Project:** RICO ARGENTINE SITE OU01, RICO, CO.
**Project No:** 60157757

**Tested By:** EMR **Checked By:** WPQ

# PARTICLE SIZE ANALYSIS OF SOILS ASTM D422




| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 0.0 | 0.1 | 18.0 | 5.8 | 64.1 | 12.0 |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| #4 | 100.0 | | |
| #10 | 99.9 | | |
| #20 | 88.9 | | |
| #40 | 81.9 | | |
| #60 | 79.0 | | |
| #100 | 77.5 | | |
| #200 | 76.1 | | |

* (no specification provided)

**Material Description**

LIME TREATMENT SOLIDS - POND 18 - REDDISH BROWN

**Atterberg Limits**

PL= 62 LL= 67 PI= 5

**Coefficients**

$D_{90}$= 0.9174 $D_{85}$= 0.6099 $D_{60}$= 0.0427
$D_{50}$= 0.0372 $D_{30}$= 0.0280 $D_{15}$= 0.0059
$D_{10}$= 0.0045 $C_u$= 9.57 $C_c$= 4.12

**Classification**

USCS= AASHTO= A-5(11)

**Remarks**

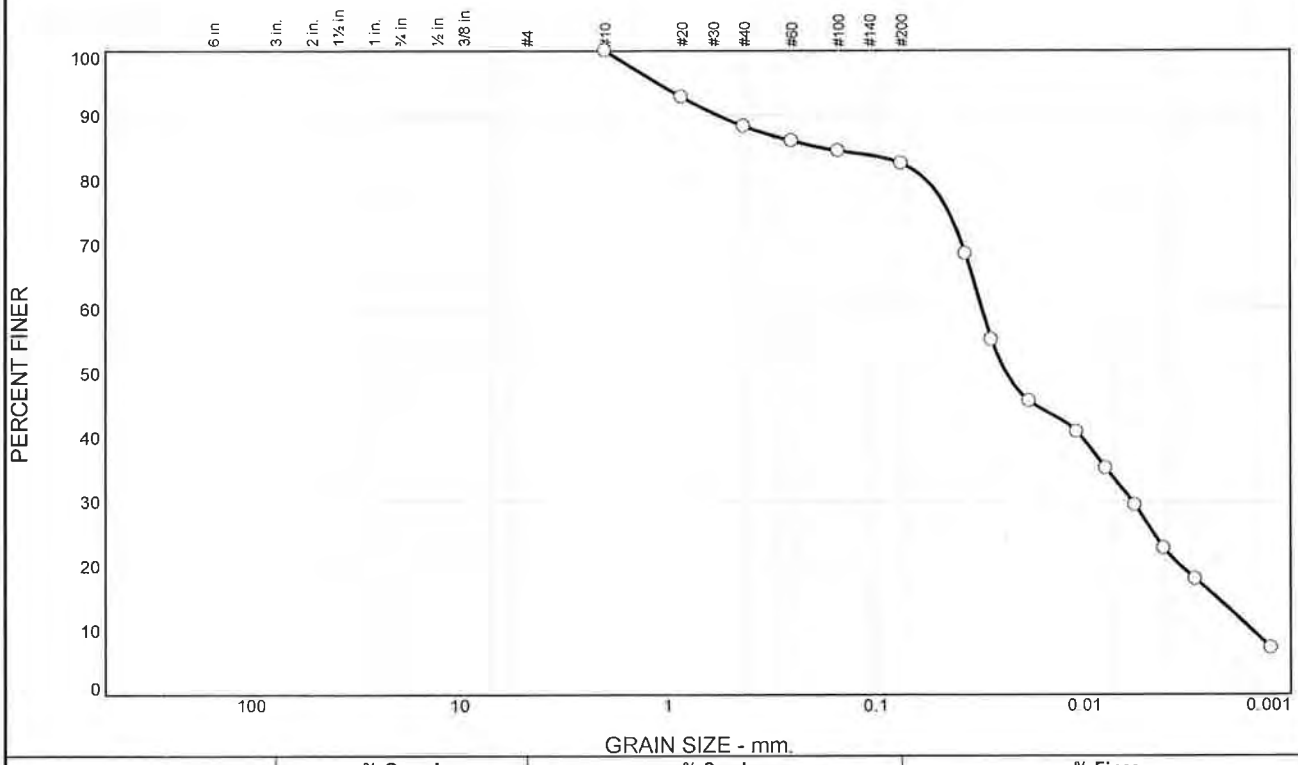
**Source of Sample:** B-ST18-1 **Depth:** 0.0"-30.0"
**Sample Number:** ST18-1 **Date:** 10/27/2011

AECOM

**Client:** BP
**Project:** RICO ARGENTINE SITE OU01, RICO, CO.
**Project No:** 60157757

**Tested By:** EMR **Checked By:** WPQ

# PARTICLE SIZE ANALYSIS OF SOILS ASTM D422




| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 0.0 | 0.0 | 11.6 | 5.9 | 55.5 | 27.0 |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| #10 | 100.0 | | |
| #20 | 92.9 | | |
| #40 | 88.4 | | |
| #60 | 86.1 | | |
| #100 | 84.5 | | |
| #200 | 82.5 | | |

* (no specification provided)

**Material Description**

LIME TREATMENT SOLIDS - POND 18 - REDDISH BROWN

**Atterberg Limits**

PL= 74 LL= 77 PI= 3

**Coefficients**

$D_{90}$= 0.5651 $D_{85}$= 0.1805 $D_{60}$= 0.0311
$D_{50}$= 0.0238 $D_{30}$= 0.0058 $D_{15}$= 0.0023
$D_{10}$= 0.0015 $C_u$= 20.38 $C_c$= 0.71

**Classification**

USCS= AASHTO= A-5(13)

**Remarks**

**Source of Sample:** B-ST18-3 **Depth:** 12.0"-42.0"
**Sample Number:** ST18-3 **Date:** 10/27/2011

AECOM

**Client:** BP
**Project:** RICO ARGENTINE SITE OU01, RICO, CO.
**Project No:** 60157757

**Tested By:** EMR **Checked By:** WPQ

# Starter Dike Foundation Calculations

Max. Additional load from Starter Dike (relative to existing grade):

SSR-102

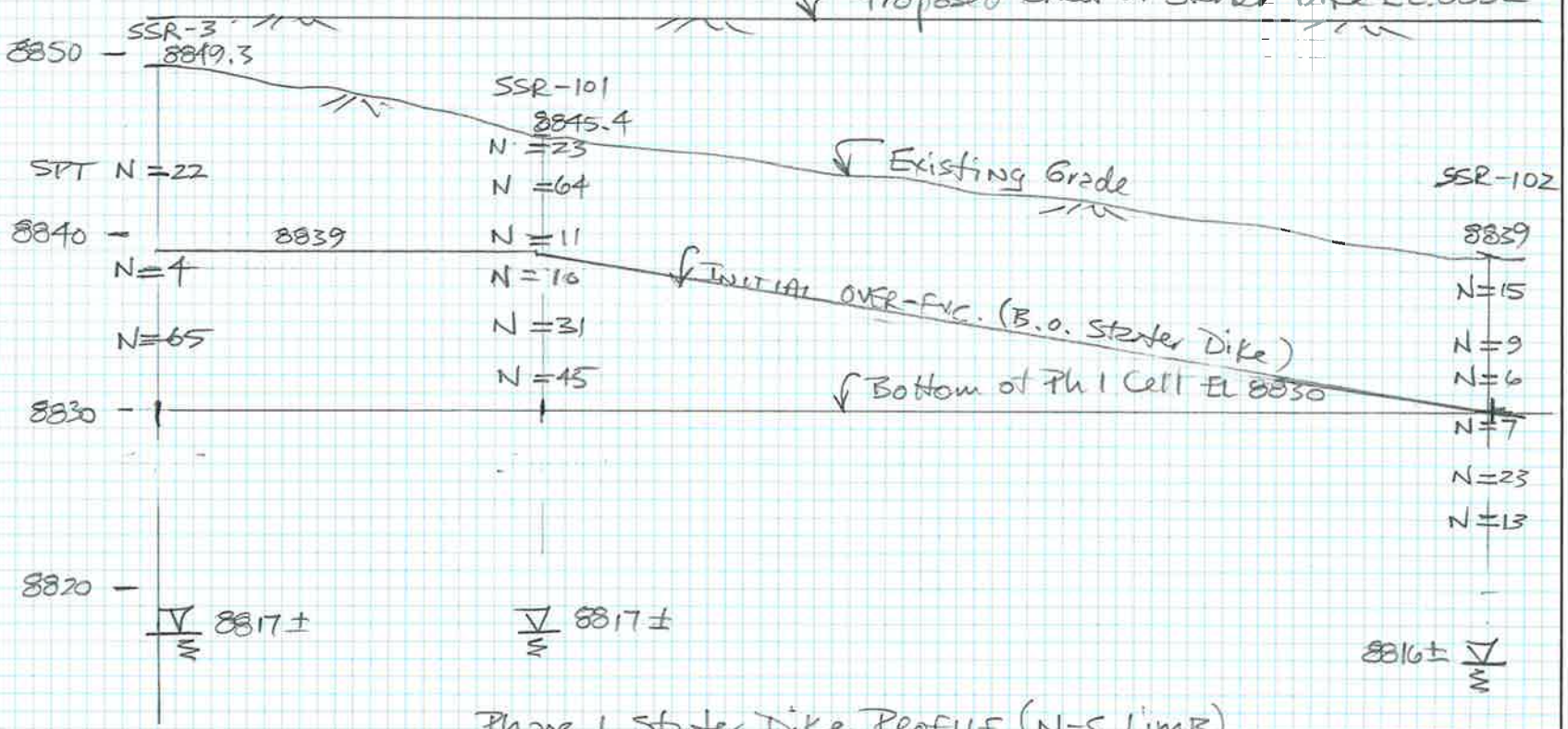
$\Delta \bar{\sigma}_v \cong 130\,pcf\,(8852 - 8839) = 1690 \approx 1700\,psf = 1.7\,ksf$

Considering overexc. Elev:

$\Delta \bar{\sigma}_v \approx 130\,pcf\,(8852 - 8830) = 2860\,psf = 2.86\,ksf$

For mat foundation, max. $\Delta H = 1$ inch foundation settlement

$\bar{\sigma}_{allow}\,(ksf) = N/4 \Rightarrow N_{min} = \sigma_{allow}\,(ksf) \cdot 4 = 2.86(4) \cong 11$ bpf (initial recompaction @ overexc. level will improve subgrade to achieve this)




Phase I Starter Dike Profile (N-S Limb)

AECOM

JOB TITLE Fico - Ph II Repository (Starter Dike foundation)

JOB NO. 60306858

CALCULATION NO.

ORIGINATOR ESD

DATE 10-14 2013

REVIEWER

DATE

SCALE

SHEET NO. 1 OF 6

Grid: 10x10 = 1"

AECOM

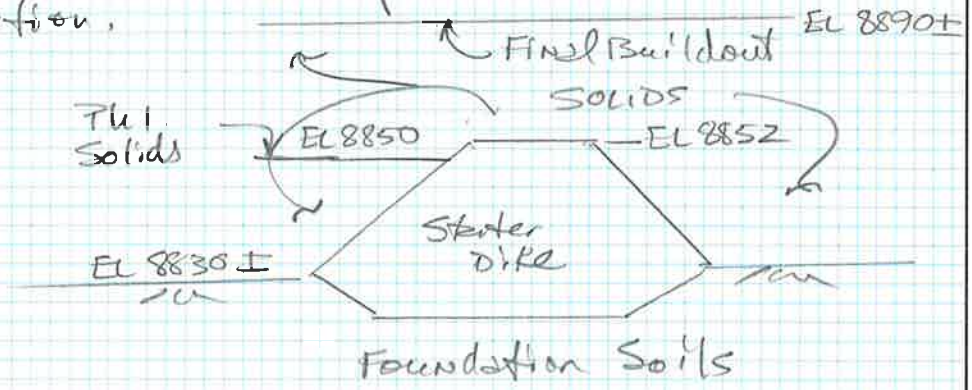
JOB TITLE Pico - Repository
JOB NO. CALCULATION NO.
ORIGINATOR SED DATE 10-14-13
REVIEWER DATE
SCALE SHEET NO. 2 OF 6

~~At~~ Final Buildout, Bearing Capacity

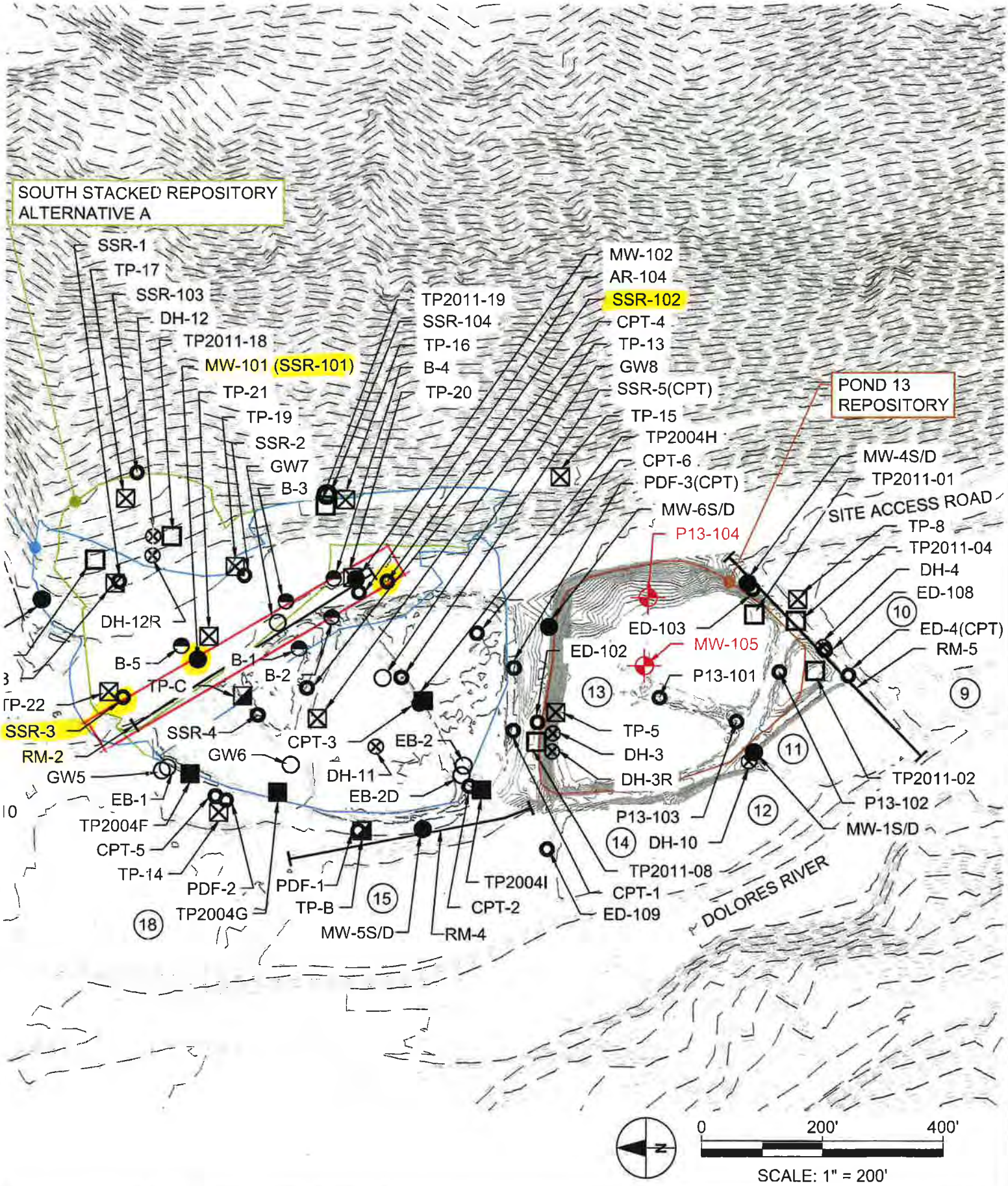
$$\overline{\Delta\sigma_v} \approx \underbrace{(8890-8852)(60\,pcf)}_{\text{solids}} + \underbrace{(8852-8830)(130\,pcf)}_{\text{starter dike}} = 2280 + 2860 = 5140\,psf \text{ or } 5.14\,ksf$$

$$\therefore N_{reqd} = \overline{\sigma}_{v\,allow} \times 4 = 5.14\,ksf\,(4) = 20.5 \approx \underline{20\ bpf}$$ reqd of fdn. material

Since solids would be placed incrementally over many years, the granular foundation would have opportunity to consolidate & strengthen over time, in addition to overexc./recompaction at time of orig. construction.




Grid: 10x10 = 1"


SOUTH STACKED REPOSITORY
ALTERNATIVE A
POND 13
REPOSITORY
SITE ACCESS ROAD
DOLORES RIVER
SSR-1
TP-17
SSR-103
DH-12
TP2011-18
MW-101 (SSR-101)
TP-21
TP-19
SSR-2
GW7
B-3
TP2011-19
SSR-104
TP-16
B-4
TP-20
MW-102
AR-104
SSR-102
CPT-4
TP-13
GW8
SSR-5(CPT)
TP-15
TP2004H
CPT-6
PDF-3(CPT)
MW-6S/D
P13-104
MW-4S/D
TP2011-01
TP-8
TP2011-04
DH-4
ED-108
ED-4(CPT)
RM-5
DH-12R
B-5
B-1
B-2
TP-C
TP-22
SSR-3
RM-2
SSR-4
GW6
GW5
EB-1
TP2004F
CPT-5
TP-14
PDF-2
TP2004G
PDF-1
TP-B
MW-5S/D
CPT-3
DH-11
EB-2
EB-2D
RM-4
CPT-2
TP2004I
ED-109
CPT-1
TP2011-08
DH-10
P13-103
P13-101
ED-103
MW-105
ED-102
TP-5
DH-3
DH-3R
TP2011-02
P13-102
MW-1S/D
9
10
11
12
13
14
15
18
0
200'
400'
SCALE: 1" = 200'

4/6

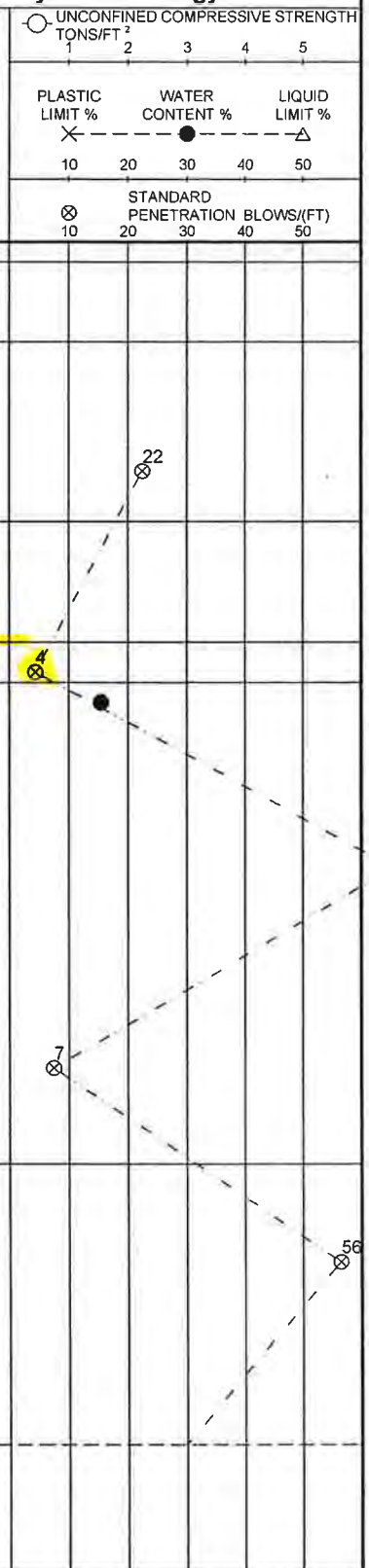
AECOM

| CLIENT | LOG OF BORING NUMBER |
|---|---|
| **Atlantic Richfield Company** | **SSR3** |
| PROJECT NAME | ARCHITECT-ENGINEER |
| **Rico-Argentine Site - OU01** | **Drilling Company: Boart Longyear** |

SITE LOCATION

SURFACE ELEVATION +8,849.3 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT LBS./FT³ |
|---|---|---|---|---|---|---|---|
| | | 1 | SS | | | 0.5 CONCRETE pad<br>Well graded GRAVEL with Clay and Sand (GW-GC) - subangular to subrounded 3" minus gravel - wet - brown | |
| | | | PA | | | 2.5 Well graded GRAVEL with Sand (GW) - angular to rounded gravel-cobbles 6" minus - medium dense - dry - brown | |
| 5.0 | | 2 | SS | | | | |
| | | | PA | | | 7.0 Damp<br>Gravelly CLAY with Sand (GC) - subangular gravel - cobble 4" minus - damp - brown | |
| 10.0 | | 3 | SS | | | 10.0 Well graded GRAVEL with Sand (GW) - subangular to rounded - wet - brown - loose - saturated<br>11.0 Gravelly CLAY with Sand (CL) - gravel to cobbles - subangular to subrounded 5" minus - very dense to loose - damp - brown | |
| | | | PA | | | | |
| 15.0 | | 4 | SS | | | | |
| | | | PA | | | | |
| 20.0 | | 5 | SS | | | Less cobbles | |
| | | | PA | | | 23.0 Clayey GRAVEL with Sand (GC) - gravel to cobbles - subangular to subrounded 5" minus - very dense to medium dense - damp - brown | |
| 25.0 | | 6 | SS | | | | |
| | | | PA | | | | |
| 30.0 | | | | | | ... continued | |




The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60157757 | SHEET NO. 1 OF 4

AECOM LOG 60157757.GPJ FS_DATATEMPLATE.GDT 12/13/11

AECOM

| CLIENT | LOG OF BORING NUMBER |
|---|---|
| Atlantic Richfield Company | SSR-101 (MW) DRAFT |
| PROJECT NAME | ARCHITECT-ENGINEER |
| Rico - Argentine Mine Site | Anderson Engineering Company, Inc. |

