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February 13, 1998

MEMORANDUM

SUBJECT: Report on Hydrological Connection Associated With Molycorp Mining Activity, Questa, New Mexico

FROM: Larry D. Wright, Chief Larry Wright
Source Water Protection Branch (6WQ-S)

TO: Jack Ferguson, Chief
NPDES Permits Branch (6WQ-P)

In response to a request for technical assistance from the NPDES Permits Branch, the Groundwater Center of Excellence has reviewed several technical reports to determine if Molycorp mining activities, at its mine site and tailings ponds, are a source of Red River contamination through a ground water hydrological connection. Reports on water quality studies and historic observations from Molycorp, conservation groups, and the New Mexico Environment Department were reviewed to determine if sampling methodology, surface and subsurface geological research, and historic research were adequate to document a source and a ground water hydrological connection between the source and the acidic, high metals concentrations discharged to the river via seeps.

The Amigos Bravos and New Mexico Citizens for Clean Air and Water conservation groups contend that the Molycorp Mine waste rock dumps are the source for high metals concentrations discharged at Red River seeps adjacent to the mine site. However, Molycorp considers the surface water runoff and sediment loading from naturally occurring erosional scars as the primary source of Red River contamination. The available information indicates that two most probable sources exist at the mine site: the Molycorp mine waste rock dumps, and the naturally occurring erosional scars.

The available data document a groundwater hydrological connection, via the shallow aquifers, between the erosional scars and waste rock dumps and the acidic, high metals concentrations discharged via Red River seeps at the mine site. However, the percentage of metals concentrations or discharge volume supplied to a particular seep by each probable source could not be determined using the available information.

Documentation exists for a groundwater hydrological connection, via the shallow aquifers, between the tailings ponds and the adjacent Red River seeps. Tailings pond water infiltrates to the shallow ground water and is discharged to the river. However, due to attenuation of pond leachate (high metals and sulfate concentrations in pond water) through groundwater transport, no ground water discharge of high metals concentrations to the river has been documented.

Attachments (1)

REPORT ON HYDROLOGICAL CONNECTION ASSOCIATED WITH MOLYCORP MINING ACTIVITY, QUESTA, NEW MEXICO

Report on Hydrological Connection Associated With Molycorp Mining Activity, Questa, New Mexico

Prepared for:

USEPA, Region 6
NPDES Permits Branch (6WQ-P)

by:

David Abshire
Geologist,
USEPA, Region 6
Groundwater/UIC (6WQ-SG)

Date:

February 13, 1998

EXECUTIVE SUMMARY

This study was initiated following a request from the EPA Region 6 National Pollution Discharge Elimination Systems (NPDES) Permits Branch for assistance in determining if mining activities at the Union Oil of California Molycorp (Molycorp) Questa Molybdenum Mine and associated tailings ponds are a source of contamination to the Red River. Specifically, the request was to determine if these mining activities are resulting in the discharge of acidic, metal laden ground water to surface water via seeps along the Red River through a ground water hydrological connection. The study was conducted by the EPA Region 6 Ground Water Center of Excellence (GWCE). The NPDES Permits Branch supplied several technical reports and correspondence pertaining to the Molycorp site for review. Additional information was acquired from the New Mexico Environment Department (NMED), Molycorp, conservation groups, and a site visit.

With respect to this report, the Molycorp site consists of the actual mine located between the towns of Red River and Questa, New Mexico; and the Questa Valley tailings pond area, located approximately 10 miles downstream from the mine area near the town of Questa. This study focuses on river seeps (ground water flowing gently from the river bank above river water level) in reaches of the Red River adjacent to the Molycorp mining operations and tailings ponds. The seeps are the primary non-point source discharge relative to the NPDES program at these sites. For this investigation, the GWCE evaluated the available geologic, water quality and well test data to determine 1) if ground water and adjacent Red River seep water contamination exist, 2) the probable source for ground water contamination, and 3) if a ground water hydrological connection exists between the source and the contaminated ground water discharged by seeps to the river. As with all reports reviewed during this study, some conclusions in this report are based on the application of scientific principles relative to the issues.