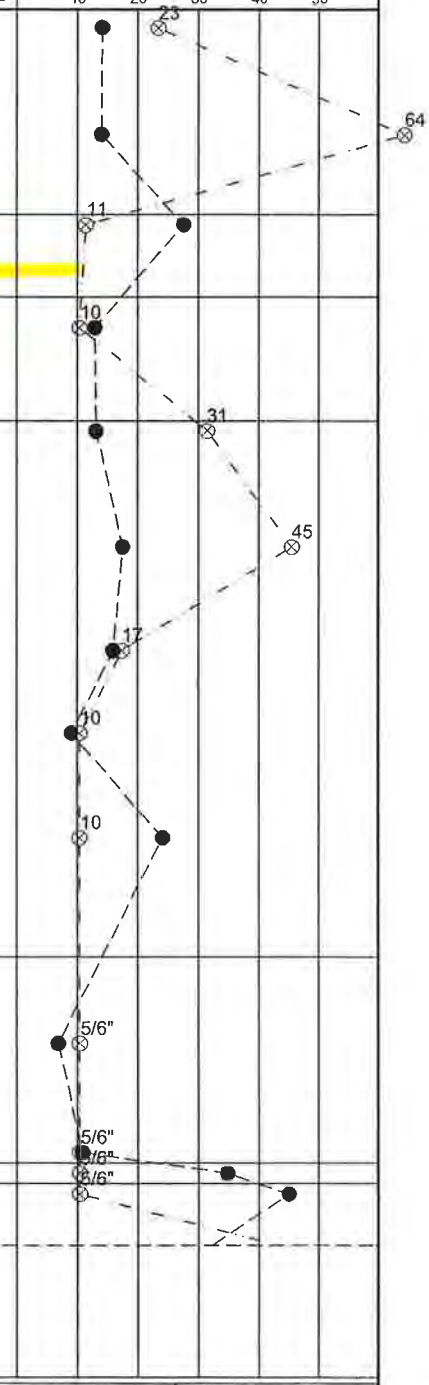
SITE LOCATION
Rico-Argentine

UNCONFINED COMPRESSIVE STRENGTH TONS/FT.$^2$ 1 2 3 4 5

PLASTIC LIMIT % — WATER CONTENT % — LIQUID LIMIT % 10 20 30 40 50

STANDARD PENETRATION BLOWS/(FT) 10 20 30 40 50

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.$^3$ |
|---|---|---|---|---|---|---|---|
| | | | | | | SURFACE ELEVATION +8,845.4 Feet | |
| | | 1 | SS | | | FILL: Well graded gravel, some fine to coarse sand, little silt/clay - dark brown 7.5YR3/2 - medium dense to dense - moist (FILL: GC) NOTE: Cobbles noted at 1.5 ft | |
| | | | RB | | | | |
| | | 2 | SS | | | | |
| 5.0 | | | RB | | | 5.0 | |
| | | 3 | SS | | | FILL: Well graded sand, some fine to coarse gravel, some silt and clay - brown 10YR4/3 - medium dense - moist (FILL: SC) | |
| | | | RB | | | 7.0 | |
| | | 4 | SS | | | FILL: Well graded gravel, some fine to coarse sand, little silt and clay - very pale brown 10YR8/3 - loose - moist (FILL: GM) | |
| 10.0 | | | RB | | | 10.0 | |
| | | 5 | SS | | | FILL (MINE WASTE ROCK): Well graded gravel and fine to coarse sand, some silt/clay, with pyrite flecks - oxidized colors, grays to red browns grading to mostly yellow 2.5Y7/6 with oxidized zones - dense to loose- moist (FILL: GM - MINE WASTE ROCK) | |
| | | | RB | | | | |
| | | 6 | SS | | | | |
| 15.0 | | | RB | | | EL 8830± | |
| | | 7 | SS | | | | |
| | | | RB | | | | |
| | | 8 | SS | | | | |
| 20.0 | | | RB | | | | |
| | | 9 | SS | | | | |
| | | | RB | | | 23.0 | |
| 25.0 | | 10 | SS | | | FILL: Well graded gravel and sand, trace silt/clay - yellowish brown 10YR5/4 - loose - moist (FILL: GW-GM) | |
| | | | RB | | | | |
| | | 11 | SS | | | 28.0 | |
| | | 11B | SS | | | 28.5 FILL: Poorly graded gravel and sand, little silt/clay, trace organics - 40% fine gravel, 38% fine to coarse sand, 14% to 22% silt/clay - dark | |
| | | 11C | SS | | | | |
| 30.0 | | | | | | | |




. . . continued

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

AECOM JOB NO. 60239818 | SHEET NO. 1 OF 6

6/6

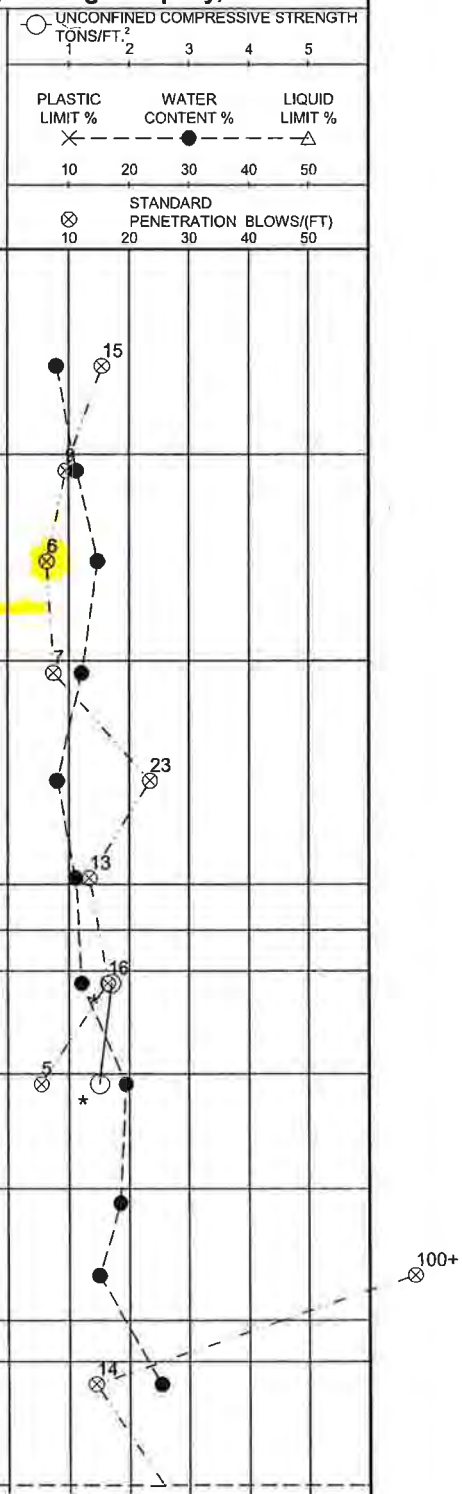
AECOM

| CLIENT | LOG OF BORING NUMBER |
|---|---|
| **Atlantic Richfield Company** | **SSR-102/102A** |
| PROJECT NAME | ARCHITECT-ENGINEER |
| **Rico - Argentine Mine Site** | **Anderson Engineering Company, Inc.** |

SITE LOCATION
**Rico-Argentine**

SURFACE ELEVATION +8,839.0 Feet

| DEPTH(FT) | ELEVATION(FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DISTANCE | RECOVERY | DESCRIPTION OF MATERIAL | UNIT DRY WT. LBS./FT.³ |
|---|---|---|---|---|---|---|---|
| | | 1 | AS | | | FILL: Clayey well graded sand, some fine gravel - 26% gravel, 47% sand, 27% fines - brown 10YR5/3 - medium dense - moist (FILL: SC) | |
| | | 2 | SS | | | | |
| 5.0 | | | HSA | | | 5.0 | |
| | | 3 | SS | | | FILL: Clayey gravelly silt, some fine to coarse sand - dark brown 7.5YR3/4 - loose - moist (FILL: ML) | |
| | | | HSA | | | | |
| | | 4 | SS | | | EL. 8830 ± | |
| 10.0 | | | HSA | | | 10.0 | |
| | | 5 | SS | | | FILL: Clayey gravel, some fine to coarse sand - 89% sand and gravel, 11% fines - dark brown 10YR3/3 - loose to medium dense - wet (FILL: GC) | |
| | | | HSA | | | | |
| | | 6 | SS | | | | |
| 15.0 | | | HSA | | | 15.4 | |
| | | 7 | SS | | | Partly organic gravelly clay (possible buried topsoil), low plasticity - black - medium dense - moist (GC) | |
| | | | HSA | | | 16.5 Cobbles and gravel | |
| | | | | | | 17.5 | |
| | | 8 | SS | | | Silt, little coarse sand, little gravel, non-plastic - dark brown 10YR3/4 - stiff (CL) | |
| 20.0 | | | HSA | | | 20.0 | |
| | | 9 | SS | | | Lean clay, some fine to coarse gravel, little fine to coarse sand - dark brown 10YR3/4 - stiff (CL) | |
| | | | HSA | | | 22.8 | |
| | | 10 | ST | | | Well graded gravel, some fine to coarse sand, little silt and clay - dark grayish brown 10YR4/2 - extremely dense - wet (GC-GM) | 109 |
| 25.0 | | 11 | SS | | | | |
| | | | HSA | | | 26.0 Cobble | |
| | | | | | | 27.0 | |
| | | 12 | SS | | | Well graded gravel, some fine to coarse sand, little silt and clay - dark grayish brown 10YR4/2 - medium dense - wet (GC-GM) | |
| 30.0 | | | | | | | |




. . . continued

* Calibrated Penetrometer

The stratification lines represent the approximate boundary lines between soil types: in situ, the transition may be gradual.

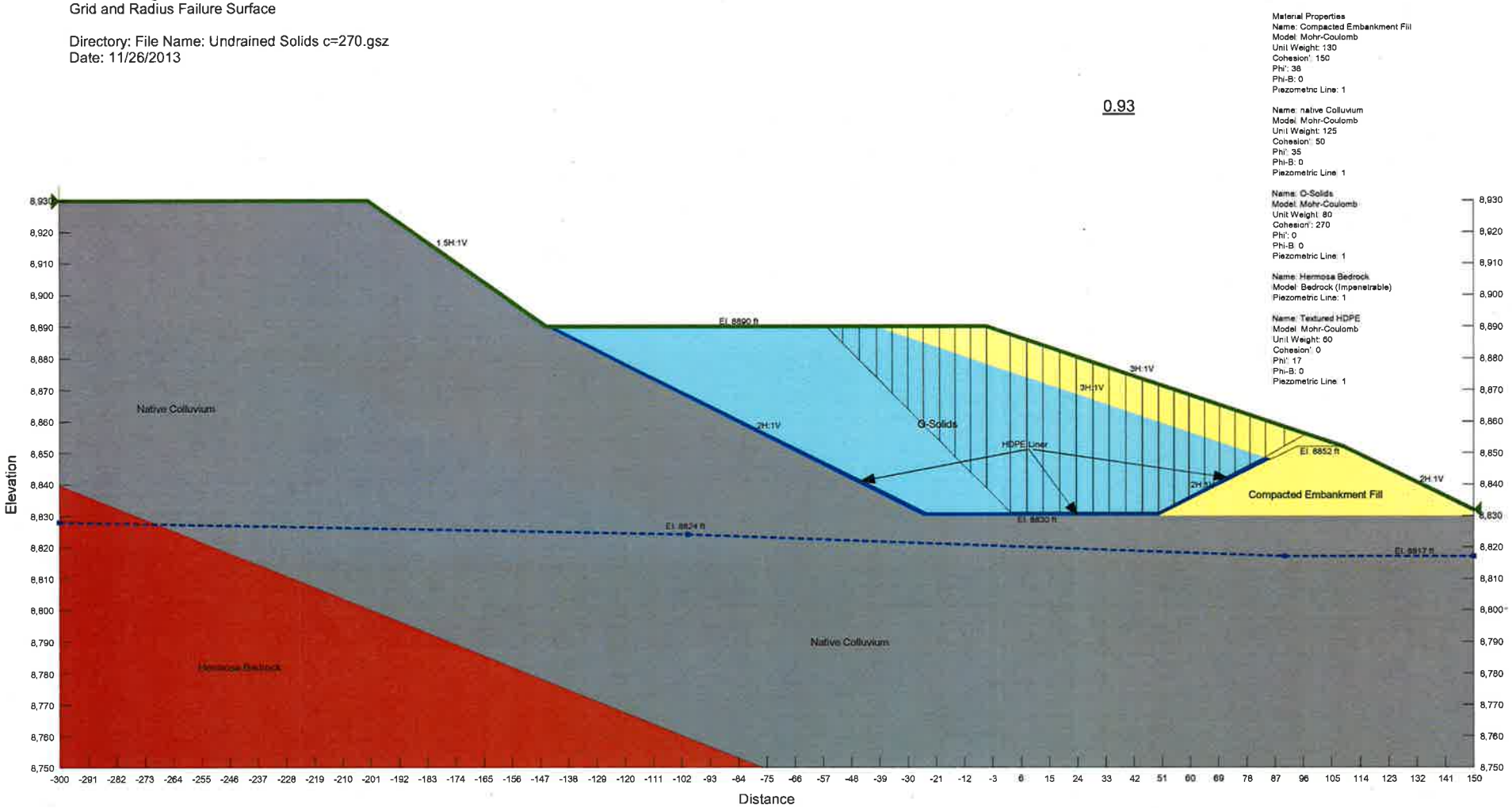
AECOM JOB NO. 60239818 | SHEET NO. 1 OF 6

AECOM LOG 60239818 RICO-UPDATED 4-8-13.GPJ FS_DATATEMPLATE.GDT 4/29/13

# Slope Stability Results

Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Undrained Solids c=270.gsz
Date: 11/26/2013



Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Undrained Solids 1.gsz
Date: 11/25/2013

1.99

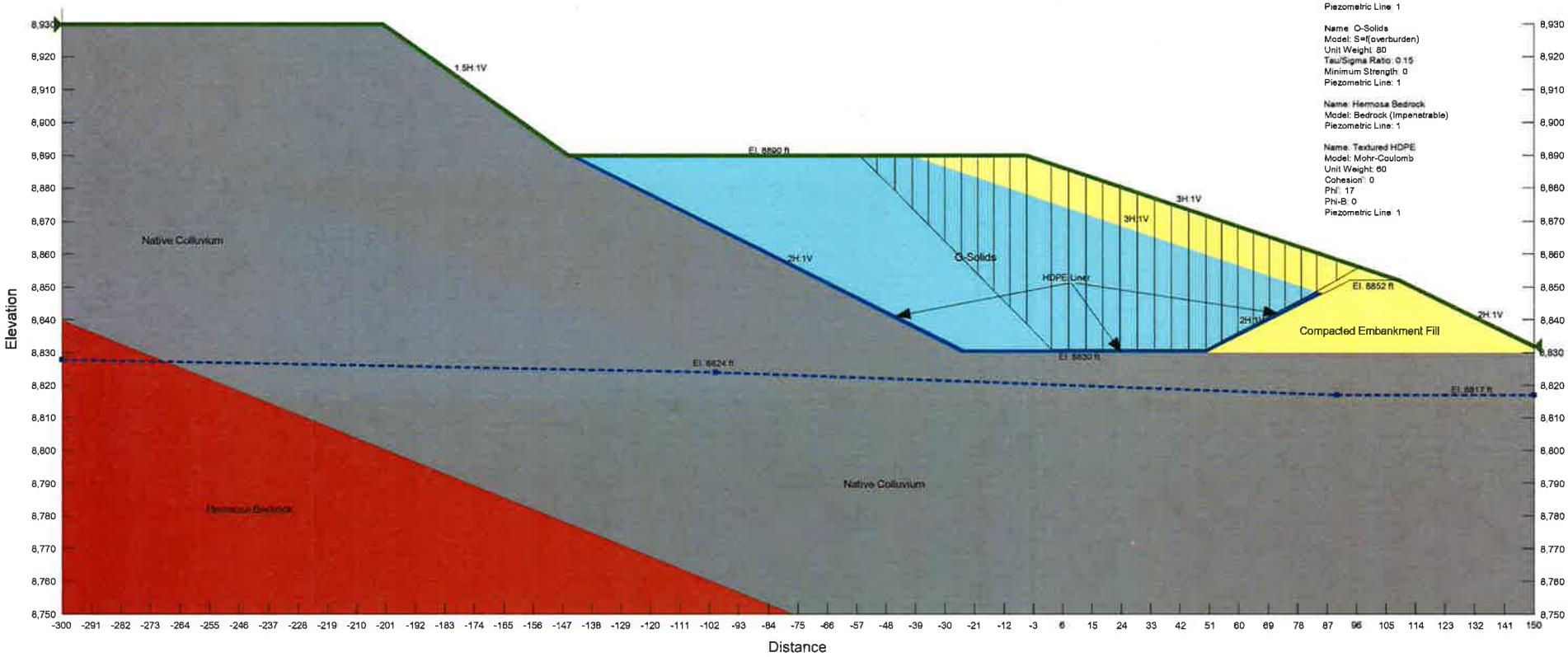
Material Properties
Name: Compacted Embankment Fill
Model: Mohr-Coulomb
Unit Weight: 130
Cohesion': 150
Phi': 38
Phi-B: 0
Piezometric Line: 1

Name: native Colluvium
Model: Mohr-Coulomb
Unit Weight: 125
Cohesion': 50
Phi': 35
Phi-B: 0
Piezometric Line: 1

Name: O-Solids
Model: S=f(overburden)
Unit Weight: 80
Tau/Sigma Ratio: 0.15
Minimum Strength: 0
Piezometric Line: 1

Name: Hermosa Bedrock
Model: Bedrock (Impenetrable)
Piezometric Line: 1

Name: Textured HDPE
Model: Mohr-Coulomb
Unit Weight: 60
Cohesion': 0
Phi': 17
Phi-B: 0
Piezometric Line: 1



Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Undrained Solids 2.gsz
Date: 11/25/2013

2.63

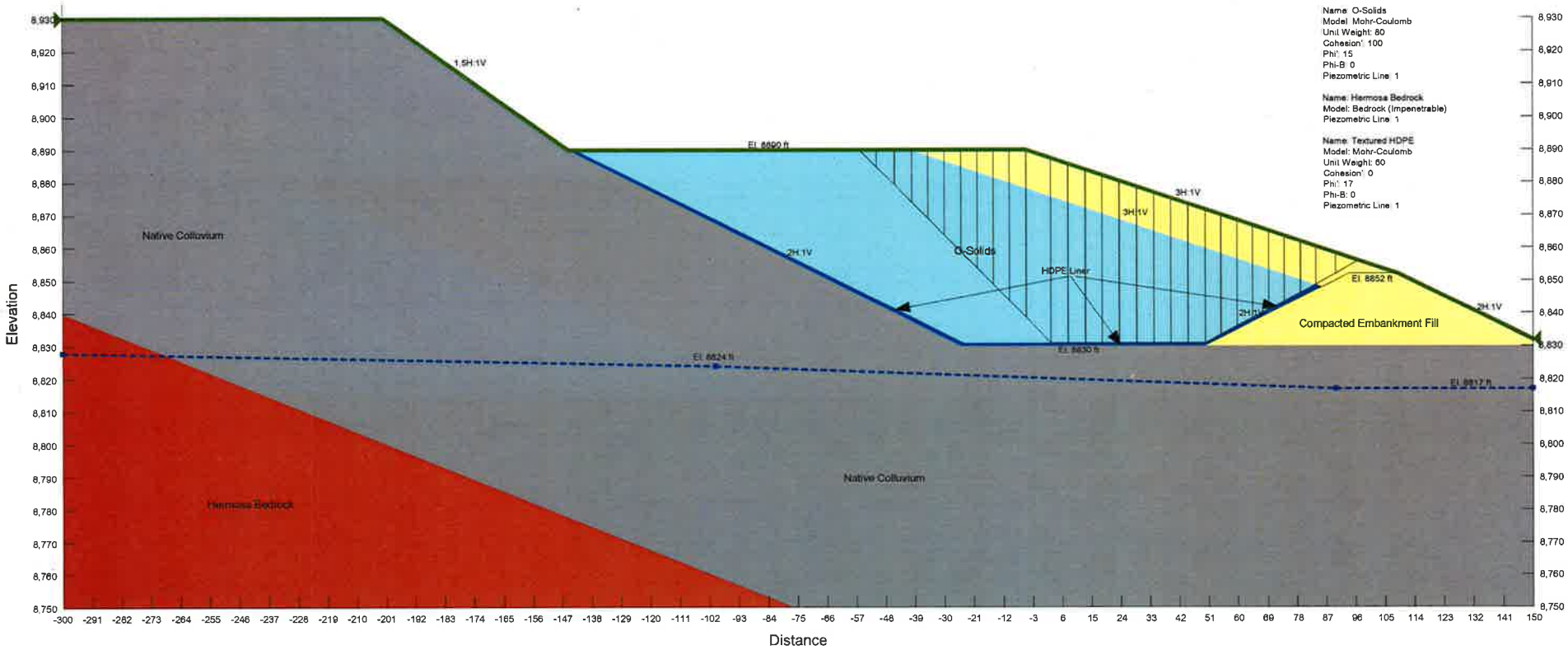
Material Properties
Name: Compacted Embankment Fill
Model: Mohr-Coulomb
Unit Weight: 130
Cohesion': 150
Phi': 38
Phi-B: 0
Piezometric Line: 1

Name: native Colluvium
Model: Mohr-Coulomb
Unit Weight: 125
Cohesion': 50
Phi': 35
Phi-B: 0
Piezometric Line: 1

Name: O-Solids
Model: Mohr-Coulomb
Unit Weight: 80
Cohesion': 100
Phi': 15
Phi-B: 0
Piezometric Line: 1

Name: Hermosa Bedrock
Model: Bedrock (Impenetrable)
Piezometric Line: 1

Name: Textured HDPE
Model: Mohr-Coulomb
Unit Weight: 60
Cohesion': 0
Phi': 17
Phi-B: 0
Piezometric Line: 1



Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Drained Solids Phi=15 FS.gsz
Date: 11/26/2013

2.63

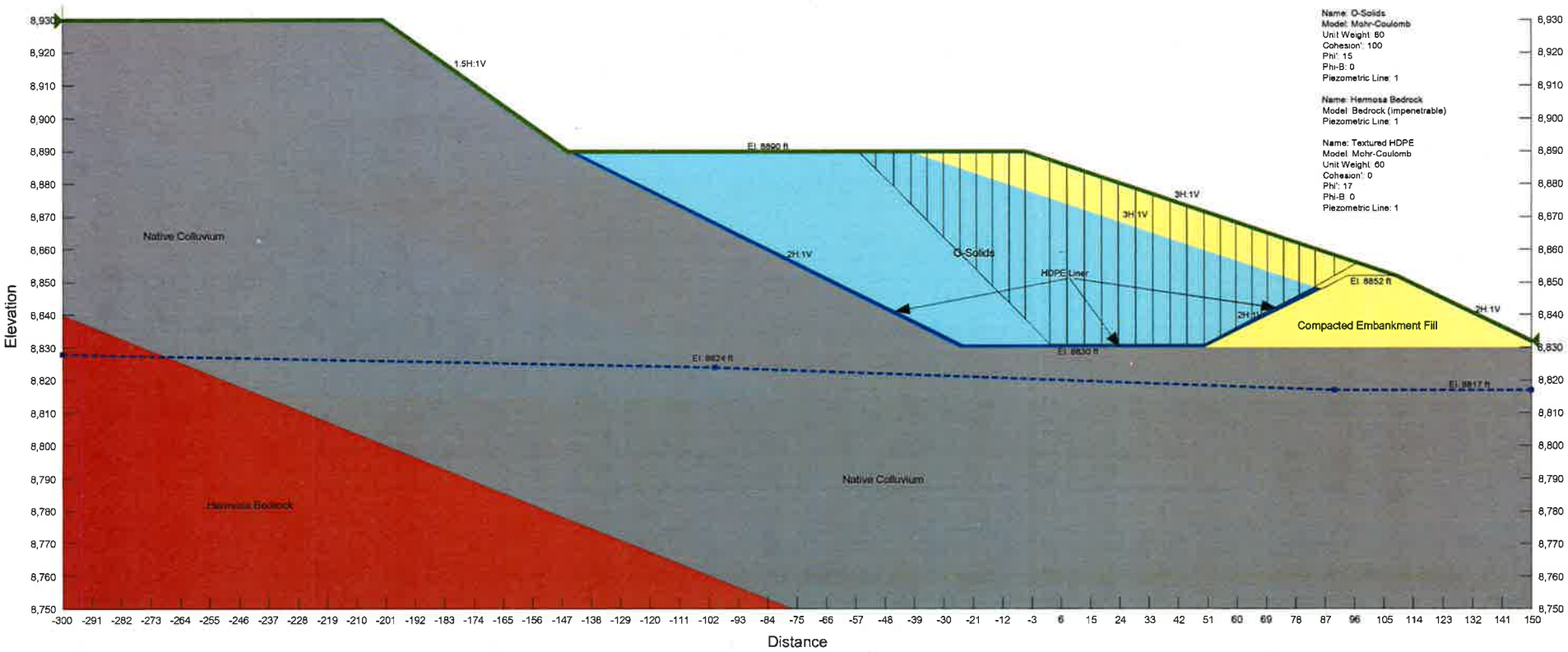
Material Properties
Name: Compacted Embankment Fill
Model: Mohr-Coulomb
Unit Weight: 130
Cohesion': 150
Phi': 38
Phi-B: 0
Piezometric Line: 1

Name: native Colluvium
Model: Mohr-Coulomb
Unit Weight: 125
Cohesion': 50
Phi': 35
Phi-B: 0
Piezometric Line: 1

Name: O-Solids
Model: Mohr-Coulomb
Unit Weight: 80
Cohesion': 100
Phi': 15
Phi-B: 0
Piezometric Line: 1

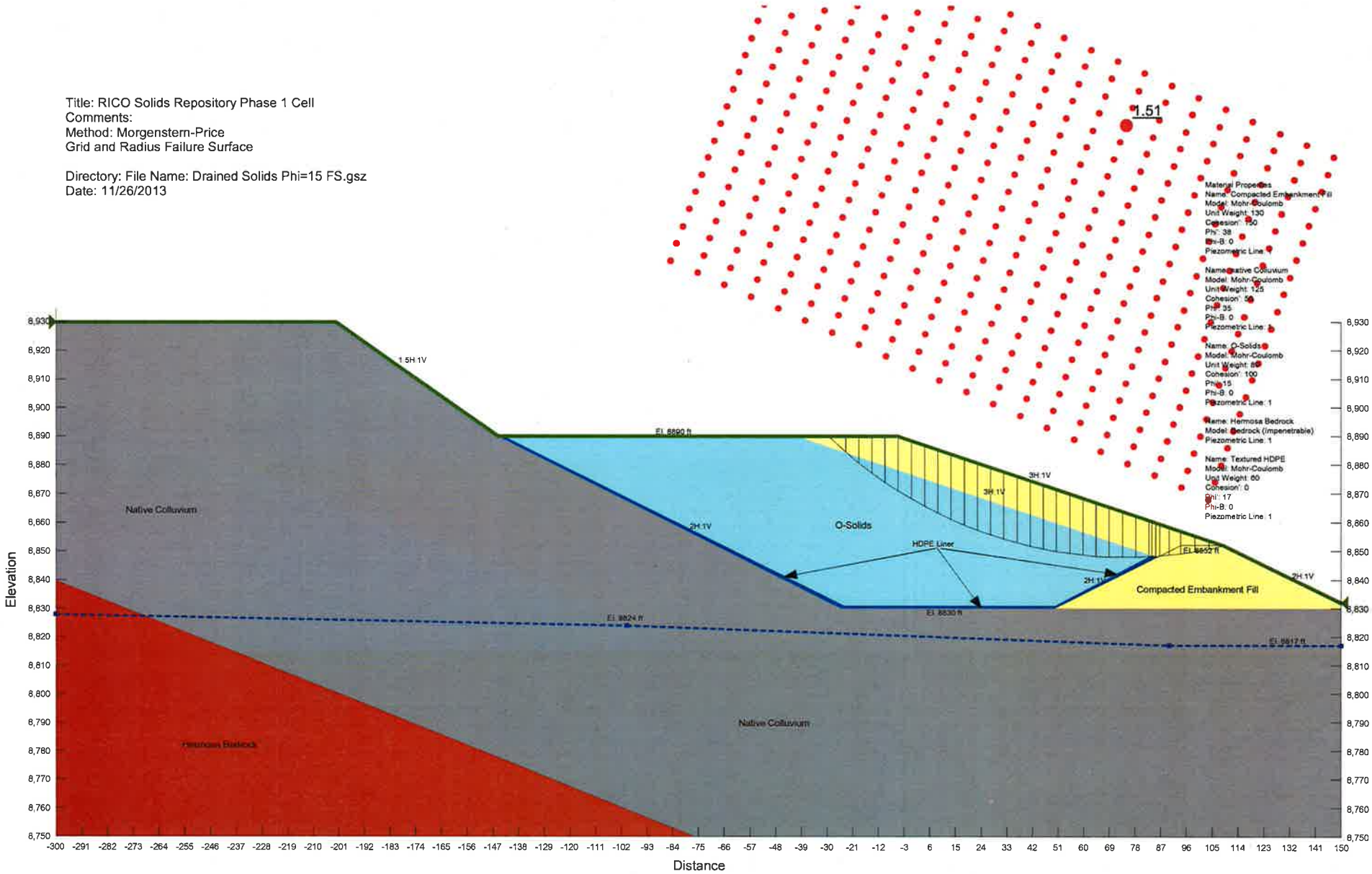
Name: Hermosa Bedrock
Model: Bedrock (impenetrable)
Piezometric Line: 1

Name: Textured HDPE
Model: Mohr-Coulomb
Unit Weight: 60
Cohesion': 0
Phi': 17
Phi-B: 0
Piezometric Line: 1



Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Drained Solids Phi=15 FS.gsz
Date: 11/26/2013

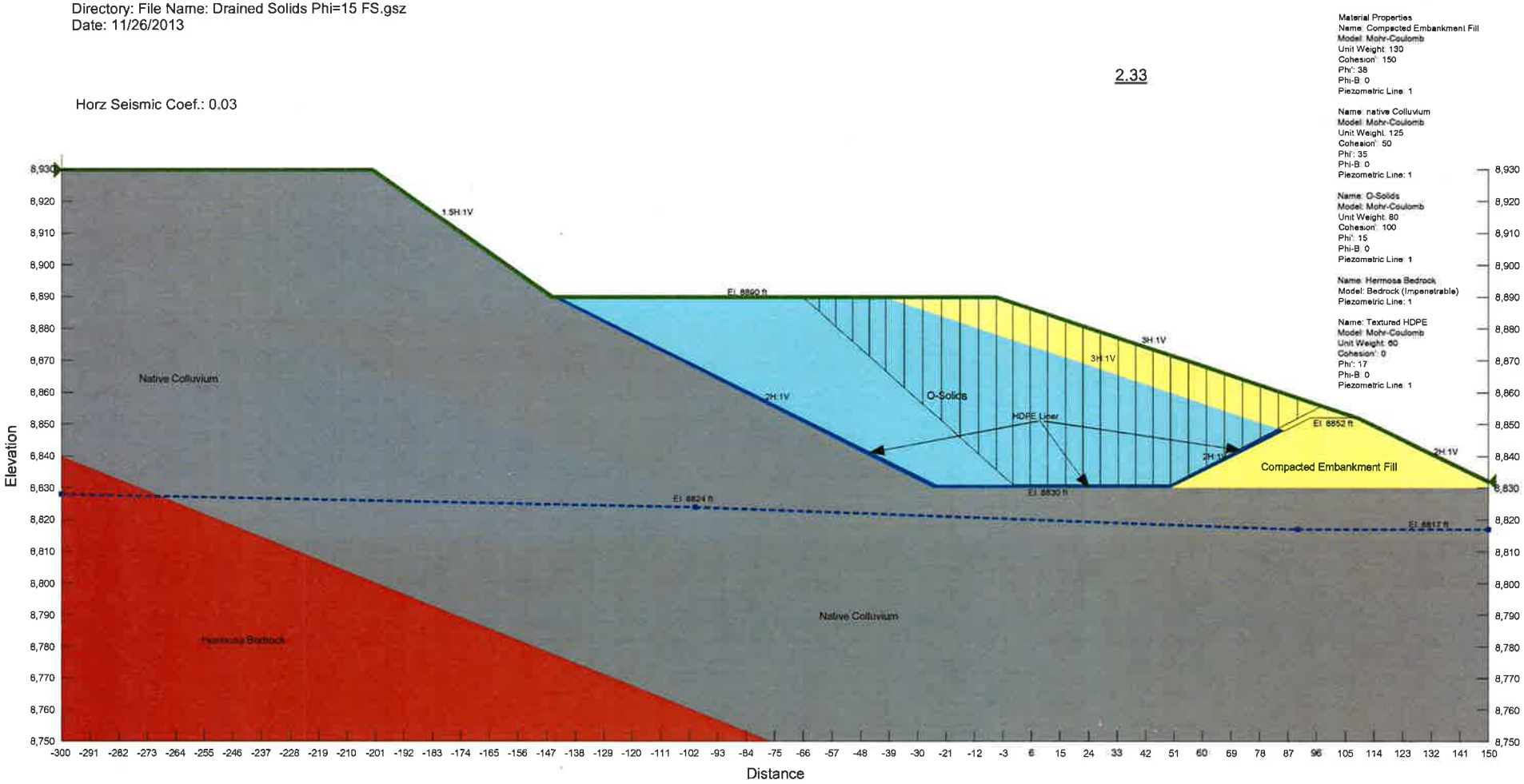


Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Drained Solids Phi=15 FS.gsz
Date: 11/26/2013

2.33

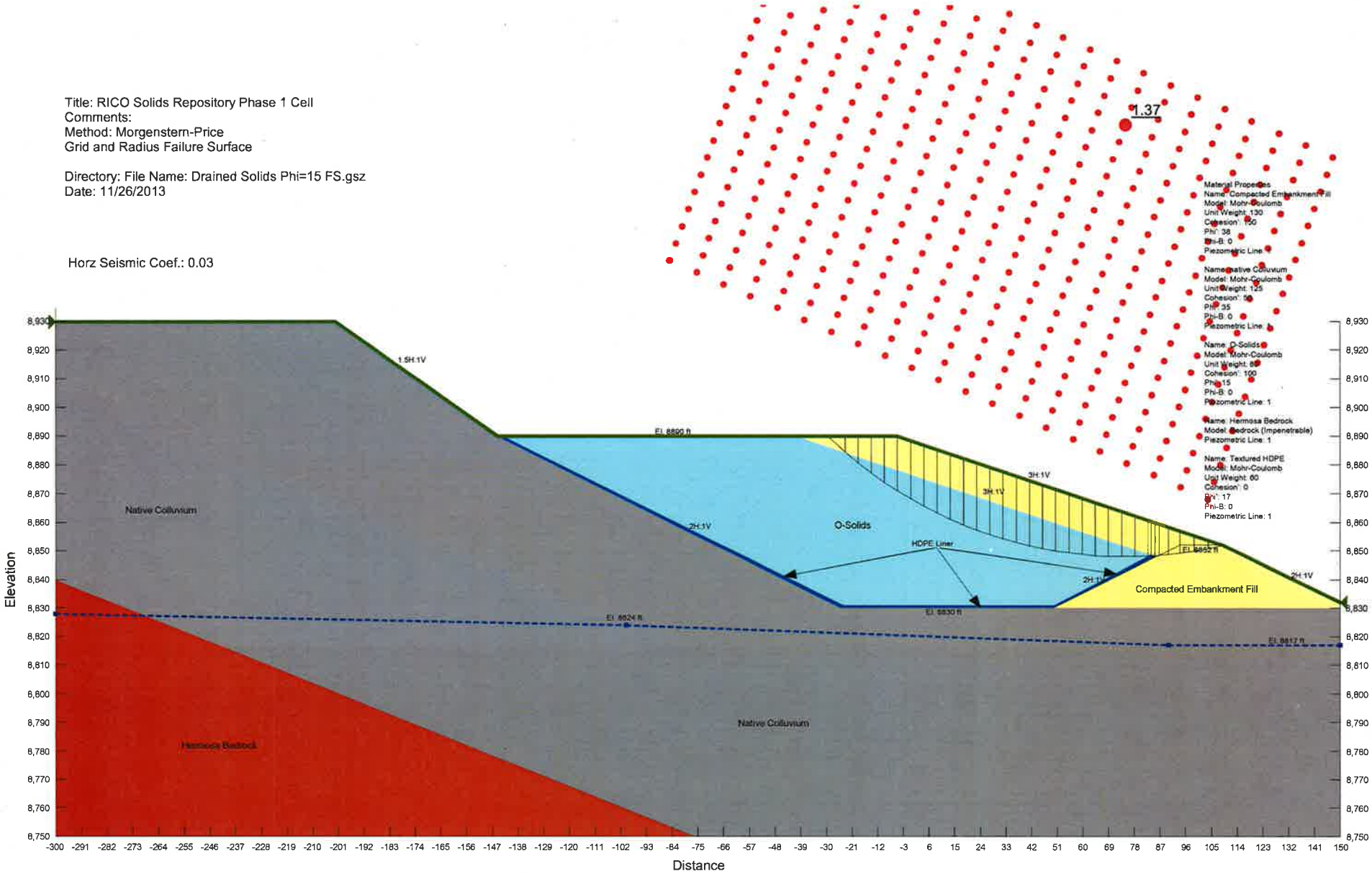
Horz Seismic Coef.: 0.03



Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Drained Solids Phi=15 FS.gsz
Date: 11/26/2013

Horz Seismic Coef.: 0.03

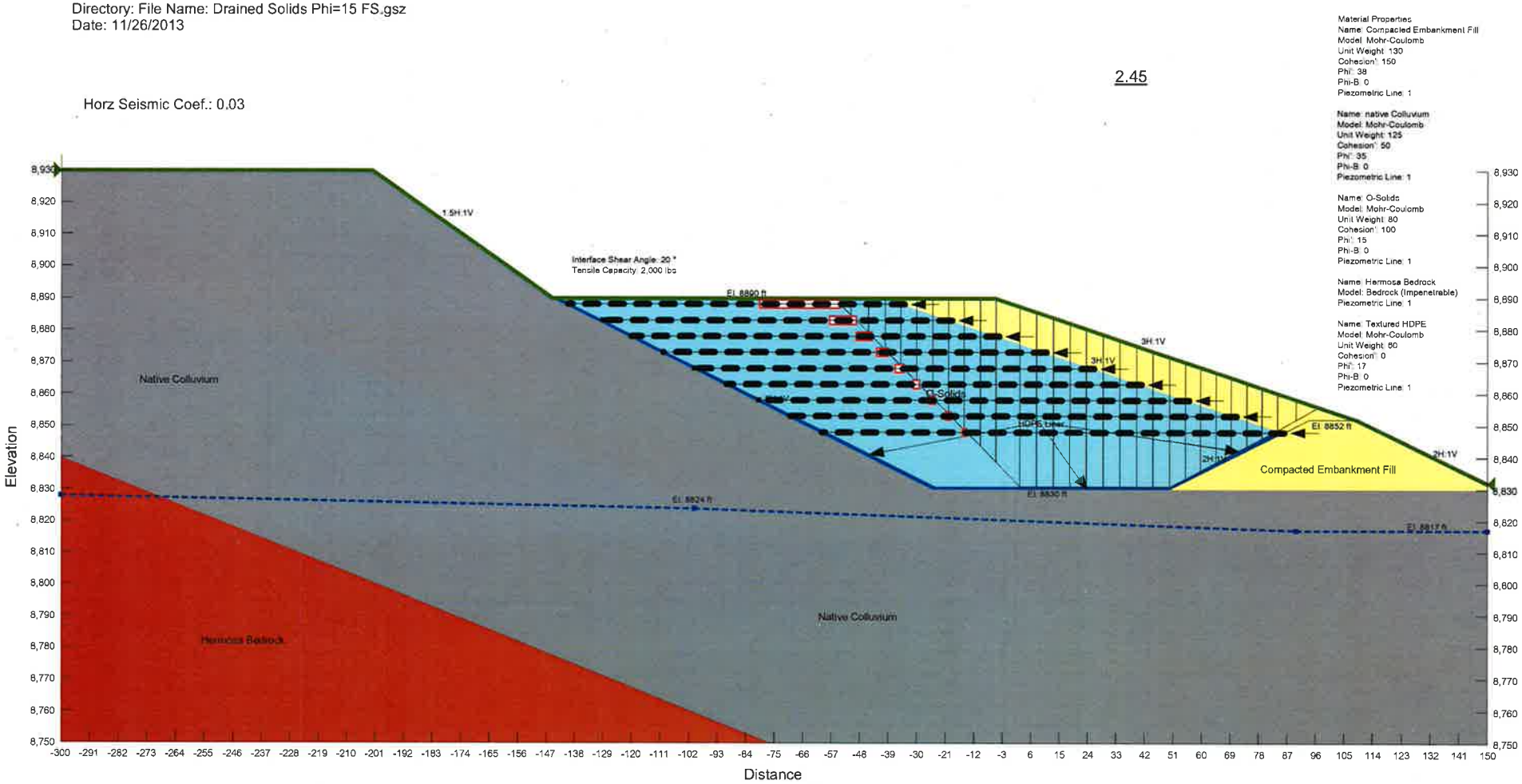


Title: RICO Solids Repository Phase 1 Cell
Comments:
Method: Morgenstern-Price
Grid and Radius Failure Surface

Directory: File Name: Drained Solids Phi=15 FS.gsz
Date: 11/26/2013

2.45

Horz Seismic Coef.: 0.03



# Surface Water Runon Calculations

**Solids Repository - Runon Calculations (TR-55 method)**

| | Sub Basin | Entire Catchment (west of FS road) | North Catchment (west of FS road) | South Catchment (west of FS road) | North Catchment (worst case) | South Catchment (worst case) | Notes |
|---|---|---|---|---|---|---|---|
| | Area (ft^2) | 675975 | 222238 | 453737 | 347498 | 759049 | |
| | Area (acres) | 15.52 | 5.10 | 10.42 | 7.98 | 17.43 | |
| Am | Area (square miles) | 0.02425 | 0.00797 | 0.01628 | 0.01246 | 0.02723 | |
| | Storm Event (i.e. 100yr, 24hr) | 100yr, 24hr | 100yr, 24hr | 100yr, 24hr | 100yr, 24hr | 100yr, 24hr | required by CDPHE |
| P | Design rainfall (inches) | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | source: NOAA Atlas 14, Volume 8, Version 2 |
| P | 2-yr, 24-hr rainfall (inches) | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 | source: NOAA Atlas 14, Volume 8, Version 2 |
| CN | Curve Number CN | 74 | 74 | 74 | 74 | 74 | see calc below, source: Technical Release 55 |
| S | Potential Max Retention (inches) | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | |
| Ia | Initial Abstraction (inches) | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | |
| Q | Runoff (inches) | **1.38** | **1.38** | **1.38** | **1.38** | **1.38** | |
| Q | **Runoff (acre-ft)** | **1.78** | **0.59** | **1.20** | **0.92** | **2.00** | |
| L | Total Flow Length (ft) | 1100 | 1100 | 1100 | 3000 | 3000 | |
| s | Slope (ft/ft) | 0.62 | 0.62 | 0.62 | 0.58 | 0.58 | |
| n | Manning coefficient (during sheet flow) | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | woods with light underbrush |
| L | Sheet Flow Length (ft) | 300 | 300 | 300 | 300 | 300 | |
| L | Concentrated Flow Length (ft) | 800 | 800 | 800 | 2700 | 2700 | |
| Tt | Sheet Flow Travel Time (hrs) | 0.293 | 0.293 | 0.293 | 0.301 | 0.301 | |
| V | Concentrated Flow Average Velocity (ft/s) | 12 | 12 | 12 | 11.8 | 11.8 | |
| Tt | Concentrated Flow Travel Time (hrs) | 0.019 | 0.019 | 0.019 | 0.064 | 0.064 | |
| Tc | Total Time of Concentration (hrs) | 0.312 | 0.312 | 0.312 | 0.365 | 0.365 | |
| | Ia/P | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | |
| qu | Unit peak Discharge (csm/in) | 625 | 625 | 625 | 575 | 575 | |
| | Percentage of Pond or Swamp (%) | 0 | 0 | 0 | 0 | 0 | |
| Fp | Pond Adjustment Factor | 1 | 1 | 1 | 1 | 1 | |
| qp | **Peak Discharge (cfs)** | **20.9** | **6.87** | **14.04** | **9.89** | **21.60** | |

| | |
|---|---|
| | Non-highlighted cell are calculated |
| | Input cells |
| | Reference Table 2-2 from TR-55 |
| | Reference Table 3-1 from TR-55 |
| | Reference Figure 3-1 and Exhibit 4-II from TR-55 |

weighted CN calc:

| map unit | percent of area | soil group | woods-grass combination, fair condition |
|---|---|---|---|
| 154 | 17.4% | B | 65 |
| 830 | 82.6% | C | 76 |
| | | **weighted CN:** | **74** |

**Channel Sizing (manning equation, open channel flow, trapezoidal channel)**

| Section | Flow (Q) | Top Width of Flow | Flow Depth | Channel Side Slope | Bottom Width | Cross-sectional Area | Wetted Perimeter | Hydraulic Radius | Minimum Design Slope | Channel Length | Minimum Vertical Drop | Velocity | Mannings n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cfs | ft | ft | ft/ft | ft | ft^2 | ft | ft | ft/ft | ft | ft | ft/s | |
| North Catchment (west of FS road) | 6.87 | 4.5 | 0.63 | 0.50 | 2.0 | 2.05 | 4.82 | 0.43 | 0.010 | 300 | 2.94917 | 3.35 | 0.025 |
| South Catchment (west of FS road) | 14.04 | 5.6 | 0.90 | 0.50 | 2.0 | 3.42 | 6.02 | 0.57 | 0.010 | 420 | 4.24 | 4.10 | 0.025 |
| North Catchment (worst case) | 9.89 | 5.0 | 0.76 | 0.50 | 2.0 | 2.68 | 5.40 | 0.50 | 0.010 | 300 | 2.94 | 3.70 | 0.025 |
| South Catchment (worst case) | 21.60 | 6.4 | 1.11 | 0.50 | 2.0 | 4.68 | 6.96 | 0.67 | 0.010 | 420 | 4.27 | 4.61 | 0.025 |

Revised channel depth until minimum design slope = 0.01 (1 percent)
Trapezoidal channel will be constructed 2 feet deep, 10 feet wide, 2 foot bottom width, and 2:1 side slopes.
Channel typically needs stabilization if velocity is greater than 5 ft/sec, therefore no riprap stabilization necessary.
However, design includes 30 mil HDPE textured membrane plus 6 inches of gravel mulch extending over the bottom and side slopes.

| | |
|---|---|
| | Non-highlighted cell are calculated |
| | Input cells |

| Material | Manning n |
|---|---|
| *Excavated Earth Channels* | |
| Clean | 0.022 |
| Gravelly | 0.025 |
| Weedy | 0.030 |
| Stony, Cobbles | 0.035 |

Source: www.lmnoeng.com/manningn.htm

# HELP Model Results

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************



PRECIPITATION DATA FILE:    C:\HELP3\DATA4.D4
TEMPERATURE DATA FILE:      C:\HELP3\DATA7.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\DATA13.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\DATA11.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\SOLIDS1.D10
OUTPUT DATA FILE:           C:\HELP3\SOLIDS1.OUT



TIME:  12:19     DATE:  11/26/2013



******************************************************************************

     TITLE:  Solids Repository - Closed after Full Buildout

******************************************************************************



     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.