The Red River has 21 perennial tributaries which originate as very high quality mountain streams. Those tributaries which are not near sulfide rich outcrops or historic or recent mining areas remain high quality streams until their confluence with the Red River. The NMED reported that long-time residents considered the Red River pristine prior to mining operations. However, Molycorp contends that its mining operations cannot be the only source for the acidic, high metals seep discharge due to the fact that place names such as Sulphur Gulch, Bitter Creek and Red River allude to the conditions that existed when the region was settled. River water quality in some areas up-river of the mine site is periodically affected by storm events which deliver elevated metals concentrations (above surface water standards) to the river. The NMED states that there are a number of ground water related nonpoint sources of contamination to the river, and that sampling shows that the greatest impact is from acidic, high metals seeps.

Seeps discharge acid rock drainage (ARD) into the river in the mountainous region of the Red River watershed. ARD is characterized by low pH, and elevated concentrations of metals and total dissolved solids (TDS) which typically exceed New Mexico Ground Water Standards (NMGWS). The most common mechanism for its formation involves the oxidation and hydration of sulfide minerals (e.g., pyrite, or iron sulfide) resident in the source rock (volcanic rhyolite).

This chemical reaction results in the generation of sulfuric acid and elevated concentrations of iron. Rhyolite is found in naturally occurring erosional scars within the watershed, and in Molycorp's waste rock dumps (WRDs). The primary metals involved in contaminant transport include; aluminum, magnesium, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, and zinc.

There are two general modes of contaminant transport in the mountainous region (which incorporates the mining area) of the Red River watershed: steady-state, and pulse loading. In pulse loading, large volumes of weathered sulfide rock are periodically transported to stream channels by storm events. Regional sampling conducted by the NMED revealed that metal loading problems associated with pulse events are largely temporal, and that in most cases a degree of equilibrium is restored to affected stream reaches within a few days. Molycorp has recently constructed a surface water collection system to capture and redirect most of the runoff within the mining area. This system is designed to reduce pulse loading to this reach of the river. Steady-state refers to the relatively continuous discharge of ground water to the river.

At the mine site, the erosional scar and WRD geochemistry are correlative to the adjacent ground water quality. Constituent correlation also exists between ground water and the discharge at seeps along the river. Data from several monitor wells indicate that the shallow alluvial aquifers are saturated, and that these aquifers have the potential to transport low pH ground water with high metals concentrations to surface water. In addition, United States Geological Survey (USGS) data indicate that this particular reach of the Red River is a gaining stream supplied by ground water. Therefore, the erosional scars and WRDs are most probably hydrologically connected through a shallow alluvial aquifer conduit to the Red River seeps within the mine property.

The tailings ponds contain spent slurry from the mine site. Surface water runoff, which contains ARD, is collected and used for milling operations. The milling operations generate the spent slurry which is then piped to the ponds for disposal. The pond fluid is characterized by low pH and high metals concentrations (i.e., ARD). Although Molycorp has constructed a surface water drainage system to divert runoff from entering the pond area, sulfate and metals concentrations found in ground water below and down gradient of the tailings ponds exceed NMGWS due to infiltration of pond slurry water containing ARD. Due to the area's gentle surface gradient and the surface water collection system, steady-state (i.e., ground water) appears to be the only mode of transport within the tailings pond area.

A ground water hydrological connection via the shallow alluvial aquifer exists between the tailings ponds and seeps adjacent to the Red River. Seep discharges in this area are characterized by sulfate concentrations slightly above ground water background. However, metals concentrations do not exceed NMGWS or NMSWS at these seeps. River water quality adjacent to the tailings ponds appears to meet New Mexico Surface Water Standards (NMSWS).

According to the NMED, the seeps down gradient of the tailings ponds are part of a continuing Molycorp monitoring program, which indicates that seep water quality is not deteriorating. Molycorp has constructed a shallow ground water collection system to capture pond leachate being transported to the river; however, some contaminants bypass this system. Molycorp is presently installing extraction wells to capture leachate that bypasses the collection system.