                                    LAYER  1
                                    --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
          THICKNESS                  =      6.00   INCHES
          POROSITY                   =      0.3980 VOL/VOL
          FIELD CAPACITY             =      0.2440 VOL/VOL
          WILTING POINT              =      0.1360 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.3681 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
```

NOTE: SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY 3.00
FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

LAYER 2
---

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 21

| | | | |
|---|---|---|---|
| THICKNESS | = | 12.00 | INCHES |
| POROSITY | = | 0.3970 | VOL/VOL |
| FIELD CAPACITY | = | 0.0320 | VOL/VOL |
| WILTING POINT | = | 0.0130 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.0589 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.300000012000 | CM/SEC |
| SLOPE | = | 5.00 | PERCENT |
| DRAINAGE LENGTH | = | 250.0 | FEET |

LAYER 3
---

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

| | | | |
|---|---|---|---|
| THICKNESS | = | 0.06 | INCHES |
| POROSITY | = | 0.0000 | VOL/VOL |
| FIELD CAPACITY | = | 0.0000 | VOL/VOL |
| WILTING POINT | = | 0.0000 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.0000 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.199999996000E-12 | CM/SEC |
| FML PINHOLE DENSITY | = | 5.00 | HOLES/ACRE |
| FML INSTALLATION DEFECTS | = | 4.00 | HOLES/ACRE |
| FML PLACEMENT QUALITY | = | 4 - POOR | |

LAYER 4
---

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 22

| | | | |
|---|---|---|---|
| THICKNESS | = | 462.00 | INCHES |
| POROSITY | = | 0.4190 | VOL/VOL |
| FIELD CAPACITY | = | 0.3070 | VOL/VOL |
| WILTING POINT | = | 0.1800 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.3070 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.189999992000E-04 | CM/SEC |

```
                        LAYER  5
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  10
THICKNESS                   =     18.00   INCHES
POROSITY                    =      0.3980 VOL/VOL
FIELD CAPACITY              =      0.2440 VOL/VOL
WILTING POINT               =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.2440 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC


                        LAYER  6
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  22
THICKNESS                   =    198.00   INCHES
POROSITY                    =      0.4190 VOL/VOL
FIELD CAPACITY              =      0.3070 VOL/VOL
WILTING POINT               =      0.1800 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.3070 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.189999992000E-04 CM/SEC


                        LAYER  7
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   3
THICKNESS                   =      6.00   INCHES
POROSITY                    =      0.4570 VOL/VOL
FIELD CAPACITY              =      0.0830 VOL/VOL
WILTING POINT               =      0.0330 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0838 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.310000009000E-02 CM/SEC


                        LAYER  8
                        --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER  21
THICKNESS                   =     12.00   INCHES
POROSITY                    =      0.3970 VOL/VOL
```

```
FIELD CAPACITY              =      0.0320 VOL/VOL
WILTING POINT               =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0320 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.300000012000     CM/SEC
SLOPE                       =      2.00   PERCENT
DRAINAGE LENGTH             =    250.0    FEET
```

LAYER 9
---

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

```
THICKNESS                   =      0.06   INCHES
POROSITY                    =      0.0000 VOL/VOL
FIELD CAPACITY              =      0.0000 VOL/VOL
WILTING POINT               =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY         =      5.00   HOLES/ACRE
FML INSTALLATION DEFECTS    =      4.00   HOLES/ACRE
FML PLACEMENT QUALITY       =  4 - POOR
```

LAYER 10
---

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 10

```
THICKNESS                   =      6.00   INCHES
POROSITY                    =      0.3980 VOL/VOL
FIELD CAPACITY              =      0.2440 VOL/VOL
WILTING POINT               =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.2021 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC
```

GENERAL DESIGN AND EVAPORATIVE ZONE DATA
---

```
NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
         SOIL DATA BASE USING SOIL TEXTURE #10 WITH A
         POOR STAND OF GRASS, A SURFACE SLOPE OF  5.%
         AND A SLOPE LENGTH OF  250. FEET.

SCS RUNOFF CURVE NUMBER             =     90.30
FRACTION OF AREA ALLOWING RUNOFF    =    100.0    PERCENT
```

| | | | |
|---|---|---|---|
| AREA PROJECTED ON HORIZONTAL PLANE | = | 4.260 | ACRES |
| EVAPORATIVE ZONE DEPTH | = | 18.0 | INCHES |
| INITIAL WATER IN EVAPORATIVE ZONE | = | 2.915 | INCHES |
| UPPER LIMIT OF EVAPORATIVE STORAGE | = | 7.152 | INCHES |
| LOWER LIMIT OF EVAPORATIVE STORAGE | = | 0.972 | INCHES |
| INITIAL SNOW WATER | = | 0.000 | INCHES |
| INITIAL WATER IN LAYER MATERIALS | = | 212.027 | INCHES |
| TOTAL INITIAL WATER | = | 212.027 | INCHES |
| TOTAL SUBSURFACE INFLOW | = | 0.00 | INCHES/YEAR |

## EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
RICO COLORADO

| | | | |
|---|---|---|---|
| STATION LATITUDE | = | 37.69 | DEGREES |
| MAXIMUM LEAF AREA INDEX | = | 2.00 | |
| START OF GROWING SEASON (JULIAN DATE) | = | 109 | |
| END OF GROWING SEASON (JULIAN DATE) | = | 293 | |
| EVAPORATIVE ZONE DEPTH | = | 18.0 | INCHES |
| AVERAGE ANNUAL WIND SPEED | = | 5.90 | MPH |
| AVERAGE 1ST QUARTER RELATIVE HUMIDITY | = | 60.00 | % |
| AVERAGE 2ND QUARTER RELATIVE HUMIDITY | = | 36.00 | % |
| AVERAGE 3RD QUARTER RELATIVE HUMIDITY | = | 36.00 | % |
| AVERAGE 4TH QUARTER RELATIVE HUMIDITY | = | 57.00 | % |

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 1.98 | 2.51 | 2.22 | 1.74 | 1.64 | 1.33 |
| 2.46 | 2.90 | 2.20 | 1.89 | 1.91 | 2.18 |

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.00 | 24.20 | 29.10 | 35.60 | 45.20 | 52.70 |
| 57.90 | 56.30 | 49.40 | 40.40 | 30.00 | 22.50 |

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO
AND STATION LATITUDE = 37.69 DEGREES

**********

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 100

| | JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|---|
| **PRECIPITATION** | | | | | | |
| TOTALS | 1.98 | 2.65 | 2.20 | 1.83 | 1.56 | 1.29 |
| | 2.69 | 2.85 | 2.11 | 2.19 | 2.13 | 2.14 |
| STD. DEVIATIONS | 1.04 | 1.52 | 1.14 | 1.01 | 1.20 | 1.11 |
| | 2.03 | 1.49 | 1.61 | 1.51 | 1.39 | 1.46 |
| **RUNOFF** | | | | | | |
| TOTALS | 0.126 | 0.774 | 2.773 | 1.301 | 0.094 | 0.077 |
| | 0.412 | 0.244 | 0.181 | 0.128 | 0.115 | 0.135 |
| STD. DEVIATIONS | 0.315 | 0.969 | 2.050 | 2.069 | 0.272 | 0.163 |
| | 0.591 | 0.320 | 0.300 | 0.238 | 0.282 | 0.306 |
| **EVAPOTRANSPIRATION** | | | | | | |
| TOTALS | 0.634 | 0.583 | 0.931 | 1.990 | 1.407 | 1.061 |
| | 1.944 | 2.228 | 1.494 | 1.198 | 0.803 | 0.642 |
| STD. DEVIATIONS | 0.095 | 0.073 | 0.340 | 0.584 | 0.913 | 0.858 |
| | 1.162 | 1.029 | 0.950 | 0.603 | 0.286 | 0.173 |
| **LATERAL DRAINAGE COLLECTED FROM LAYER 2** | | | | | | |
| TOTALS | 0.0109 | 0.1261 | 0.7802 | 0.9200 | 0.1982 | 0.1414 |
| | 0.3851 | 0.3196 | 0.3036 | 0.5766 | 0.4969 | 0.0489 |
| STD. DEVIATIONS | 0.1048 | 0.3892 | 0.7919 | 0.8667 | 0.4529 | 0.3076 |
| | 0.6045 | 0.4632 | 0.5120 | 0.8569 | 0.7354 | 0.1614 |
| **PERCOLATION/LEAKAGE THROUGH LAYER 3** | | | | | | |
| TOTALS | 0.0000 | 0.0004 | 0.0024 | 0.0029 | 0.0007 | 0.0005 |
| | 0.0013 | 0.0011 | 0.0011 | 0.0020 | 0.0018 | 0.0002 |

```
  STD. DEVIATIONS        0.0003   0.0012   0.0024   0.0026   0.0014   0.0010
                         0.0019   0.0016   0.0017   0.0029   0.0025   0.0006

 LATERAL DRAINAGE COLLECTED FROM LAYER  8
 ----------------------------------------
  TOTALS                 0.0012   0.0009   0.0008   0.0011   0.0016   0.0015
                         0.0013   0.0013   0.0011   0.0010   0.0010   0.0013

  STD. DEVIATIONS        0.0008   0.0007   0.0007   0.0005   0.0003   0.0004
                         0.0005   0.0005   0.0006   0.0006   0.0006   0.0007

 PERCOLATION/LEAKAGE THROUGH LAYER  9
 -------------------------------------
  TOTALS                 0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

 PERCOLATION/LEAKAGE THROUGH LAYER 10
 -------------------------------------
  TOTALS                 0.0003   0.0002   0.0002   0.0003   0.0003   0.0003
                         0.0003   0.0003   0.0003   0.0003   0.0003   0.0002

  STD. DEVIATIONS        0.0009   0.0008   0.0008   0.0007   0.0007   0.0006
                         0.0006   0.0006   0.0005   0.0005   0.0005   0.0005


-------------------------------------------------------------------------------
               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


 DAILY AVERAGE HEAD ON TOP OF LAYER  3
 -------------------------------------
  AVERAGES               0.0010   0.0130   0.0742   0.0905   0.0189   0.0139
                         0.0367   0.0305   0.0299   0.0548   0.0488   0.0046

  STD. DEVIATIONS        0.0100   0.0403   0.0753   0.0852   0.0431   0.0303
                         0.0575   0.0441   0.0503   0.0815   0.0722   0.0153

 DAILY AVERAGE HEAD ON TOP OF LAYER  9
 -------------------------------------
  AVERAGES               0.0003   0.0002   0.0002   0.0003   0.0004   0.0004
                         0.0003   0.0003   0.0003   0.0002   0.0002   0.0003

  STD. DEVIATIONS        0.0002   0.0002   0.0002   0.0001   0.0001   0.0001
                         0.0001   0.0001   0.0001   0.0001   0.0001   0.0002

*******************************************************************************
```

**********

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

| | INCHES | | CU. FEET | PERCENT |
|---|---|---|---|---|
| PRECIPITATION | 25.62 | ( 4.233) | 396219.7 | 100.00 |
| RUNOFF | 6.359 | ( 2.7990) | 98340.52 | 24.820 |
| EVAPOTRANSPIRATION | 14.916 | ( 2.3439) | 230650.41 | 58.213 |
| LATERAL DRAINAGE COLLECTED FROM LAYER 2 | 4.30746 | ( 1.43491) | 66609.766 | 16.81132 |
| PERCOLATION/LEAKAGE THROUGH LAYER 3 | 0.01439 | ( 0.00483) | 222.568 | 0.05617 |
| AVERAGE HEAD ON TOP OF LAYER 3 | 0.035 | ( 0.012) | | |
| LATERAL DRAINAGE COLLECTED FROM LAYER 8 | 0.01397 | ( 0.00358) | 216.057 | 0.05453 |
| PERCOLATION/LEAKAGE THROUGH LAYER 9 | 0.00043 | ( 0.00010) | 6.641 | 0.00168 |
| AVERAGE HEAD ON TOP OF LAYER 9 | 0.000 | ( 0.000) | | |
| PERCOLATION/LEAKAGE THROUGH LAYER 10 | 0.00318 | ( 0.00757) | 49.174 | 0.01241 |
| CHANGE IN WATER STORAGE | 0.023 | ( 2.1102) | 353.81 | 0.089 |

**********

```
*******************************************************************************

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ----------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              4.18         64638.684

      RUNOFF                                     2.831        43779.4336

      DRAINAGE COLLECTED FROM LAYER  2           1.63491      25281.94340

      PERCOLATION/LEAKAGE THROUGH LAYER  3       0.004496        69.52649

      AVERAGE HEAD ON TOP OF LAYER  3            4.818

      MAXIMUM HEAD ON TOP OF LAYER  3            8.405

      LOCATION OF MAXIMUM HEAD IN LAYER  2
            (DISTANCE FROM DRAIN)               31.4 FEET

      DRAINAGE COLLECTED FROM LAYER  8           0.00007          1.08779

      PERCOLATION/LEAKAGE THROUGH LAYER  9       0.000002         0.03087

      AVERAGE HEAD ON TOP OF LAYER  9            0.001

      MAXIMUM HEAD ON TOP OF LAYER  9            0.007

      LOCATION OF MAXIMUM HEAD IN LAYER  8
            (DISTANCE FROM DRAIN)                0.0 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER 10       0.000286         4.42492

      SNOW WATER                                 11.41        176470.1410


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.2760

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.0540


       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

*******************************************************************************
```

**********

FINAL WATER STORAGE AT END OF YEAR 100

| LAYER | (INCHES) | (VOL/VOL) |
|---|---|---|
| 1 | 1.3388 | 0.2231 |
| 2 | 0.3230 | 0.0269 |
| 3 | 0.0000 | 0.0000 |
| 4 | 141.8340 | 0.3070 |
| 5 | 4.3920 | 0.2440 |
| 6 | 60.7860 | 0.3070 |
| 7 | 0.5021 | 0.0837 |
| 8 | 0.3841 | 0.0320 |
| 9 | 0.0000 | 0.0000 |
| 10 | 0.9377 | 0.1563 |
| SNOW WATER | 3.817 | |

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************



PRECIPITATION DATA FILE:    C:\HELP3\DATA4.D4
TEMPERATURE DATA FILE:      C:\HELP3\DATA7.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\DATA13.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\DATA11.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\SOLIDS2.D10
OUTPUT DATA FILE:           C:\HELP3\SOLIDS2.OUT



TIME:  12:21     DATE:  11/26/2013



******************************************************************************

     TITLE:  Solids Repository - Closed after Phase 1

******************************************************************************



     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.



                                    LAYER  1
                                    --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
          THICKNESS                  =      6.00   INCHES
          POROSITY                   =      0.3980 VOL/VOL
          FIELD CAPACITY             =      0.2440 VOL/VOL
          WILTING POINT              =      0.1360 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.3681 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
```

NOTE: SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY 3.00
FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

LAYER 2
---

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 21

| | | | |
|---|---|---|---|
| THICKNESS | = | 12.00 | INCHES |
| POROSITY | = | 0.3970 | VOL/VOL |
| FIELD CAPACITY | = | 0.0320 | VOL/VOL |
| WILTING POINT | = | 0.0130 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.0589 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.300000012000 | CM/SEC |
| SLOPE | = | 5.00 | PERCENT |
| DRAINAGE LENGTH | = | 75.0 | FEET |

LAYER 3
---

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

| | | | |
|---|---|---|---|
| THICKNESS | = | 0.06 | INCHES |
| POROSITY | = | 0.0000 | VOL/VOL |
| FIELD CAPACITY | = | 0.0000 | VOL/VOL |
| WILTING POINT | = | 0.0000 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.0000 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.199999996000E-12 | CM/SEC |
| FML PINHOLE DENSITY | = | 5.00 | HOLES/ACRE |
| FML INSTALLATION DEFECTS | = | 4.00 | HOLES/ACRE |
| FML PLACEMENT QUALITY | = | 4 - POOR | |

LAYER 4
---

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 10

| | | | |
|---|---|---|---|
| THICKNESS | = | 18.00 | INCHES |
| POROSITY | = | 0.3980 | VOL/VOL |
| FIELD CAPACITY | = | 0.2440 | VOL/VOL |
| WILTING POINT | = | 0.1360 | VOL/VOL |
| INITIAL SOIL WATER CONTENT | = | 0.2440 | VOL/VOL |
| EFFECTIVE SAT. HYD. COND. | = | 0.119999997000E-03 | CM/SEC |

```
                        LAYER  5
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  22
THICKNESS                   =    198.00   INCHES
POROSITY                    =      0.4190 VOL/VOL
FIELD CAPACITY              =      0.3070 VOL/VOL
WILTING POINT               =      0.1800 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.3070 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.189999992000E-04 CM/SEC


                        LAYER  6
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   3
THICKNESS                   =      6.00   INCHES
POROSITY                    =      0.4570 VOL/VOL
FIELD CAPACITY              =      0.0830 VOL/VOL
WILTING POINT               =      0.0330 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0830 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.310000009000E-02 CM/SEC


                        LAYER  7
                        --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER  21
THICKNESS                   =     12.00   INCHES
POROSITY                    =      0.3970 VOL/VOL
FIELD CAPACITY              =      0.0320 VOL/VOL
WILTING POINT               =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0320 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.300000012000     CM/SEC
SLOPE                       =      2.00   PERCENT
DRAINAGE LENGTH             =     75.0    FEET


                        LAYER  8
                        --------

            TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER  35
```

```
THICKNESS                   =      0.06   INCHES
POROSITY                    =      0.0000 VOL/VOL
FIELD CAPACITY              =      0.0000 VOL/VOL
WILTING POINT               =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY         =      5.00   HOLES/ACRE
FML INSTALLATION DEFECTS    =      4.00   HOLES/ACRE
FML PLACEMENT QUALITY       =  4 - POOR
```

```
                        LAYER  9
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  10
THICKNESS                   =      6.00   INCHES
POROSITY                    =      0.3980 VOL/VOL
FIELD CAPACITY              =      0.2440 VOL/VOL
WILTING POINT               =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.2102 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC
```

```
          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #10 WITH A
          POOR STAND OF GRASS, A SURFACE SLOPE OF  5.%
          AND A SLOPE LENGTH OF   75. FEET.

SCS RUNOFF CURVE NUMBER             =     90.90
FRACTION OF AREA ALLOWING RUNOFF    =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =      1.450  ACRES
EVAPORATIVE ZONE DEPTH              =     18.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      2.915  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =      7.152  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      0.972  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =     70.236  INCHES
TOTAL INITIAL WATER                 =     70.236  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

```
           EVAPOTRANSPIRATION AND WEATHER DATA
           -----------------------------------
```

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
RICO COLORADO

| | | |
|---|---|---|
| STATION LATITUDE | = | 37.69 DEGREES |
| MAXIMUM LEAF AREA INDEX | = | 2.00 |
| START OF GROWING SEASON (JULIAN DATE) | = | 109 |
| END OF GROWING SEASON (JULIAN DATE) | = | 293 |
| EVAPORATIVE ZONE DEPTH | = | 18.0 INCHES |
| AVERAGE ANNUAL WIND SPEED | = | 5.90 MPH |
| AVERAGE 1ST QUARTER RELATIVE HUMIDITY | = | 60.00 % |
| AVERAGE 2ND QUARTER RELATIVE HUMIDITY | = | 36.00 % |
| AVERAGE 3RD QUARTER RELATIVE HUMIDITY | = | 36.00 % |
| AVERAGE 4TH QUARTER RELATIVE HUMIDITY | = | 57.00 % |

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 1.98 | 2.51 | 2.22 | 1.74 | 1.64 | 1.33 |
| 2.46 | 2.90 | 2.20 | 1.89 | 1.91 | 2.18 |

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.00 | 24.20 | 29.10 | 35.60 | 45.20 | 52.70 |
| 57.90 | 56.30 | 49.40 | 40.40 | 30.00 | 22.50 |

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO
AND STATION LATITUDE = 37.69 DEGREES

**********

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 100
---

| | JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|---|
| **PRECIPITATION** | | | | | | |
| TOTALS | 1.98 | 2.65 | 2.20 | 1.83 | 1.56 | 1.29 |
| | 2.69 | 2.85 | 2.11 | 2.19 | 2.13 | 2.14 |
| STD. DEVIATIONS | 1.04 | 1.52 | 1.14 | 1.01 | 1.20 | 1.11 |
| | 2.03 | 1.49 | 1.61 | 1.51 | 1.39 | 1.46 |
| **RUNOFF** | | | | | | |
| TOTALS | 0.126 | 0.776 | 2.774 | 1.308 | 0.105 | 0.089 |
| | 0.449 | 0.274 | 0.204 | 0.146 | 0.122 | 0.135 |
| STD. DEVIATIONS | 0.316 | 0.972 | 2.047 | 2.068 | 0.277 | 0.182 |
| | 0.626 | 0.347 | 0.327 | 0.258 | 0.287 | 0.307 |
| **EVAPOTRANSPIRATION** | | | | | | |
| TOTALS | 0.634 | 0.583 | 0.931 | 1.961 | 1.392 | 1.055 |
| | 1.919 | 2.222 | 1.482 | 1.200 | 0.802 | 0.642 |
| STD. DEVIATIONS | 0.095 | 0.073 | 0.339 | 0.587 | 0.911 | 0.841 |
| | 1.144 | 1.009 | 0.944 | 0.601 | 0.287 | 0.174 |
| **LATERAL DRAINAGE COLLECTED FROM LAYER 2** | | | | | | |
| TOTALS | 0.0112 | 0.1366 | 0.8356 | 0.8915 | 0.1903 | 0.1407 |
| | 0.3729 | 0.3011 | 0.3040 | 0.5560 | 0.4799 | 0.0429 |
| STD. DEVIATIONS | 0.1056 | 0.4080 | 0.8425 | 0.9207 | 0.4693 | 0.3022 |
| | 0.5822 | 0.4417 | 0.5100 | 0.8378 | 0.7251 | 0.1538 |
| **PERCOLATION/LEAKAGE THROUGH LAYER 3** | | | | | | |
| TOTALS | 0.0000 | 0.0001 | 0.0004 | 0.0005 | 0.0002 | 0.0001 |
| | 0.0003 | 0.0002 | 0.0003 | 0.0005 | 0.0004 | 0.0000 |
| STD. DEVIATIONS | 0.0001 | 0.0002 | 0.0004 | 0.0004 | 0.0003 | 0.0002 |
| | 0.0004 | 0.0003 | 0.0004 | 0.0006 | 0.0006 | 0.0001 |
| **LATERAL DRAINAGE COLLECTED FROM LAYER 7** | | | | | | |
| TOTALS | 0.0000 | 0.0000 | 0.0002 | 0.0006 | 0.0003 | 0.0001 |
| | 0.0002 | 0.0002 | 0.0002 | 0.0003 | 0.0004 | 0.0003 |
| STD. DEVIATIONS | 0.0002 | 0.0001 | 0.0003 | 0.0003 | 0.0003 | 0.0002 |
| | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0005 | 0.0005 |
| **PERCOLATION/LEAKAGE THROUGH LAYER 8** | | | | | | |
| TOTALS | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

```
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

    STD. DEVIATIONS       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  PERCOLATION/LEAKAGE THROUGH LAYER  9
  -------------------------------------
    TOTALS                0.0001   0.0001   0.0002   0.0004   0.0003   0.0001
                          0.0002   0.0003   0.0003   0.0003   0.0004   0.0003

    STD. DEVIATIONS       0.0005   0.0010   0.0006   0.0008   0.0005   0.0003
                          0.0004   0.0006   0.0011   0.0008   0.0011   0.0007


-------------------------------------------------------------------------------
               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  3
  -------------------------------------
    AVERAGES              0.0003   0.0042   0.0238   0.0263   0.0055   0.0042
                          0.0107   0.0086   0.0090   0.0159   0.0141   0.0012

    STD. DEVIATIONS       0.0030   0.0127   0.0240   0.0271   0.0134   0.0089
                          0.0167   0.0126   0.0150   0.0239   0.0214   0.0044

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES              0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

    STD. DEVIATIONS       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                     INCHES            CU. FEET       PERCENT
                                 -------------------   -------------   ---------
 PRECIPITATION                    25.62    (   4.233)     134863.5     100.00

 RUNOFF                            6.508   (  2.8012)      34255.37     25.400

 EVAPOTRANSPIRATION               14.823   (  2.3313)      78021.02     57.852

 LATERAL DRAINAGE COLLECTED        4.26272 (  1.40623)     22436.854   16.63671
   FROM LAYER  2
```

| | | | | |
|---|---|---|---|---|
| PERCOLATION/LEAKAGE THROUGH LAYER 3 | 0.00302 | ( 0.00112) | 15.900 | 0.01179 |
| AVERAGE HEAD ON TOP OF LAYER 3 | 0.010 | ( 0.003) | | |
| LATERAL DRAINAGE COLLECTED FROM LAYER 7 | 0.00298 | ( 0.00105) | 15.692 | 0.01164 |
| PERCOLATION/LEAKAGE THROUGH LAYER 8 | 0.00004 | ( 0.00001) | 0.208 | 0.00015 |
| AVERAGE HEAD ON TOP OF LAYER 8 | 0.000 | ( 0.000) | | |
| PERCOLATION/LEAKAGE THROUGH LAYER 9 | 0.00301 | ( 0.00663) | 15.852 | 0.01175 |
| CHANGE IN WATER STORAGE | 0.023 | ( 2.1092) | 118.73 | 0.088 |

**********

```
*******************************************************************************

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ----------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              4.18         22001.430

      RUNOFF                                     2.832        14904.7197

      DRAINAGE COLLECTED FROM LAYER  2           3.05289      16068.91310

      PERCOLATION/LEAKAGE THROUGH LAYER  3       0.001180         6.21143

      AVERAGE HEAD ON TOP OF LAYER  3            2.699

      MAXIMUM HEAD ON TOP OF LAYER  3            4.413

      LOCATION OF MAXIMUM HEAD IN LAYER  2
            (DISTANCE FROM DRAIN)               13.5 FEET

      DRAINAGE COLLECTED FROM LAYER  7           0.00005          0.28767

      PERCOLATION/LEAKAGE THROUGH LAYER  8       0.000001         0.00350

      AVERAGE HEAD ON TOP OF LAYER  8            0.000

      MAXIMUM HEAD ON TOP OF LAYER  8            0.000

      LOCATION OF MAXIMUM HEAD IN LAYER  7
            (DISTANCE FROM DRAIN)                0.0 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  9       0.000545         2.86945

      SNOW WATER                                 11.41        60066.1289


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.2760

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.0540


       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

*******************************************************************************
```

**********

FINAL WATER STORAGE AT END OF YEAR 100

| LAYER | (INCHES) | (VOL/VOL) |
|---|---|---|
| 1 | 1.3388 | 0.2231 |
| 2 | 0.3120 | 0.0260 |
| 3 | 0.0000 | 0.0000 |
| 4 | 4.3920 | 0.2440 |
| 5 | 60.7860 | 0.3070 |
| 6 | 0.4980 | 0.0830 |
| 7 | 0.3840 | 0.0320 |
| 8 | 0.0000 | 0.0000 |
| 9 | 0.9642 | 0.1607 |
| SNOW WATER | 3.817 | |

**********
**********

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************



PRECIPITATION DATA FILE:    C:\HELP3\DATA4.D4
TEMPERATURE DATA FILE:      C:\HELP3\DATA7.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\DATA13.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\DATA11.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\SOLIDS3.D10
OUTPUT DATA FILE:           C:\HELP3\SOLIDS3.OUT



TIME:  12:21     DATE:  11/26/2013



******************************************************************************

     TITLE:  Solids Repository - Unclosed after Phase 1

******************************************************************************



     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.



                                    LAYER  1
                                    --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  10
          THICKNESS                  =     18.00   INCHES
          POROSITY                   =      0.3980 VOL/VOL
          FIELD CAPACITY             =      0.2440 VOL/VOL
          WILTING POINT              =      0.1360 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.3001 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
```

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
         FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                         LAYER  2
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  22
  THICKNESS                   =    198.00   INCHES
  POROSITY                    =      0.4190 VOL/VOL
  FIELD CAPACITY              =      0.3070 VOL/VOL
  WILTING POINT               =      0.1800 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.3020 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.189999992000E-04 CM/SEC


                         LAYER  3
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   3
  THICKNESS                   =      6.00   INCHES
  POROSITY                    =      0.4570 VOL/VOL
  FIELD CAPACITY              =      0.0830 VOL/VOL
  WILTING POINT               =      0.0330 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.1102 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.310000009000E-02 CM/SEC


                         LAYER  4
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER  21
  THICKNESS                   =     12.00   INCHES
  POROSITY                    =      0.3970 VOL/VOL
  FIELD CAPACITY              =      0.0320 VOL/VOL
  WILTING POINT               =      0.0130 VOL/VOL
  INITIAL SOIL WATER CONTENT  =      0.0321 VOL/VOL
  EFFECTIVE SAT. HYD. COND.   =  0.300000012000     CM/SEC
  SLOPE                       =      2.00   PERCENT
  DRAINAGE LENGTH             =     75.0    FEET


                         LAYER  5
```

```
                         --------

             TYPE 4 - FLEXIBLE MEMBRANE LINER
               MATERIAL TEXTURE NUMBER  35
   THICKNESS                   =      0.06   INCHES
   POROSITY                    =      0.0000 VOL/VOL
   FIELD CAPACITY              =      0.0000 VOL/VOL
   WILTING POINT               =      0.0000 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
   FML PINHOLE DENSITY         =      5.00   HOLES/ACRE
   FML INSTALLATION DEFECTS    =      4.00   HOLES/ACRE
   FML PLACEMENT QUALITY       =  4 - POOR


                         LAYER  6
                         --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
               MATERIAL TEXTURE NUMBER  10
   THICKNESS                   =      6.00   INCHES
   POROSITY                    =      0.3980 VOL/VOL
   FIELD CAPACITY              =      0.2440 VOL/VOL
   WILTING POINT               =      0.1360 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.2000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.119999997000E-03 CM/SEC


          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #10 WITH A
          POOR STAND OF GRASS, A SURFACE SLOPE OF  5.%
          AND A SLOPE LENGTH OF   75. FEET.

SCS RUNOFF CURVE NUMBER             =     90.90
FRACTION OF AREA ALLOWING RUNOFF    =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =      1.450  ACRES
EVAPORATIVE ZONE DEPTH              =     32.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      8.700  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =     13.030  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      4.968  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =     67.434  INCHES
TOTAL INITIAL WATER                 =     67.434  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

## EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
RICO COLORADO

| | | |
|---|---|---|
| STATION LATITUDE | = | 37.69 DEGREES |
| MAXIMUM LEAF AREA INDEX | = | 2.00 |
| START OF GROWING SEASON (JULIAN DATE) | = | 109 |
| END OF GROWING SEASON (JULIAN DATE) | = | 293 |
| EVAPORATIVE ZONE DEPTH | = | 32.0 INCHES |
| AVERAGE ANNUAL WIND SPEED | = | 5.90 MPH |
| AVERAGE 1ST QUARTER RELATIVE HUMIDITY | = | 60.00 % |
| AVERAGE 2ND QUARTER RELATIVE HUMIDITY | = | 36.00 % |
| AVERAGE 3RD QUARTER RELATIVE HUMIDITY | = | 36.00 % |
| AVERAGE 4TH QUARTER RELATIVE HUMIDITY | = | 57.00 % |

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 1.98 | 2.51 | 2.22 | 1.74 | 1.64 | 1.33 |
| 2.46 | 2.90 | 2.20 | 1.89 | 1.91 | 2.18 |

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 22.00 | 24.20 | 29.10 | 35.60 | 45.20 | 52.70 |
| 57.90 | 56.30 | 49.40 | 40.40 | 30.00 | 22.50 |

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR GRAND JUNCTION COLORADO
AND STATION LATITUDE = 37.69 DEGREES

**********

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 100

| | JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|---|
| **PRECIPITATION** | | | | | | |
| TOTALS | 1.98 | 2.65 | 2.20 | 1.83 | 1.56 | 1.29 |
| | 2.69 | 2.85 | 2.11 | 2.19 | 2.13 | 2.14 |
| STD. DEVIATIONS | 1.04 | 1.52 | 1.14 | 1.01 | 1.20 | 1.11 |
| | 2.03 | 1.49 | 1.61 | 1.51 | 1.39 | 1.46 |
| **RUNOFF** | | | | | | |
| TOTALS | 0.118 | 0.729 | 2.664 | 1.314 | 0.115 | 0.089 |
| | 0.437 | 0.261 | 0.201 | 0.150 | 0.123 | 0.131 |
| STD. DEVIATIONS | 0.302 | 0.913 | 1.993 | 2.038 | 0.290 | 0.182 |
| | 0.621 | 0.337 | 0.336 | 0.272 | 0.261 | 0.287 |
| **EVAPOTRANSPIRATION** | | | | | | |
| TOTALS | 0.633 | 0.578 | 0.867 | 2.205 | 2.116 | 1.657 |
| | 3.476 | 2.507 | 1.562 | 1.179 | 0.727 | 0.627 |
| STD. DEVIATIONS | 0.097 | 0.066 | 0.256 | 0.561 | 0.823 | 0.798 |
| | 1.446 | 1.084 | 0.798 | 0.471 | 0.197 | 0.174 |
| **LATERAL DRAINAGE COLLECTED FROM LAYER 4** | | | | | | |
| TOTALS | 0.0610 | 0.0522 | 0.0424 | 0.0297 | 0.0196 | 0.0173 |
| | 0.1257 | 0.2176 | 0.1898 | 0.1550 | 0.1218 | 0.0940 |
| STD. DEVIATIONS | 0.0896 | 0.0902 | 0.0851 | 0.0694 | 0.0431 | 0.0356 |
| | 0.1507 | 0.1658 | 0.1557 | 0.1482 | 0.1339 | 0.1210 |
| **PERCOLATION/LEAKAGE THROUGH LAYER 5** | | | | | | |
| TOTALS | 0.0003 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| | 0.0004 | 0.0007 | 0.0007 | 0.0006 | 0.0005 | 0.0004 |
| STD. DEVIATIONS | 0.0003 | 0.0003 | 0.0003 | 0.0002 | 0.0001 | 0.0001 |
| | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0004 | 0.0004 |
| **PERCOLATION/LEAKAGE THROUGH LAYER 6** | | | | | | |
| TOTALS | 0.0006 | 0.0006 | 0.0007 | 0.0007 | 0.0007 | 0.0004 |
| | 0.0003 | 0.0003 | 0.0003 | 0.0004 | 0.0004 | 0.0005 |
| STD. DEVIATIONS | 0.0008 | 0.0007 | 0.0007 | 0.0006 | 0.0006 | 0.0003 |
| | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0005 |

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

| | | | | | | |
|---|---|---|---|---|---|---|
| AVERAGES | 0.0043 | 0.0041 | 0.0030 | 0.0022 | 0.0014 | 0.0013 |
| | 0.0089 | 0.0155 | 0.0140 | 0.0110 | 0.0090 | 0.0067 |
| STD. DEVIATIONS | 0.0064 | 0.0070 | 0.0061 | 0.0051 | 0.0031 | 0.0026 |
| | 0.0107 | 0.0118 | 0.0114 | 0.0105 | 0.0098 | 0.0086 |