In summary, this investigation concluded that the possible sources for the high metals and sulfate concentrations discharged to the river at the mine site are: 1) historic and recent mine waste rock, 2) erosional scars, 3) remnant deposits of tailings resulting from pipeline breaks, 4) a landfill area at the head of Spring Gulch, 5) the Moly tunnel, (6) the caved area in Goathill Gulch, and 7) runoff directed to the underground workings for collection. Of these, the most probable sources are considered to be the WRDs and the erosional scars based upon the results of material analysis and water quality; and that the acidic seeps and these two sources are wide spread while other sources are localized. The only probable source of ground water contamination at the tailings ponds area are the ponds.

The NPDES Program regulates point sources. NPDES regulations (40 CFR, §122.2) define point source as "any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure,...from which pollutants are or may be discharged..." A documented ground water hydrological connection between a source and surface water discharge may be viewed as a conduit; or a discernible, confined, and discrete conveyance. To identify the source for surface water contamination, proper sampling and monitor wells are required to verify constituent correlation and a ground water hydrological connection between the source and the discharge to surface water. Support exists for a ground water hydrological connection between a source and surface water discharge if water quality analysis and monitor well data determine that 1) there is reasonable constituent correlation between surface discharge, source leachate, and ground water; 2) the ground water gradient is to surface water (gaining stream); and 3) aquifer characteristics support a connection. The most probable sources (erosional scars, waste rock dumps, and the tailings ponds) satisfy these requirements. The tailings ponds supply water and elevated metals concentrations to the ground water through infiltration, but no documentation exists for the ponds being a source of river metals concentrations. Therefore, it appears that contaminants in ground water are attenuated prior to the discharge of ground water and pond water to the river in this area. At the mine site, the percentage of metals concentrations or discharge volume supplied to a particular seep by each probable source (erosional scar or waste rock dump) could not be determined using the available information.

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INTRODUCTION

1.0 INTRODUCTION

The objective of this report is to determine the source for the acidic, high metals seeps (ground water flowing gently from the soil) along the Red River bank and to determine if sufficient documentation exists to substantiate a ground water or surface water hydrological connection between the source and seep discharge to the river. Surface water drainage pathways were evaluated to determine if surface water runoff could supply contaminants to the seeps. Monitor well tests and ground water quality data were evaluated to determine if subsurface pathways existed between the source and the seeps

The Amigos Bravos and New Mexico Citizens for Clean Air and Water conservation groups (hereafter referred to as Amigos et al) contend that the Union Oil of California Molycorp (or Molycorp) excavation and disposal activities at the mine site are the cause for the increase in metals concentrations delivered to the river through a ground water hydrological connection to seeps located along the river bank. Amigos et al, have requested that the Region 6, National Pollution Discharge Elimination System (NPDES), Permits Branch require Molycorp to obtain a permit for this ground water discharge. The New Mexico Environment Department (NMED) considers the acidic, high metals seeps, which exist within the Molycorp mine boundary, the principal cause for metals loading to this reach. In contrast, Molycorp considers the erosion and surface water transport of sulfide rich naturally occurring erosional scar material as the major source of metals loading to the river. Therefore, although all possible sources were evaluated as to their relative metals contribution to surface water, this report concentrates on historic and recent mine sites and natural factors which may be a source for the continuing degradation of the Red River.

The Red River watershed is located in north central New Mexico, Taos County. Studies by the United States Geological Survey (USGS) and others have documented that for most of its length, the Red River is a gaining stream supplied by groundwater. As indicated in Appendix 1, the river is classified in the New Mexico Standards for Interstate and Intrastate Streams from the Rio Grande upstream to the mouth of Placer Creek with the following uses: coldwater fishery, fish culture, irrigation, livestock watering, wildlife habitat, and secondary contact. It has been documented (NMED, March 1996) that Red River standards are most often not attained due to various non-point sources. Its impairment is mainly due to the influx of low pH levels, metals, biological toxins, septic tank effluent, municipal sludge, petroleum products, and sediment loading due to storm events. The most incessant and wide-spread effect to river water quality is from the influx of fluids with low pH and high metals concentrations, which are delivered to the river via ground water transport to seeps along the river and surface water runoff.