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

| | INCHES | | CU. FEET | PERCENT |
|---|---|---|---|---|
| PRECIPITATION | 25.62 | ( 4.233) | 134863.5 | 100.00 |
| RUNOFF | 6.330 | ( 2.7714) | 33319.49 | 24.706 |
| EVAPOTRANSPIRATION | 18.134 | ( 2.4006) | 95445.95 | 70.772 |
| LATERAL DRAINAGE COLLECTED FROM LAYER 4 | 1.12602 | ( 0.97000) | 5926.832 | 4.39469 |
| PERCOLATION/LEAKAGE THROUGH LAYER 5 | 0.00424 | ( 0.00313) | 22.319 | 0.01655 |
| AVERAGE HEAD ON TOP OF LAYER 5 | 0.007 | ( 0.006) | | |
| PERCOLATION/LEAKAGE THROUGH LAYER 6 | 0.00582 | ( 0.00617) | 30.629 | 0.02271 |
| CHANGE IN WATER STORAGE | 0.027 | ( 2.9236) | 140.59 | 0.104 |

```
*******************************************************************************

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ----------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              4.18         22001.430

      RUNOFF                                     2.850        15003.0859

      DRAINAGE COLLECTED FROM LAYER  4           0.02150        113.15482

      PERCOLATION/LEAKAGE THROUGH LAYER  5       0.000062         0.32516

      AVERAGE HEAD ON TOP OF LAYER  5            0.047

      MAXIMUM HEAD ON TOP OF LAYER  5            0.093

      LOCATION OF MAXIMUM HEAD IN LAYER  4
            (DISTANCE FROM DRAIN)                1.6 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  6       0.000237         1.24616

      SNOW WATER                                11.41         60066.1289


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.3775

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.1553

       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 100

| LAYER | (INCHES) | (VOL/VOL) |
|---|---|---|
| 1 | 4.4142 | 0.2452 |
| 2 | 59.7928 | 0.3020 |
| 3 | 0.6538 | 0.1090 |
| 4 | 0.3846 | 0.0321 |
| 5 | 0.0000 | 0.0000 |
| 6 | 1.0422 | 0.1737 |
| SNOW WATER | 3.817 | |

**********
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# Appendix H

# Storm Water Management Plan

# Stormwater Management Plan

Rico – Argentine Mine Project Site

Prepared By:
Anderson Engineering Company
977 West 2100 South
Salt Lake City, Utah 84119

2013

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## APPENDICES

A CDPHE General Construction Stormwater Permit
B Site Vicinity Map
C Grading Plan, with Limits of Disturbance
D Best Management Practices and Erosion and Sediment Control Plan
E Observation Forms
F SWMP Revision Log/Review/Changes
G Reassignment of Permit Coverage and Inactivation Notice

# 1.0 INTRODUCTION

This Stormwater Management Plan (SWMP) is to comply with the Colorado Department of Public Health and Environment's (CDPHE) General Permit (Appendix A). The primary objective of the SWMP is to identify Best Management Practices (BMPs), which, when implemented, will meet the terms and conditions of the permit, by minimizing or reducing the pollution of waters of the State of Colorado.

Anderson Engineering Company, Inc. (AECI) and their subcontractors seek coverage under the general permit, and have prepared this SWMP for new construction activity in accordance with the requirements of the Colorado Discharge Permitting System (CDPS) permit. This SWMP addresses the limits of disturbance for the Rico-Argentine Mine Projects located in Rico, Colorado, as shown on the site vicinity map, Appendix B.

This SWMP was prepared in accordance with good engineering, hydrologic, and pollution control practices. It is intended to be a dynamic document that will be updated as needed to address planned development, new disturbances, and other changes needed to manage stormwater and protect surface water quality.

## 1.1 Project Location and Description

The project encompasses the limits of disturbance and grading plans for the various projects are being conducted pursuant to the Unilateral Administrative Order for Removal Action (UAO), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Docket No. 08-20011-0005, effective March 23, 2011 (UAO; U.S. Environmental Protection Agency [U.S. EPA], 2011b), and the associated Removal Action Work Plan (RAWP) dated March 9, 2011 (U.S. EPA, 2011a). This Work Plan is developed pursuant to Task F Subtask F2 of the Redial Action Work Plan, which requires the completion of treatment system conceptual designs and additional investigations to compare alternatives and support water treatment system designs as shown in Appendix C.

The project and limits of disturbance are located within the St. Louis Ponds area of the site, with coordinates of the Lime Plant Building that is located on patented claims within the St. Louis Ponds area at N 37° 42' 27.47" and W 108° 01' 48.90." The address for this location is 13100 St. Louis Road; Rico, Colorado 81332.

The project locations are as identified on Figures within Appendix B.

## 1.2 Project Owner and Operator

The Martha and Mervin patented claims where a portion of the work is being completed are owned by Atlantic Richfield. Other patented claims in the vicinity are in negotiation for purchase by Atlantic Richfield. The remaining area of the St Louis Ponds is situated on Forest Service land.

The Project Operator is:

BP Remediation Management
6 Centerpointe Drive
LaPalma, California 90623

Project Manager – Tony Brown
(714) 228-6770

The Construction Manager is:

Anderson Engineering Company, Inc.
31 South Glasgow Street
Rico, Colorado 81332
Project Manager – C. E. Sanchez
Phone – (801) 971-1767

### 1.3 Stormwater Management Plan Administrator

The SWMP Administrator role is held by the local contact listed above for the Contractor The SWMP Administrator is responsible for developing, implementing, maintaining and revising the SWMP. The Contractor will fulfill this role until final stabilization.

The Plan will be located at the Rico Field Office, located at 31 South Glasgow Street, Rico, Colorado 81332.

### 1.4 Employee Training

The Construction Manager will hire Contractors who will perform the various tasks within each project. This plan will be updated annually to detail the responsible Contractors for each phase and task. Each Contractor shall employ supervisory personnel educated about the requirements of this SWMP and in recognition and understanding of the proposed BMPs. This education will include training in erosion and sediment control, good housekeeping, proper maintenance, disposal and control of waste, equipment fueling, and inspection procedures.

Appendix D has brief descriptions and detailed drawings depicting each BMP. The Employee training programs will occur on a regular or as needed basis and can be performed as part of routine or pre-project construction safety meetings by trained personnel. The dates and attendance of employee training session should be recorded.

## 2.0 PROJECT DESCRIPTION

### 2.1 Nature of Construction Activity

The location for this project is operated by BP Atlantic Richfield. The work for 2013 includes the following projects:

Solids Removal Project

- Removal of precipitated solids resulting from the St. Louis adit discharge water
- Solids to be removed from Ponds 11, 12, 14 , 15 and 18
- Relocation of removed solids to on-site controlled drying locations.
- Removal will be by both dredge and mechanical methods

Construction on this project will take place, starting July 2013 and is scheduled for completion in November 2013. As possible, all disturbance areas will be stabilized prior to completion of the

construction activities or end of season whichever occurs first. Components will be stabilized or BMPs in place to control sediment migration by the end of the project or season whichever occurs first.

Constructed Wetlands Demonstration Project

- Water Management – construction of an on-site water management system that will cycle water between the various project components to assist with dredging operations.
- Construction of horizontal and vertical wetland system consisting of multiple cells. The system includes two sedimentation basins, horizontal surface and sub-surface treatment cells, vertical wetland cell, 2 aeration channels and a rock drain.
- Clearing and Grubbing – ground cover is very minimal, approximately 5-percent.
- Excavation of calcine and unsuitable soil materials – this includes removal of unsuitable subgrade materials from the final construction locations and placement within a drying cell
- Water Management – control rainwater and drainage water within each construction area by pumping and dewatering to an on-site source.
- Placement and maintenance of unsuitable soil within a drying cell – maintenance of draining within this cell to channel water to the appropriate drainage basin and keep sediment within the cell.
- Placement of structural fill material – placement of imported fill material to make up the structural soil components of each wetland basin.
- Excavation and Placement of Piping Systems and Components – excavation and placement of bedding, piping, and other appurtenances within each pipe run. This task also includes managing spoil piles and the runoff that may occur as the result of storm events.
- Excavation and Placement of Storm Sewer Piping – excavation and placement of pipe bedding and storm sewer piping and concrete structures to convey stormwater from the project location and outside the project location to Pond 18. This task includes backfill upon completion of the pipe construction and placement of drainage channels to assist with erosion and sediment control.

Construction on this project will take place, starting August 2013 and is scheduled for completion in June 2014. As possible, all disturbance areas will be stabilized prior to completion of the construction activities or end of season whichever occurs first. Components will be stabilized or BMPs in place to control sediment migration by the end of the project or season whichever occurs first

Embankment repairs construction

- Placement of erosion protection rock on select pond dikes
- Placement of structural fill material to reinforce existing embankments
- Construction of two lifting pads that will be used to lift the dredge out of the water.
- The constructed items will be stabilized upon construction and due to the aggregate content of the fill material will not be vegetated upon completion.

Construction on this project will take place, starting June 2013 and is scheduled for completion in November 2013. As possible, all disturbance areas will be stabilized prior to completion of the construction activities or end of season whichever occurs first. Components will be stabilized or BMPs in place to control sediment migration by the end of the project or season whichever occurs first.

Geotechnical Investigation Project

- Installation of soil borings and monitoring wells that will be used to assist in review of site soil and groundwater as well as site hydrology and lithologies. Ground disturbance for each of these locations will be isolated to the vicinity of the investigation location. In some cases, as identified on the Ground Disturbance Figure, Appendix C, soil fill and grading will occur to allow for access to each location. In these cases, certain BMPs will be added to minimize or limit erosion and sediment movement.

Construction activities for this project are scheduled to begin in August 2013 and be completed by November 2013. All components will be stabilized or BMPs in place to control sediment migration by the end of the project or season.

## 2.2 Proposed Sequence of Major Activities

The proposed sequence of activities for the construction activities are as follows:

*Solids Removal Project*

- Construction on Embankments and Lifting Pads
- Placement of Piping and Pumps as part of Water Management System
- Placement of Suction Dredge
- Dredge of Sediments within Pond
- Removal of Dredge and Pumps
- Removal of shore area solids by mechanical means

*Constructed Wetlands Demonstration Project*

- Clearing and Grubbing
- Survey
- Placement of Stormwater Control Berm and Wattles along west side of Rock Drain area
- Placement of Pumps and Piping to Control Storm Water
- Excavation/Removal of Calcines and Unsuitable Soils
- Placement of Unsuitable Soils within Drying Cell
- Excavation and Fill Placement of Basin Components
- Placement of conveyance piping between basins and associated flow control structures
- Placement of storm sewer structures and piping
- Placement of Access Road
- Final Grading of Basins
- Placement of Liner
- Placement of Matrix
- Installation of Wetland Plants
- Installation of Control Building and Associated Piping and Appurtenances
- Placement of Electrical Conduit and Telemetry Items
- Startup of Systems
- Clean up of Work Areas

Embankment Repair

- Pond 18 pipe area
- Pond 14 pipe support
- Pond 9 area repair

Geotechnical Drilling

- Vertical drilling
- Incline drilling

**2.3 Estimated Total Area of Site and Expected Disturbance**

The areas of disturbance within each construction area identified in this SWMP will be conducted in the St. Louis Ponds areas. Each project area is as follows:

The Solids Removal project incorporates the field area that includes Ponds and the associated access roads to each. The estimated area of disturbance for this project is approximately 14.2 acres.

The Constructed Wetlands Demonstration Project includes the area north and east of Pond 18, west of a portion of the soil lead repository, plus the applicable access roads to each. The total expected area of disturbance encompasses approximately 3 acres.

The Geotechnical Investigation project includes several drilling locations throughout the project site. The total expected area of disturbance encompasses approximately 1.0 acre.

**2.4 Soils and Existing Potential for Soil Erosion**

Runoff characteristics in the area of the project are based on site topography and soil/vegetative conditions. The undeveloped property slopes away from the mountain and towards the St. Louis ponds, ultimately discharging into the Dolores River downstream of the ponds.

The runoff coefficient “C” is the ratio of the volume of storm water runoff from the site compared to the total volume of the precipitation that falls on the site. The General permit requires an estimate of this ratio that represents runoff conditions both before construction and after construction activities are complete and the area is finally stabilized.

The estimate of “C” is based on variables from three general terrain categories: 1) soil properties (porosity, density, etc.); 2) ground slope, and 3) the character of the vegetative cover (woodlands, pasture, grassland, etc.). Another major variable affecting “C” is rainfall intensity and duration. For any given terrain, the ratio of runoff to rainfall is expected to increase as storm intensity of duration increases.

The soil materials and terrain within all three project areas is similar – aggregates of silt, sand, and gravel that were either imported and/or reused from previous site operations.

| Area | Run-off Coefficient Before Construction | Run-off Coefficient After Construction |
|---|---|---|
| St. Louis Ponds | 0.3 | 0.3 |

The procedures in this SWMP are designed to control sediment runoff from pre- to post-construction phases. BMPs are utilized throughout construction stages and are derived from Best Management Practices commonly found in transmission line construction.

## 2.5 Existing Vegetation

The existing vegetation present in the St. Louis Ponds area is native vegetation where present. The east slope is a combination of native grass combined with evergreen and Aspin trees. The flat area is mainly occupied by settling ponds and roads.

## 2.6 Potential Pollution Sources

Potential pollution sources associated with construction sites include:

- Sediment resulting from disturbed and stockpiled soils resulting from access road construction and areas of cleared vegetation.
    - Vehicle tracking of sediment from work zones and off-site
    - Loading and unloading of soils and materials during access road construction, bank excavation and grading, and other loading and unloading of materials and supplies
- Possible overflow of ponds
- Outdoor storage such as construction material storage and contractor office areas, if improperly stored, or exposed to stormwater are potential sources of stormwater pollution;
- Vehicle and equipment fueling and maintenance activities including storage of fuels and grease, lubricants, used oil, and waste generated during these activities.
- Dust or particulate generated during construction and transportation activities
- Trash and debris from clearing activities, construction materials, and workers;
- Equipment failures during earth moving activities may result in spills of fuels, motor fluids, hydraulic fluids, etc. to the ground surface;
- Construction waste storage area, if improperly stored or exposed to stormwater may be potential sources for stormwater pollution;
- Temporary sanitation services for construction workers such as portable toilets and dumpsters to collect debris and waste

### 2.6.1 Sediment

The most common source of pollution from the construction activities associated with this project is sediment, which can be carried away from the work site with stormwater runoff and could impact the water quality of a receiving stream. Clearing, grading, and altering previously undisturbed land will increase the rate of soil erosion over pre-disturbance rates. This pollutant source will need to be managed on a daily basis. The BMPs for this pollutant source are as provided with the drawings in Appendix D.

Vehicle tracking control will be provided, as needed, at the access road to State Highway 145. This entry will occur multiple times throughout every work day at each location where work is being performed. These areas are as identified on the Erosion Control Plan in Appendix D.

Loading and unloading of soils and materials will occur periodically throughout the project, as needed, to complete construction activities. The locations will vary depending on the scope of

work. The controls detailed in the drawings within Appendix D will address any impacts from this pollution source. The limits of disturbance are as noted on the grading plan, Appendix C.

#### 2.6.2 Liquids, Residue, and Other Waste from Outdoor Storage Areas

Outdoor storage and laydown areas, residue from equipment cleaning and maintenance, and solid waste generated from land cleaning operations and human activity (trees, brush, paper, trash, etc.) present other potential pollution sources within each construction site. A contractor laydown area is located on the north end of the project site where most of these activities and equipment storage will occur. These activities will take place on a daily basis and will be controlled as shown on the drawings within Appendix D.

#### 2.6.3 Petroleum Products

Petroleum products can also be potential stormwater pollutants. These products are used in construction to power or lubricate equipment and include: fuel, gear oil, hydraulic oil, brake fluid, and grease. These activities will take place on a daily basis throughout the course of the project whenever equipment or vehicles are being utilized to perform work on the project.

A detailed process is in place to limit releases of any kind at the project location. As a result, all fueling operations will be performed with a containment basin, as determined by the Contractor, to catch any drops of fluid that may result from this operation.

#### 2.6.4 Chemicals from Temporary Sanitation Facilities

Portable toilets and waste dumpsters will be utilized to complete the project activities – these items will be secured by anchoring to prevent tipping and release of chemicals contained within and placed as needed throughout the project area. This activity and the potential release will be a daily concern throughout the project. Re-anchoring will need to occur after each maintenance or empty activity of these products.

### 2.7 Non-Stormwater Discharges

Non-stormwater discharges are caused by activities other than direct runoff from precipitation. No non-stormwater discharges are anticipated at this time. Any equipment washing or pumping of stormwater will be contained within one of the on-site ponds and will not be released off site.

### 2.8 Receiving Waters and Outfalls

Stormwater from the site generally flows towards the St. Louis ponds whereby it is collected and conveyed through the pond system to the Dolores River on the north side of the Town of Rico. Stormwater in the Rico Townsite generally flows west to the River, as well.

# 3.0 STORMWATER MANAGEMENT CONTROLS

## 3.1 Best Management Practices

Best management practices will be implemented during the construction and maintenance activities to prevent or minimize accelerated erosion and sedimentation and to control, minimize, and prevent the release of impacted soils entrained in stormwater discharges. The following subsections describe the BMPs that will be implemented for this project.

The selection of erosion and sediment control BMPs is contingent upon site specific conditions (e.g. construction, vegetation, precipitation, and evaporation). Detailed information on the design, installation, and maintenance of example BMPs is contained in Appendices D.

## 3.2 Erosion and Sediment Control

The objective of erosion and sediment controls is to minimize the release of sediments to stormwater runoff. This can be accomplished through the use of structural and/or nonstructural controls. This section describes erosion and sediment controls to be used during the construction project.

- Erosion and sediment control measures will be adequately positioned, properly constructed and maintained throughout the duration of the project
- Clearing operations will be confined to the limits of the excavation or construction activity. Existing trees and vegetation will be protected to the extent possible;
- All materials stored on-site, and in the staging area, will be stored in a neat, orderly manner, in their appropriate containers;
- Erosion and sediment control measures will be effective in retaining sediments on-site;
- Stabilization practices will be effective in permanently stabilizing disturbed areas and be implemented pursuant to the requirements described in Section 3.3 of the SWMP;
- Corrective measures will be implemented as described in Section 4 of this SWMP as soon as practicable after a deficiency is noted;
- Good housekeeping practices will be incorporated into discussions during the daily safety meetings;
- Construction site waste material will be properly disposed.

Temporary measures to control sedimentation and erosion will be used and maintained during all phases of construction. Selection of appropriate erosion control materials will be made based on soil properties, steepness of the slope, weather conditions, and anticipated surface flow. These practices will focus on the prevention of soil erosion and the removal of sediment runoff.

### 3.2.1 Structural Practices for Erosion and Sediment Control

The types and locations of structural BMPs for each disturbed area will be determined as shown on the erosion and sediment control figures, Appendix D. The types and locations of structural BMPs for the project are shown. Guidance for BMP selection is provided in Appendix D. The general sequence of BMP installation for the various construction projects includes:

- Adjacent drainages are protected with structural BMPs before construction activities

begin,

- Cut slopes and soil piles are stabilized, including placement of soil berms to control run-on to the various excavation sites and run-off from staging areas such as the Contractor laydown yard.
- Additional BMPs are installed according to site-specific plans which may include additional surface water diversion channels, sediment traps, and other temporary sediment controls and interim BMPs.
- Stabilized construction entrances will be installed where necessary.
- Inlet protection barriers will be installed at the stormwater inlets.
- Hay Bale Controls or Wattles – may be placed in drainage ditches perpendicular to the surface water flow pathways to minimize run-off velocities and prevent sediment removal from the property by intercepting stormwater runoff. These structures may also be installed on the upgradient edges of the affected areas to divert upgradient storm water flows around the work areas.

These erosion and sediment control measures will be installed in accordance with the manufacturer's specifications, where implemented. The location of the erosion and sediment control measures will be based on visual observations of the surface water migration pathways at the affected areas. Erosion control mitigation measures will be implemented in accordance with construction plans for the project.

### 3.2.2 Non-Structural Practices for Erosion and Sediment Control

Non-structural practices, such as stabilization measures, are designed to reduce the erosion potential of the placed earth materials by shielding the surface from direct erosive impacts, by slowing the rate of water run-off, and by physically holding soil in place using vegetation. Stabilization practices will be implemented in disturbed areas as soon as practicable after the completion of the final grading activities. Care will also be taken during the construction and maintenance activities to minimize the areal extent possible. The following stabilization practices will be implemented:

Dust Control – dust control will be conducted in disturbed areas and on all haul roads, as necessary, to prevent or reduce movement of wind-borne dust particles. Dust control will be accomplished using a water truck with a 180-degree spray bar or high pressure washers.
Preservation of Existing Vegetation – existing vegetation that will not be disturbed by construction activities will be protected to the extent possible. The preservation of existing vegetation will help to control erosion on the property.
Vegetation – re-vegetation of disturbed areas will be provided in channels and trails as necessary for long-term erosion control and help prevent sediment from leaving the property.

The location of the stabilization measures will be based on visual observation and the extent of disturbance within the affected areas.

## 3.3 BMP Implementation

The erosion and sediment control measures will be coordinated with the initiation of the construction phases in the areas where construction or maintenance activities are scheduled and where material will be temporarily staged, if necessary. The erosion and sedimentation control measures may be adjusted as site conditions permit during the maintenance activities at

each affected area. All erosion and sediment control devices located in the area of the ponds will remain in place and will be maintained until final stabilization is established. AECI, and their various Contractors, will be responsible for implementation of these controls as long as AECI maintains day-to-day operational control of the activities necessary to ensure compliance with this plan.

### 3.3.1 Culverts

By design, culverts transport stormwater and snow melt from construction areas for discharge downgrade into a storm drain system or natural watercourse. Diverting water into a pipe decreases the volume of water that flows across open land, thereby reducing the potential for erosion and sediment that is transported to the outfall point.

### 3.3.2 Culvert Protection

Culverts will be protected with riprap in accordance with the BMP Detail provided in Appendix C. The protection will include rip rap on both the upstream and downstream sides to protect the culvert and minimize downstream erosion.

### 3.3.3 Riprap

Riprap is a permanent, erosion-resistant layer made of stones. It is intended to provide localized protection to soil from erosion in areas of concentrated runoff. Riprap may also be used to stabilize slopes that are unstable because of seepage problems. Riprap can also be used to stabilize cut-and-fill slopes; open channel side slopes and bottoms; inlets and outlets for culverts, bridge anchorage and abutments, steep grade stabilization, as well as slope and storm drains.

### 3.3.4 Silt Fence

Silt fences are used as temporary perimeter control structure that is designed to slow, temporarily impound, and filter sediment laden water. Installation techniques and maintenance are critical for proper performance. Silt fencing is typically used along the toe of fills, in transition areas between cut and fills, adjacent to streams/waterways, or along adjacent property lines. Installation guidelines for silt fencing are described in Appendix C.

### 3.3.5 Wattles

### 3.3.6 Vegetative Buffer

Vegetated buffers are areas of either natural or established vegetation that are maintained to protect the water quality of neighboring areas. Buffer zones reduce the velocity of stormwater runoff, provide an area for the runoff to permeate the soil, contribute to ground water recharge, and act as filters to catch sediment. The reduction in velocity also helps to prevent soil erosion. Vegetated buffers can be used in any area that is able to support vegetation but they are most effective and beneficial on floodplains, near wetlands, along stream banks, and on steep, unstable slopes.

## 3.4 Materials Handling and Spill Prevention

Spills at the construction site can be largely prevented through proper training and the conscientious efforts of construction personnel during the performance of routine activities. Specifically, on-site refueling activities pose a large threat for releasing hazardous pollutants to the environment. Efforts should be made to refuel equipment away from drainage and waterways, and if possible, attempt to use the same location such as a designated equipment refueling/staging area. If a release of a hazardous substance does occur during construction activities, construction personnel will take appropriate action to minimize the impact of the spill. This will be accomplished by using absorbent material that will be stored at the construction site. Absorbent material may consist of clay, sawdust, straw, kitty litter, booms, pads or other suitable materials.

### 3.4.1 Petroleum Products

Petroleum products which may be present on-site include: gasoline, diesel fuel, lubricant oils, hydraulic oils, used oils, and solvents. Gasoline and diesel fuel will be stored in portable storage tanks with secondary containment. Lubricant, hydraulic, and miscellaneous oils and solvents will be stored in 55-gallon or smaller containers.

Pollutants from petroleum products used during construction activities adhere easily to soil particles and other surfaces. In case of a spill or leak, soils contaminated with petroleum products will be contained and removed to a proper disposal site. Proposed soil erosion and sediment control practices will aid in retention of spills or leaks. Use of secondary containment and drip pans will reduce the likelihood of spills or leaks contacting the ground. Proposed maintenance and safe storage practices will reduce the chance of petroleum products contaminating on-site soils and drainages. Oily wastes such as crankcase oil, cans, rags, and paper containing oils will be placed in proper receptacles and disposed of or recycled. An additional source of petroleum contamination is leaks from equipment and vehicles. Routine daily inspections will be conducted to identify leaks and initiate corrective actions, if needed.

The following guidelines for storing petroleum products will be used:

- All product containers will be clearly labeled.
- Drums will be kept off the ground within secondary containment and stored under cover if needed.
- Fuel tanks will be stored within secondary containment.
- Lids of drummed materials will be securely fastened.
- Emergency spill response procedures will be available on-site. Persons trained in handling spills will be on call at all times.
- Spill cleanup and containment materials (absorbent, shovels, etc.) will be easily accessible. Spills will be cleaned in a timely manner and reported as required in accordance with applicable regulations.
- Contaminated materials will be properly stored on site until they can be disposed of in accordance with applicable regulations.
- All equipment, when not in use, will be stored within an equipment storage containment area that will capture any leaks that may occur while the equipment is dormant.

Storage areas and containers will be regularly monitored for leaks and repaired or replaced as

necessary. Workers should be reminded about proper storage and handling of materials during weekly subcontractor or safety meetings.

Oil products, such as hydraulic oils, motor oils, and lubricants, will be stored in the appropriate storage location, such as flammable storage cabinets. Quantities of these items should not exceed 20 gallons. If larger quantities of these items are required to be on the site, AECI will review the storage and containment of those items. All appropriate health and safety requirements for chemical storage will be followed.

#### 3.4.2 Spill Prevention and Release

Pollution prevention measures will include the implementation of BMPs.

In the event of a release of fuel, lubricant, or coolant from equipment occurs, efforts will be made to stop the release, and the spilled fluids will be cleaned up as soon as possible. All contaminated soils and spent/used clean up materials shall be containerized (drums or dumpsters) and stored on site, until appropriate disposal methods have been identified. All stored waste will be recorded on the Waste Storage Log. Please contact your supervisor to report any spills over 5 gallons. The necessary repairs will be made to the equipment to prevent a continued release of potential pollutants.

A release of any chemical, petroleum product, or sewage which may enter waters of the State of Colorado must be reported to CDPHE Emergency Management Program Hotline at 1-877-518-5608 immediately. Written notification must follow within five (5) days.

If a reportable quantity of oil or hazardous material is discovered, AECI will notify the National Response Center at (800) 424-8802 immediately. The US EPA will be notified verbally within 24 hours, and in writing within 14 days. Complete emergency response and spill cleanup procedures are detailed in the Site-Specific Health and Safety Plan.

The site-wide *Spill Prevention and Countermeasures Control Plan* (SPCC) provides more detail regarding spill prevention, response, and chemical storage.

### 3.5 Waste Management and Disposal

Construction activities will generate various other wastes during the course of construction. Other wastes may include the following:

- Trash and debris from construction materials and workers, and;
- Sanitary sewage.

Each of these wastes will be managed so as to not contribute to stormwater pollution. Construction trash and debris will be collected in containers and hauled off-site for disposal in suitable landfills. Sanitary waste will be containerized in portable toilets or other storage tanks with waste materials regularly pumped and transported off-site for disposal at approved facilities. Portable toilets will be located in a safe area away from waterways, and where accidental tipping will not occur.

#### 3.5.1 Other Chemicals Products Management

Additional materials will be used and stored on site for use in construction and completion of the project. These materials will be stored appropriately and managed to minimize spills and leaks. Storage areas will be regularly inspected and any minor spills or leaks will be cleaned up immediately.

#### 3.5.2 Lay Down and Staging Areas

All on-site letdown or staging areas for equipment and materials storage operated or utilized by the Contractor or Subcontractors will be maintained with good housekeeping and will be inspected on a regular basis for spills, leaks, and potential contamination. This location will be noted, once defined on the SWMP Site Map.

#### 3.5.3 Off-Site Vehicles

Trucks used to transport aggregates and soils from off-site will not be required to be decontaminated from the work area during deliveries to the Contractor lay down area using the main access road. Vehicles and equipment working within the various project sites will be required to be decontaminated at the end of the project and before leaving the site, as necessary, and as determined by visual inspection. An inspection of all vehicles and equipment will be conducted to ensure that no contaminated material or soils will be tracked off-site. If necessary, wet decontamination procedures will be implemented to further reduce or eliminate off-site tracking of mud or dirt from the site if dry decontamination is determined to be ineffective.

### 3.6 Groundwater and Stormwater Dewatering

If groundwater is encountered during construction activities and pumping of the groundwater is required off the project site, a groundwater permit will need to be acquired from CDPHE and monitoring will be conducted in accordance with state requirements.

## 4.0 FINAL STABILIZATION AND LONG-TERM STORMWATER MANAGEMENT

For all new disturbances, BMPs will be installed prior to, during, and immediately following construction as practicable with consideration given to safety, access, and ground conditions (frozen ground) at the time of construction.

At the completion of the construction activities at the St. Louis Ponds site long-term stormwater management will consist of the maintenance of the erosion control measures installed pursuant to the SWMP.

# 5.0 INSPECTION AND MAINTENANCE

## 5.1 Inspection Schedule and Requirements

To meet requirements of the General Permit, inspection and maintenance of erosion and sediment controls must occur during the project. Continued inspection and maintenance is required for specific structures after construction is completed. The inspection program will include the following:

1. A qualified person familiar with the SWMP and control measures will conduct the inspections.
2. Inspections will cover these areas of the construction site:
    - Disturbed areas without stabilization,
    - Material storage areas,
    - BMPs,
    - Surface water diversions,
    - Down gradient areas.
3. A log of inspections will be kept.
4. Disturbed areas and material storage areas that are exposed to precipitation will be inspected for evidence of pollutants entering nearby drainages.
5. Sediment control BMPs will be inspected for evidence of deterioration, under-cutting, and build up of sediment. Sediment will be removed when it has built up one-third to one-half the height of the sediment retention structure.
6. Following each inspection; the SWMP will be modified as necessary to include additional controls designed to correct identified problems. Revisions to the SWMP will be made within 14 days of the inspection.
7. An inspection report summarizing the scope of the inspection, the name of the person conducting the inspection, date of inspection, and observations relating to the implementation will be prepared. Inspection reports will be retained for at least 3 years from the date that the site is finally stabilized.
8. Actions taken to modify any stormwater control measure will be recorded and maintained with the SWMP.
9. If no deficiencies are found during the inspection, the report will contain certification that the site is in compliance with the SWMP. Signatures will be in accordance with the General Permit Conditions Part F.1 (Appendix A).

A thorough inspection will be made at least every 14 calendar days. Also, post storm-event inspections will be conducted within 24 hours after the end of any precipitation or snowmelt event that causes surface erosion. Provided the timing is appropriate, the post-storm inspections may be used to fulfill the 14-day routine inspection requirement. As an alternate, inspections can also be made every 7 days, in lieu of the 14-day and post storm requirements. A more frequent inspection schedule than the minimum inspections described may be necessary to assure that BMP's continue to operate as needed to comply with the permit. The following conditional modifications to this minimum inspection schedule are allowed:

### 5.1.1 Post-Storm Event Inspections at Temporarily Idle Sites

If no construction activities will occur following a storm event, post-storm event inspections will be conducted prior to recommencing construction activities but no later than 72 hours following

the storm event. The occurrence of any such delayed inspection will be documented in the inspection record. Routine inspections will still be conducted at least every 14 calendar days.

### 5.1.2 Inspections at Completed Sites/Areas

For sites or portions of sites that meet the following criteria but where final stabilization has not yet been achieved due to a vegetative cover that has not become established, an inspection will be conducted at least once every month and post-storm event inspections are not required. This reduced inspection schedule is allowed only if:

i. All construction activities that will result in surface ground disturbance are completed.
ii. All activities required for final stabilization, in accordance with the SWMP, have been completed, with the exception of the application of seed that has not occurred due to seasonal conditions or the necessity for additional seed application to augment previous efforts.
iii. The SWMP must be amended to indicate those areas that will be inspected in accordance with the reduced schedule allowed for in this subsection.

### 5.1.3 Winter Conditions Inspections Exclusion

Inspections will not be performed at sites where construction activities are temporarily halted, snow cover exists over the entire site for an extended period and melting conditions posing a risk of surface erosion do not exist. This exception is applicable *only* during the period where melting conditions do not exist and applies to the routine 14-day and monthly inspections as well as post storm- event inspections. The following information will be documented in the inspection record for use of this exclusion: dates when snow cover occurred, date when construction ceased, and date melting conditions began. Inspections, as described above, are required at all other times.

Because there are several different construction activities that will be covered under the same permit, it will be common for different inspection frequencies to apply to different portions of the permitted area.

### 5.1.4 Completed Construction

After completion of the construction, but prior to returning the disturbed areas to approximate preconstruction conditions, the disturbed areas will be inspected at least once a month.

Maintenance will include prompt repairs and/or adjustments to any erosion and sediment control structures that are deteriorating or found to be performing inadequately. Repairs should be made as soon as possible and prior to the next anticipated storm event. Enterprise or designated contractor(s) will maintain on-site all materials necessary to make any reasonably expected repairs such as silt fencing, hay bales and stakes. Copies of the recommended inspection form are presented in Appendix E.

## 5.2 SWMP Modification Procedures

At times during the course of a construction project, the implemented BMPs will need to be modified to adapt to changing site conditions or to ensure that potential pollutants are consistently and properly managed. In the event of an inspection, pollutant source change, or other observation by qualified personnel, that requires a change in the described BMPs provided on the site map, the SWMP will be modified to accurately reflect the actual field conditions. The SWMP revisions must be made ***prior to changes in site conditions***, except as allowed under the permit (Responsive SWMP Changes).

Responsive SWMP Changes include revisions made immediately after changes are made in the field to address BMP installation and/or implementation issues; and revisions that require development of materials to modify the SWMP (e.g., design of retention pond capacity) which require modification as soon as practicable, but not more than 72 hours later.

These modifications shall be noted by the qualified personnel on the "Observation Report Form" in Appendix E, the Revision Log in Appendix F, and will be added by hand to the site map maintained with the SWMP at the site.

## 5.3 Retention of Reports

The Construction Manager must maintain a copy of this SWMP on the facility construction site from the date of project initiation to the date of final stabilization. The Owner shall retain copies of the SWMP and all reports required by the General Permit for a period of at least 3 years from the date that the project is complete.

## 5.4 Collection and Submission of Self Monitoring Information

Upon written notification from the Administrator, the Contractor will collect and report stormwater effluent or ambient water quality data of the type and at the frequency specified by the Administrator.

# 6.0 TERMINATION AND INACTIVATION NOTICE

On a site-specific basis the Permittee no longer requires coverage under this permit if all soil disturbing activities are complete and one of the following:

1. All disturbed areas have been either built on, paved, or a uniform vegetative cover has been established with a density of at least 70 percent of pre-disturbance levels or equivalent permanent, physical erosion reduction methods have been employed.

2. Areas needed for operation and maintenance of commissioned assets are developed as stabilized unpaved surfaces.

At that time, the permittee will submit to the Administrator the Inactivation Notice (Appendix G).

## 7.0 CERTIFICATION

"This Stormwater Management Plan has been prepared as a requirement of the Colorado Public Health Department Water Quality Control Division for the Stormwater Discharge Permit. I understand that additional erosion control; sediment control and water quality enhancing measures may be required of the owner and his or her agents due to unforeseen pollutant discharges or if the submitted plan does not function as intended. The requirements of this plan shall be the obligation of the land owner and/or his successors or heirs; until such time as the plan is properly completed, modified, or voided."

_____ _____
AGENT: DATE

_____
REPRESENTING:

## APPLICANT CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gathered and evaluated the information submitted. Based upon my inquiry of the person or persons who manage the systems, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signature: _____

Name: _____

Title: _____

Date: _____

## SUBCONTRACTOR CERTIFICATION

I certify under penalty of law that I understand the terms and conditions of the Rico-Argentine Mine Project SWMP and general permit that authorizes storm water discharges associated with industrial activity from the construction site identified as part of this certification.

| Signature | For | Responsible For |
|---|---|---|
| _____<br>(Name)<br>_____<br>(Position)<br>_____<br>(Signature)<br>Date: _____ | _____<br>(Company)<br>_____<br>(Street / P.O. Box)<br>_____<br>(City, State, Zip)<br>Phone: _____ | _____<br>_____<br>_____<br>(Activity) |
| _____<br>(Name)<br>_____<br>(Position)<br>_____<br>(Signature)<br>Date: _____ | _____<br>(Company)<br>_____<br>(Street / P.O. Box)<br>_____<br>(City, State, Zip)<br>Phone: _____ | _____<br>_____<br>_____<br>(Activity) |
| _____<br>(Name)<br>_____<br>(Position)<br>_____<br>(Signature)<br>Date: _____ | _____<br>(Company)<br>_____<br>(Street / P.O. Box)<br>_____<br>(City, State, Zip)<br>Phone: _____ | _____<br>_____<br>_____<br>(Activity) |

# APPENDIX A

## CDPHE GENERAL CONSTRUCTION STORMWATER PERMIT

# STATE OF COLORADO

**COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT**
**WATER QUALITY CONTROL DIVISION**
**TELEPHONE: (303) 692-3500**

## CERTIFICATION TO DISCHARGE
## UNDER
## CDPS GENERAL PERMIT COR-030000
## STORMWATER DISCHARGES ASSOCIATED WITH CONSTRUCTION

Certification Number **COR038415**

**This Certification to Discharge specifically authorizes:**

## *Atlantic Richfield Company*

LEGAL CONTACT:
***Gregory S. Tunstall, Vice President***
***Atlantic Richfield Company***
***317 Anaconda Road***
***Butte, MT 59701***
***Phone # 406/782-9964***

LOCAL CONTACT:
***Chuck Stilwell, ARCO Project Mgr,***
***Phone # 406/ 491-1129***

During the Construction Activity: **Commercial Development**
to discharge stormwater from the facility identified as **Rico Townsite Soils VCUP Project**
which is located at:

**N. St. Louis Road.**
**Rico, Co 81332**

Latitude **37/42/06,** Longitude **108/01/48**
In **Dolores County**

**to: Dolores River -- San Juan River**

Anticipated Activity begins **06/24/2005** continuing through **10/31/2005**
On **7.50** acres **(5.51** acres disturbed)

Certification is effective: **07/01/2007** Certification Expires: **06/30/2012**

Annual Fee: $245.00 **(DO NOT PAY NOW** – A prorated bill will be sent shortly.)

CDPS GENERAL PERMIT

STORMWATER DISCHARGES ASSOCIATED WITH
**CONSTRUCTION ACTIVITY**

AUTHORIZATION TO DISCHARGE UNDER THE

COLORADO DISCHARGE PERMIT SYSTEM

In compliance with the provisions of the Colorado Water Quality Control Act, (25-8-101 et seq., CRS, 1973 as amended) and the Federal Water Pollution Control Act, as amended (33 U.S.C. 1251 et seq.; the "Act"), this permit authorizes the discharge of stormwater associated with construction activities (and specific allowable non-stormwater discharges in accordance with Part I.D.3 of the permit) certified under this permit, from those locations specified throughout the State of Colorado to specified waters of the State. Such discharges shall be in accordance with the conditions of this permit.

This permit specifically authorizes the facility listed on page 1 of this permit to discharge, as of this date, in accordance with permit requirements and conditions set forth in Parts I and II hereof. All discharges authorized herein shall be consistent with the terms and conditions of this permit.

This permit and the authorization to discharge shall expire at midnight, **June 30, 2012.**

Issued and Signed this 31st day of May, 2007

COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT

Janet Kieler

Janet S. Kieler
Permits Section Manager
Water Quality Control Division

**SIGNED AND ISSUED MAY 31, 2007**

**EFFECTIVE JULY 1, 2007**

ADMINISTRATIVELY
CONTINUED EFFECTIVE
JULY 1, 2012

# APPENDIX B

# SITE VICINITY MAP

# PROJECT SITE LOCATION 1

# PROJECT SITE LOCATION 2

N 37.705927, W 108.031719

Sign in

:o, CO 81332 0.2 mi NW

more

s Labs - Help

Terms of Use - Privacy

# APPENDIX C

## GRADING PLAN WITH LIMITS OF DISTURBANCE BOUNDARY

This section left blank. Grading Plan with Limits of Disturbance Boundary for the Solids Repository will be provided with the 2014 update to the SWMP.

# APPENDIX D

# BEST MANAGEMENT PRACTICES AND EROSION AND SEDMINENT CONTROL PLAN

This section left blank. Best Management Practices and Erosion and Sediment Control Plan for the Solids Repository will be provided with the 2014 update to the SWMP.

# APPENDIX E

# OBSERVATION FORMS

977 West 2100 South
Salt Lake City, Utah 84119
(801) 972-6222

| EROSION & SEDIMENT CONTROL MEASURES OBSERVATION REPORT | |
|---|---|
| **Project Name**: Rico – Argentine Mine Site | |
| **Project Address/Location**: 31 South Glasgow, Rico, CO | |
| **Date**: | **Time**: |
| **Inspection Type:** Biweekly _____ Post Storm_____ Follow Up_____ | |
| **Weather:** Temperature_____, Sunny_____, Rain ____, Snow _____, Cloudy ____, Windy _____, | |
| SW Permit available on-site and posted | Y, N Comments: |
| SWMP available on-site | Y, N Updated |
| Inspection reports available on-site | Y, N Up to date? |

| Construction Activity | | Comments |
|---|---|---|
| Grading | | |
| Excavation | | |
| Utility Construction | | |
| Foundations | | |
| Concrete | | |
| Asphalt Paving | | |
| Landscaping | | |

| Erosion & Sediment Control Measures BMPs | | | | | |
|---|---|---|---|---|---|
| | Per SWMP and Design | Requires Maintenance | Needs Replacement | Needs Installing | **Follow up completed include initials and Date** |
| Diversion Swales/Berms | | | | | |
| Slope Drain | | | | | |
| Check Dams | | | | | |
| Inlet Protection | | | | | |
| Outlet Protection | | | | | |
| Silt Fence | | | | | |
| Seed/Sod | | | | | |
| Vehicle Track Pad | | | | | |
| Sediment Basin | | | | | |
| Erosion Blanket | | | | | |
| Street Sweeping | | | | | |
| Concrete Washout | | | | | |
| Stock Pile Management | | | | | |
| Hydro Mulch | | | | | |
| Wattles | | | | | |

Notes:

Inspection By: _____ Date: _____

Name

_____

Signature

# APPENDIX F

# SWMP REVISION LOG/REVIEW/CHANGES

SWMP Revision Log

| Item No. | Description | Date | Initials |
|---|---|---|---|
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# APPENDIX G

# REASSIGNMENT OF PERMIT COVERAGE AND INACTIVATION NOTICE

This section is left blank. No information has been generated for this appendix (G) to date (November 2013). The permit coverage is ongoing.

# Appendix I

# Construction Quality Assurance Project Plan

Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
AECOM
Denver, CO
60306858
December 2013

# Construction Quality Assurance Project Plan
# Solids Repository

# Rico-Argentine Mine Site
# Rico, Colorado

Submitted to:
US EPA Region 8
Denver, CO

Submitted by:
AECOM
Denver, CO
60306858
December 2013

# Construction Quality Assurance Project Plan
# Solids Repository

# Rico-Argentine Mine Site
# Rico, Colorado

Prepared By James Litz, P.E.

Reviewed By Thomas Kreutz, P.E

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# List of Acronyms

| | |
|---|---|
| AECI | Anderson Engineering Company, Inc. |
| AECOM | AECOM Technical Services, Inc. |
| AR | Atlantic Richfield Co |
| CQA | Construction Quality Assurance |
| CQAPP | Construction Quality Assurance Project Plan |
| CQC | Construction Quality Control |
| CSP | Certified Safety Professional |
| EPA | U.S. Environmental Protection Agency |
| HASP | Health and Safety plan |
| HSO | Health and Safety Officer |
| OSC | On-Scene Coordinator |
| OSC | On-Scene Coordinator |
| PE | Professional Engineer |
| RA | Risk Assessment |
| QC | Quality Control |
| SOP | Standard Operating Procedure |
| TSEA | Task Safety and Environmental Assessment |

# 1.0 Introduction

AECOM Technical Services, Inc. (AECOM) on behalf of Atlantic Richfield Co (AR) has prepared this Construction Quality Assurance Project Plan (CQAPP) for construction of the Solids Repository at the Rico-Argentine Mine Site (also known as the St. Louis Ponds Site) near the Town of Rico in Dolores County, Colorado. The work shall include the excavation of the repository cell, berm installation, liner and leachate collection system installation, discharge piping installation, storm water controls, and grading. This CQAPP addresses the Construction Quality Assurance (CQA) and Construction Quality Control (CQC) for construction activities as part of managing the total project quality to meet the project expectations.

The objectives of CQAPP are to:

- Ensure through observation, inspection, and measurements that the work and materials incorporated into the project are in conformity with the pertinent requirements listed in this plan.
- Provide an opportunity for timely response when results indicate that either the materials or the work are not in conformity with the requirements of this plan.
- Provide an opportunity for timely response when observations indicate that unanticipated conditions, the material, or work as constructed are not consistent with the overall intent of the selected remedy.

A summary of the CQA inspection requirements and frequencies are provided in Table 1 of this document.

CQC is a component of CQA involving specific test procedures, frequencies, and standards to ensure that materials and work meet the requirements of the CQAPP.

The objectives of CQC are to:

- Ensure through inspection and both laboratory and field testing that the work and materials incorporated into the project are in conformity with the pertinent requirements this plan.
- Provide an opportunity for timely response when test results indicate that either the materials or the work are not in conformity with the requirements of this plan.
- Document all calibrations of test equipment, quality control testing, inspections, and observations. Identify any corrective actions required, document completed corrective actions, and record any discrepancies.

## 1.1 Purpose

The purpose of this CQAPP is to present the quality assurance program to be implemented during the construction of the solids repository. This CQAPP was prepared to ensure that solids repository construction activities meet or exceed all design criteria testing listed in this plan.

## 1.2 Organization

This report is organized as follows:

- Section 1 presents the purpose and organization of the report.
- Section 2 outlines the project organization, roles and responsibilities.
- Section 3 presents the project meeting requirements.
- Section 4 describes the inspection and testing activities required to ensure that construction and materials comply with this plan.
- Section 5 describes documentation requirements of construction quality assurance activities.
- Section 6 describes surveying and site layout.

# 2.0 Project Organization, Roles, and Responsibilities

The purpose of this section is to define the areas of responsibility and lines of authority for each organization and for the members of the CQA/CQC team. This will be used to establish lines of communication to facilitate the decision making process during implementation of the CQAPP. Responsibilities of team members are described in the following sections.

## 2.1 Regulatory/Permitting Agency

As the regulatory agency, the U.S. Environmental Protection Agency (EPA) is responsible for overseeing AR performance of work for consistency and compliance with the provisions of the Removal Action Work Plan. EPA will designate an individual as its On-Scene Coordinator (OSC). The EPA or their oversight contractor will periodically be on site during solids repository area construction activities.

## 2.2 Facility Owner

As the responsible party, AR has the ultimate responsibility and authority for the project. AR will coordinate the overall management of implementation of the solids repository area construction activities.

AR is responsible for complying with the project documents and has the authority to select and dismiss organizations charged with design, construction activities, and CQA responsibilities. AR also has the authority to accept or reject CQAPP, reports, and recommendations of the CQA Officer and the materials and workmanship of any Contractor.

## 2.3 Project Manager

Mr. Anthony Brown has been selected by AR to fulfill the responsibilities of the Project Manager. Mr. Brown possesses the necessary skills and expertise to carry out their responsibilities.

As the Project Manager, Mr. Brown will be AR's key contact person for EPA during the remedial action. The Project Manager will also:

- Approve and sign submittals and progress reports. The Project Manager may authorize others to sign submittals and progress reports on his behalf.
- Certify that the construction has been completed in full satisfaction of the design and specification requirements. The Project Manager will sign the Completion of Construction Report in addition to a certifying professional engineer.
- Assist EPA as required for Community Relations.

## 2.4 Construction Manager

Mr. Christopher Sanchez, C.S.P. Anderson Engineering Company, Inc. (AECI) will serve as the Construction Manager for the solids repository construction activities. The duties of the Construction Manager include:

- Report to the Project Manager for AR
- Oversee on-site project activities
- Coordinate and schedule activities for the Contractors performing the work
- Ensure that site activities are recorded
- Oversee project schedule
- Chair project meetings

### 2.5 Design/Certifying Engineer

Mr. Doug Yadon, P.E. (AECOM) will serve as the Design/Certifying Engineer. The Design/Certifying Engineer is responsible for the preparation of the design. In addition, the Design/Certifying Engineer will be responsible for:

- Design modifications deemed necessary during the course of construction
- Periodic observation, when on site, of construction to assure that the work is harmonious with the Engineer's intentions
- Interpretation of the design
- Certify that the project was completed in accordance with the design and this CQAPP
- Participate in key technical discussions with EPA
- Oversee and sign technical submittals
- Oversee CQAPP implementation

### 2.6 Construction Quality Assurance (CQA) Officer

Mr. Alan Jewel (AECI) will serve as the CQA Officer. The CQA Officer will be on site during construction to supervise and be responsible for all inspections and testing in accordance with the approved CQAPP and the design. The duties of the CQA Officer are as follows:

- Monitor completion of record drawings.
- Monitor construction contractor compliance with submittal requirements.
- Provide field management of CQA activities.
- Review project documents for clarity and completeness so that the CQAPP can be implemented.
- Inform CQA support personnel on CQA requirements and procedures.
- The CQA officer shall exercise professional judgment to certify that pipe sizes, material, placement and pipe grades are in accordance with the design.
- The CQA officer shall inspect all prefabricated structures for conformity with the design and for defective manufacturing.
- Ensure that regular calibration of testing equipment is conducted and recorded.
- Ensure that CQA test results are accurately recorded.

- Identify work that should be accepted, rejected, or uncovered for observation, or that may require special testing, inspection, or approval.
- Reject defective work and verify that corrective measures are implemented.
- Scheduling and coordinating CQA inspection activities.

## 2.7 Health and Safety Officer

Mr. John Gallegos. (AECI) or appointed designee will serve as the Health and Safety Officer (HSO). The HSO will ensure that all Health and Safety requirements are effectively employed and enforced during activities completed on-site. The duties of the HSO are as follows:

- Ensure that all Health and Safety Program (Control of Work) defined practices are implemented as applicable to the site work.
- Maintain compliance records and documents as required by the Health and Safety Program.
- Observe and insure that all field work is in compliance with the Health and Safety Program and applicable regulations.
- Obtain and review TSEAs, SOPs and RAs for QA and QC activities.

## 2.8 Contractor(s)

The General Contractor and the Contractor's Project Manager shall be determined. Information regarding other task specific general contractors will be provided to EPA as the contractors are selected. The General Contractor(s) and its subcontractors will be responsible for supplying materials and labor to construct the project in reasonable conformity with the requirements of the latest project documents. As such, each Contractor is responsible for CQC to ensure that the work meets the requirements of the project documents.

Before performing work at the site, the Contractor must ensure that all necessary EPA approvals, authorizations, and coordination for EPA oversight have been secured or arranged. Work performed at the site without the necessary EPA approvals or authorizations will not be considered to be part of the remedy unless acknowledged and approved by EPA. However, EPA will be under no obligation to acknowledge any work undertaken without the necessary EPA approvals, authorizations, or construction observation.

CQC services furnished by the Contractor will include all laboratory and field testing, inspection, documentation of inspection, identification of any corrective actions required, documentation of completed corrective actions, written disposition on any discrepancies, and responses to the concerns of the CQA Officer. In addition, when requested by the CQA Officer, OSC, or the EPA oversight contractor, the Contractor will furnish access, facilities, and labor assistance, as necessary, for the duties to be performed by the CQA Officer, OSC, or EPA oversight contractor.

The Contractor will inform the CQA Officer and the EPA oversight contractor of CQC sampling and testing and, if requested, and coordinate such sampling with any or all of these individuals.

Within seven calendar days of discovering that, based on the results of CQC testing or inspection, one or more project requirements are not being met, the Contractor will provide a copy of the test

results or inspection report and a plan to correct or otherwise address the deficiency to the CQA Officer, and EPA. Upon approval, the Contractor will execute the plan and document its completion and outcome.

The Contractor will immediately notify the CQA Officer of any unanticipated conditions encountered during remediation or any other condition that the Contractor knows or suspects could affect the ability of the design to meet remediation objectives.

### 2.9 Construction Quality Control (CQC) Officer

Each Contractor will designate a CQC Officer. The CQC Officer is responsible for:

- Scheduling and coordinating CQC inspection activities
- Perform observations and tests by verifying that:
  - Regular calibration of testing equipment is properly conducted and recorded
  - The testing equipment, personnel and procedures do not change over time or that any changes do not adversely impact the inspection process
  - The test data are accurately recorded and maintained
- Preparing and tracking submittals required by the project documents
- Reviewing task plans and operating procedures to ensure quality objectives are met
- Ensuring that CQC testing is performed, as required by the project documents, or as necessary to provide a quality product
- Ensuring that materials and equipment meet the design before purchased and incorporated into the work
- Reviewing land survey services to ensure surveys are completed in an accurate and timely manner, and construction drawings are updated as work progresses in preparation for the as built drawings
- Ensuring that all data required for the as built drawings are collected before any work is closed/concealed
- Identifying deficient work items and recommending corrective actions
- Ensuring that agreed-upon corrective actions have been conducted and are sufficient to correct the deficiency
- Providing the CQA Officer with reports on the inspection results including:
  - Review and interpretation of all data sheets and reports
  - Identification of work that should be accepted, rejected or uncovered for observation, or that may require special testing, inspection or approval
  - Rejection of defective work and verification that corrective measures are implemented
  - Verification that a Contractor's CQC is in accordance with the project documents

- Provide CQC documentation to the Construction Manager on a daily or weekly basis as required by the project. Documentation (including photographs) shall be both hard copy and electronic.

CQC support personnel include persons experienced in their respective field of expertise and who will perform CQC for their specific aspect of the work. CQC Support Personnel will include, at a minimum:

- Surveyor to verify elevations
- Geotechnical laboratory personnel to certify soil conditions, and
- Personnel to certify pipe installation.
- The duties of the CQC Support Personnel are as follows:
- Conduct CQC tests and inspections as indicated in the CQAPP
- Accurately record test results and inspections
- Calibrate testing equipment in good working order, and
- Immediately notify CQC Officer whether or not test results comply with the design.

### 2.10 Quality Assurance/Quality Control (CQA/CQC) Testing Laboratories

CQA/CQC Testing Laboratories that will conduct CQA/CQC tests will be selected and identified by the Contractors. AECI must approve the selected CQC laboratory prior to employing the laboratory and prior to commencement of construction activities. The duties of the CQA/CQC Testing Laboratories are to provide CQA/CQC testing of construction activities, as requested by the CQC Officer and CQA Officer, to confirm construction activities have been implemented according to the project documents.

# 3.0 Project Meetings

Project meetings as detailed herein will be held during the construction period to ensure that all tasks are accomplished according to schedule and that they are completed in accordance with the project documents. Project meetings will be held at the site in Rico, Colorado. The following sections describe the purpose and topics of the expected meetings and the personnel that needs to attend each.

For all meetings held on site during the construction, the CQA Officer will take minutes. Copies of the minutes will be forwarded to EPA and all organizations present at the meetings.

## 3.1 Pre-Construction Meeting

Purpose

To resolve any uncertainties in the project documents, and to review levels of responsibility, reporting requirements, and health and safety requirements.

Present

AR Project Manager, Construction Manager, Design/Certifying Engineer, Contractor Representative, CQA Officer, and EPA and/or oversight contractor.

Topics

- Present requirements of CQAPP, Site-specific HASP, and other relevant documents.
- Review of Health and Safety (Control of Work) requirements and expectations.
- Health and Safety (Control of Work) specific documentation required prior to start of Work.
- Review of Work Schedule and critical tasks.
- Procurement of materials and approvals schedule
- Review the activities to be conducted during construction.
- Review roles of each organization relative to the project documents.
- Determine any need to modify the CQAPP that may be necessary to ensure that the construction is performed to meet or exceed the specified design criteria.
- Review lines of authority and communication.
- Discuss the established procedures or protocol for observations and tests including sampling strategies.
- Discuss the established procedures or protocols for handling construction deficiencies, repairs, and re-testing.
- Review methods for documenting and reporting inspection data.
- Review methods for submitting, distributing and storing documents and reports.

- Review work area delineation, security, site access by contractor and vendors. Discuss the location for storing construction equipment and materials and the protection of these items during inclement weather.
- Discuss the protection of uncompleted construction work during off-hours and during inclement weather.
- Conduct a site tour to verify design criteria and plans are understood, and to review equipment and material storage locations.

### 3.2 Weekly Progress Meetings

Purpose

To provide an update of work progress on a weekly basis, and identify schedule slippages and efforts required to get back onto schedule, if required. These meetings will also provide construction progress update to EPA.

Present

AR Project Manager (as required), Construction Manager, CQA Officer, Design/Certifying Engineer (as required), Contractor Representatives (as required), HSO, and EPA and/or oversight contractor (as required).

Topics

- Review health and safety deficiencies for previous period's activities and review health and safety requirements and potential problems for the upcoming activities.
- Review work activities for the previous period.
- Compare actual progress to scheduled work activities, noting of schedule slippages, and discuss actions to be implemented to regain project schedules.
- Review work activities for the next period.
- Review potential construction problems and proposed solutions.
- Review potential change orders to the Contract.

### 3.3 Problem Resolution Meetings

Purpose

Meetings held as required if a problem or deficiency is present or likely to occur.

Present

AR Project Manager (as required), Construction Manager, CQA Officer, CQC Officer (as required), Design/Certifying Engineer (as required), Contractor Representatives, and EPA and/or oversight contractor (as required).

Topics

- Define and discuss problem or deficiency.
- Review alternative solutions.
- Develop and implement a plan to resolve the problem or deficiency.

### 3.4 Pre-Installation Meetings

Purpose

To review conditions of installation, preparation, and installation procedures of major components of the solids repository construction work.

Present

Construction Manager, CQA Officer, Contractor Representatives, Design/Certifying Engineer (as required), and EPA and/or oversight contractor (as required).

Topics

- Review coordination of related work.
- Review preparation and installation procedures.

### 3.5 Pre-Final Completion of Construction Inspection

Purpose

To determine whether the project is complete and consistent with the EPA approved final documents and approved work.

Present

AR Project Manager, Construction Manager, CQA Officer, Design/Certifying Engineer, and EPA and/or oversight contractor.

Topics

- Walk-through inspection of the entire project site.
- Identify and note any outstanding construction work.
- Review of test for treatment equipment and certify.

### 3.6 Final Completion of Construction Inspection

Purpose

To verify that outstanding issues identified during the Pre-final Completion of Construction Inspection were addressed.

Present

AR Project Manager, Construction Manager, CQA Officer, Design/Certifying Engineer, and EPA and/or oversight contractor.

Topics

- Walk-through inspection of the entire project site.
- Verify that all outstanding construction work identified during the Pre-final Completion of Construction Inspection was addressed.

# 4.0 Inspection and Testing Activities

## 4.1 Scope

Throughout implementation of the construction activities there will be inspections and testing requirements for specific work tasks. The inspection and testing requirements will ensure compliance with the project documents, as well as ensure completion of the work tasks to the highest level of quality. Inspections and testing will provide a means of monitoring the quality and progress of work performed.

## 4.2 Inspections

Throughout the period of construction, the quality of work completed and material used for each of the work tasks will be maintained at its highest possible level through regular inspections of the work. The CQA Officer, CQC personnel, and representatives of EPA (as required) will complete inspections throughout construction.

In general, inspections to be conducted by the CQA Officer and CQC personnel include the following:

- Daily inspections of the work progress
- Inspections of material as it is delivered to the site to check for physical damage or other characteristics rendering material unsuitable for use
- Comparison of the material delivered to the site to the design criteria to ensure that the material delivered to the site meets applicable project design criteria
- Inspection of materials following installation to verify that materials have not been damaged during installation and that the materials have been installed in accordance with the project documents
- A pre-construction inspection will be performed prior to beginning work on any major work task. The pre-construction inspection will include the following:
  - Review of contract requirements to ensure that all materials and/or equipment have been determined to meet applicable standards and design criteria,
  - Confirmation that provisions have been made to provide required Quality Control (QC) testing,
  - Examination of the work area to ascertain that all applicable preliminary work tasks have been completed, and
  - Coordination of work activities with corresponding CQA required testing and inspections.
- General inspections will be performed periodically as the amount of work completed warrants an inspection. A general inspection will include the following:
  - Examination of the quality of workmanship,
  - Testing of materials for compliance with contract requirements,

  - Any identification of omissions, and
  - General progress of work performed.

- A final inspection will be performed upon completion of each work task to ensure compliance with the project documents and to ensure that deficiencies identified in the general inspections have been corrected

The CQA Officer will perform these inspections and the results of the inspections will be provided in the final construction report. The CQA Officer will notify EPA representatives at least three days in advance of any major final inspections. The results of all inspections will be recorded in the daily site logbook as described in Section 5.2.

The components of each work task to be inspected, the types of inspections required and the frequency of the inspections are detailed in this plan and in the design.

### 4.3 Testing

In addition to the daily construction progress inspections, quality control testing of materials and equipment testing will be carried out as required in the CQAPP and the project documents. In some cases, the required testing can be performed at the manufacturing facility, while in other instances the testing is required once the component is on-site or installed. Testing of select material and equipment provides additional assurances that the component has been properly manufactured, installed, and coordinated with other components of construction.

The testing requirements, methods/standards for testing, testing frequency for each of these work-task components, and submittals (test reports, certificates verifying material quality/workmanship, etc.) are detailed in the design.

# 5.0 CQA/CQC Documentation

Proper documentation and reporting will be an integral part of the CQA/CQC activities. This section specifically deals with the record keeping and storage of CQA/CQC documents and final acceptance of the project.

## 5.1 General

This section details the documentation requirements for the CQAPP. The proper, thorough, and accurate documentation of all CQA site activities is important in ensuring quality installation. CQA testing will be documented daily.

## 5.2 Supervising Contractor's Daily Site Log Book

A representative of the Supervising Contractor will record daily QC activities in a Daily Site Log Book to be kept on-site at all times. The logbook will include the following information:

- Date, time, and weather conditions
- Present phase and location of construction activities
- Health and safety considerations
- All site activities including equipment and personnel on the project
- A summary of any meetings held and attendees
- Decisions made regarding records and approval of units of material or project activity
- Supplier submittals including documentation identifying material characteristics and quantities of material delivered to the site
- Quantitative identification of work progress
- The calibration and recalibration of test equipment
- QC test and inspection results
- The daily inspection report from each inspector
- Construction delays, and causes
- Areas affected by delays
- Construction problems and corrective actions
- Material and/or equipment delivered to the site and demobilized from the site
- Corrective actions to be taken in cases of substandard quality
- Instructions given by the CQA Officer
- Changed conditions/conflicts encountered, and
- Remarks.

The Construction Manager for the Supervising Contractor will sign the log entry daily as verification to its correctness. A copy of the signed entry will be provided to the CQA Officer on a daily basis for verification.

### 5.3 CQC Instrument Calibration

The CQC personnel will record calibrations of test equipment in an Instrument Calibration Logbook, maintained on-site by the CQA Officer. Actions taken as a result of re-calibration will be recorded in the Inspection Logbook, as described in the next section.

### 5.4 Inspection Log Book

The CQC personnel will record all observations and QC field tests in an Inspection Logbook. These books will be kept on-site and maintained by the CQC Officer. The Inspection Logbook will include the following information:

- Date, time, weather conditions
- Description or title of the inspection activity
- Location of the inspection activity or location at which the testing or sample collection was completed
- Type of inspection activity and procedure used (reference to standard method when appropriate)
- Recorded observation or test data, with all necessary calculations
- Results of the inspection activity and comparison with specification requirements
- Personnel involved in the inspection activity, and
- Signature of the appropriate CQC inspection personnel and concurrence by the CQA Officer.

Items above shall be formulated into checklists so that details are not overlooked.

### 5.5 Problem/Corrective Action Reports

A problem is defined as material or workmanship that does not meet the design criteria. Problem/Corrective Action Reports should be cross-referenced to specific inspection entries in the Inspection Logbook where the problem was identified.

Problem/Corrective Action Reports will include the following information:

- Detailed description of the problem
- Location of the problem
- Probable cause
- How and when the problem was located (reference to Inspection Log Book)
- Estimation of how long problem has existed
- Suggested corrective action
- Documentation of correction (reference to Inspection Log Book)
- Final results

- Suggested methods to prevent similar problems, and
- Signature of the appropriate CQC personnel and concurrence by the CQA Officer.

In some cases, not all of the above information will be available or obtainable. However, when available, such efforts to document problems could help to avoid similar problems in the future.

## 5.6 Project Modifications

During the course of construction, modifications may be identified to enhance system performance, improve constructability, or provide better value. The procedures to be employed in the review and approval of any identified modification depend on the significance and magnitude of the change with respect to the overall project. Three types of modifications are defined as follows:

- Process-Related Modifications are proposed design or construction changes that could affect the performance of the remedy
- Other Design Modifications are proposed changes to building structures or other components which do not have the potential of affecting the performance of the remedy but nonetheless require detailed engineering evaluation and approval, and
- Minor Modifications are proposed changes for constructability that do not have the potential of affecting the remedy and require minimal engineering review.

Process-Related Modifications to the design will be prepared, as directed by AR, and presented to EPA for review and approval. No Process-Related Modifications will be forwarded to the Contractor's for inclusion in the work without prior approval.

Other Design Modifications may be made from time to time throughout the project to improve constructability or increase value. AECI, AECOM or the Contractor will initiate these modifications as value engineering changes. All design modifications will be evaluated by AR, AECI, AECOM and will require EPA approval.

In addition, the Contractor may institute Minor Modifications. In this case, AECI will work closely with the Contractor to continuously record any changes or modifications to the design drawings or design criteria. Minor Modifications will be initiated without prior notification of the EPA. Minor Modifications will be verbally identified to the EPA oversight contractor in a timely manner as part of general project communication with EPA.

Records of all project modifications will be kept on-site. Copies of these records will be provided to the EPA.

## 5.7 Project Documents and Records

### 5.7.1 Shop Drawings

For some elements of construction, the design criteria require the Contractor to prepare technical data and submit this information to AECI/AECOM for review. This prevents any misinterpretation of the design criteria that may otherwise impact the design objectives or construction schedule. Typical submittals required as part of the design criteria include, but are not limited to: material samples; manufacturers' product literature; dimensioned engineering drawings of the component; installation drawings; operating descriptions; layout drawings; and detail drawings. Required submittals are noted in the project documents.

The shop drawing submittal and review process affords an opportunity to monitor and control the quality of construction before materials are delivered to the site. AECI/AECOM will review and approve all shop drawings and maintain the shop drawing submittals on file. In the event a shop drawing submittal is not approved, the Contractor will be responsible for making corrections to each submittal, as required by AECI/AECOM. Approved copies of shop drawings will be made available to the EPA field representatives upon request.

### 5.7.2 Record Drawings

During construction, each Contractor is required to keep one set of Project Drawings at the site. The Contractor will show all project modification changes (regardless of how minor) to the work associated with this project on these drawings. The drawings will be kept current on a day-to-day basis in concert with the progress of the work. Where applicable, any changes marked on the drawings will include the notation “per Change Order No. ____” or similar reference that cites the reason for the change. These drawings will be made available to the EPA for review upon request. Upon substantial completion of the project, the Contractors will provide the Record Drawings to AECI for inclusion in the Certification of Construction Completion Report. AECI will distribute to AR project team members. The Construction Manager will maintain the Record Drawings.

### 5.7.3 Photographic Records

Photographs may be used as tools to document the progress and acceptability of the work and may be incorporated into the daily site logbook reporting, the inspection logbook reporting, and the acceptance report. Each photo shall be identified with the following information:

- The date, time and location of photograph
- The name of photographer
- The signature of photographer

## 5.8 Completion of Construction

Completion of construction will include, at a minimum, the following:

### 5.8.1 Pre-Final Completion of Construction Inspection

AR will notify EPA upon substantial completion of project construction for the purpose of conducting a Pre-final Completion of Construction Inspection. The inspection will consist of a walk-through inspection of the entire project site by AR accompanied by EPA. The inspection is to determine whether the project is complete and consistent with the design documents and EPA approved plans regarding the site. Any outstanding construction work discovered by AR or EPA during the inspection will be identified and noted.

### 5.8.2 Pre-Final Completion of Construction Inspection Report

The Pre-final Completion of Construction Inspection Report, prepared by AR will outline any outstanding construction work, actions required to resolve outstanding construction work, tentative completion dates for outstanding construction, and a proposed date for final completion of construction inspection. The Pre-final Completion of Construction Inspection Report will be submitted to EPA for approval.

### 5.8.3 Final Completion of Construction Inspection

AR will notify EPA upon completion of any outstanding construction work for the purpose of conducting a final completion of construction inspection. The final completion of construction inspection will consist of a walk through inspection of the project site conducted by AR and accompanied by EPA. The Pre-final Completion of Construction Inspection Report will be used as a checklist for the final completion of construction inspection focusing on the outstanding construction work previously identified.

### 5.8.4 Final Completion of Construction Report

After completion of a successful final completion of construction Inspection and upon receipt of all necessary documentation from the Contractors, AR will prepare and submit for approval by EPA, a Completion of Construction Report. In the report, a registered professional engineer and BP's Project Manager will certify that the project is consistent with the project documents.

The report will include, but not be limited to the following elements:

- Introduction
- Chronology of events
- Performance Standards and Construction Quality Control
- Summary of construction activities
- Summary of final inspection
- Certification by the CQA officer that the construction has been prepared and constructed in accordance with engineering design
- Record drawings (as-builts) signed and stamped by a professional engineer
- All daily summary reports
- Explanation of any modifications to the plans and why these were necessary for the project
- Certification that the system is operational and functional
- Results of site monitoring, indicating that the work will meet or exceed the performance standards, and
- Explanation of the O&M (including monitoring) to be undertaken at the site and any changes required based on modification of site plans during construction

A Professional Engineer (PE) licensed in the State of Colorado will certify the Final Completion of Construction Report. The certifying engineer will have been on site during inspection and testing of critical aspects of construction. The PE will provide certification that the Completion of Construction Report and record drawings were completed in accordance with the final design documents.

### 5.8.5 Acceptance of Completed Construction

EPA will notify AR that the construction has been fully performed following receipt of the Final Construction Completion Report.

## 5.9 Storage of Records

During construction, the CQA Officer will maintain a copy of the design, CQAPP and Problem/Corrective Action reports in the site office. Once the construction is complete, all CQA documents (originals) will be retained by AR, AECOM and AECI. Electronic data will also be distributed to AR, AECOM and AECI.

# Table

# Table 1 - Summary of Construction Quality Assurance and Construction Quality Control Testing

| Test Description | Test Method | CQC Test Frequency | CQA Test Frequency |
|---|---|---|---|
| Earthwork and Subgrade/Embankment Preparation | | | |
| Field Density and Moisture Content | ASTM D2922, D3017 | 1 per 5,000 sf per lift | 1 per 50,000 sf or 1 per 10 QC tests |
| Standard Proctor | ASTM D698 | 1 per material type | 1 per 5 QC tests |
| Piping Installation | | | |
| Hydrostatic Testing | ASTM F2164 - 13 | All non-perforated piping | Not required |
| | ASTM D1785 - 12 | | |
| Geomembranes | | | |
| Destructive Field Seam Testing | | | |
| Seam Peal | ASTM D4437 | 1 test (sample) per 500 feet of seam | 1 test (sample) per 5000 feet of seam |
| Tensile Strength | ASTM D4437 | 1 test (sample) per 500 feet of seam | 1 test (sample) per 5000 feet of seam |
| Non-Destructive Field Seam Testing | | | |
| Vacuum Chamber | ASTM D5641 | Continuous | Not Required |
| Pressurized Air Channel Evaluation | ASTM D5820 | Continuous | Not Required |
| Cushion Layer/Sand Filter Layer | | | |
| Particle Size Analysis | ASTM D421, 422 | 2 per 5,000 tons | 1 per 25,000 tons or 1 per 5 QC tests |
| | | | |
| Gravel Drainage Layer | | | |
| Particle Size Analysis | ASTM D421, 422 | 2 per 5,000 tons | 1 per 25,000 tons or 1 per 5 QC tests |
| | | | |