As illustrated by Figures 1 and 2, the Molycorp mining operations include the open pit, old and new underground mining areas, waste rock dumps (WRDs), a mill site and associated tailings piles. The Molycorp mine property is located north of the Red River and Highway 38 between the towns of Red River and Questa and incorporates approximately five square miles. Molycorp began the underground mine workings in 1923 for molybdenum, an element used in strengthening steel. In

1941, mining had extended to such depths that a mile-long tunnel (hereafter referred to as the Moly Tunnel) was constructed to facilitate drainage of the underground workings into the Red River. In 1965, Molycorp abandoned the underground working and switched to open pit operations over the existing underground mine. Within this period, the Moly Tunnel was closed by placing concrete plugs at each end. To obtain access to the subsurface molybdenum deposits, during open pit operations the overlying surface material was excavated and deposited progressively down gradient in canyons as WRDs. Molycorp has covered approximately 500 surface acres near the operations with hundreds of feet of this waste rock material. In 1983, Molycorp ceased open pit operations and commenced new underground mining approximately 4,000 feet southwest of the old location. Mining operations were temporarily suspended from 1986 to 1989 and from 1992 to 1995 due to general economic conditions.

To alleviate the low pH and high metals loadings to the Red River adjacent to the Molycorp mine site, Molycorp (with NMED assistance) dug trenches and installed a series of anoxic alkaline (limestone) filters in early 1996 at a site along the river (Capulin Canyon) where NMED considers several of the seeps particularly active. Prior to limestone placement, the NMED determined that ground water quality from the trenches was correlative to the adjacent Red River seep water quality. However, after a short period of time, these filters became ineffective in modifying the pH and metals content.

The tailings impoundment is located approximately six miles west of the mine near the town of Questa and incorporates approximately 640 acres. After the molybdenite is extracted at the mine site through milling operations, the spent slurry is pumped out of the mining area through a ten mile pipeline constructed along the Red River to the tailings ponds at Questa. Since 1965, Molycorp has discharged approximately 95 million tons of tailings into the Questa impoundments.

The tailings impoundment, as illustrated on Figure 3, consists of several inactive and two active unlined ponds. The ponds were constructed consecutively within two arroyos by placing earthen dams at the down gradient end of each pond. South Pass Resources (April 13, 1995) reported that the slurry delivered to the ponds consists of 38 percent solids and 62 percent liquids. Standing water in the ponds was originally collected by surface drains and directed to Pope Lake, which is located south of Dam No. 4, and then to the Red River. In the 1970's Molycorp installed seepage barriers to intercept seepage and shallow ground water south of Dam No. 1 and southeast of Dam No. 4. Vail (September 24, 1993) states that these barriers were effective for some time but recent evidence indicates they are less effective in decreasing metals concentrations. In 1983, Molycorp installed an ion exchange facility to process the water at Pope Lake prior to discharging it to the river. An additional drainage system has been installed beneath both dams which consists of chimney drains connected to under drains at the base of the dam. Vail (September 24, 1993) states that Molycorp is presently investigating the feasibility of constructing additional seepage barriers and/or other facilities to substantially reduce the seepage flow down gradient of the tailings ponds in this area.

Several private wells located down gradient of the ponds were used by residents for drinking water purposes. In 1976 Molycorp plugged several of these wells and re-routed service from the Questa community well system due to elevated sulfate and Total Dissolved Solids (TDS) concentrations making private well water unacceptable as a drinking or irrigation source.

The NMED (March, 1996) states that in 1966, in response to Molycorp operations, the United States Department of Health, Education and Welfare conducted a baseline water quality survey of the Red River. The survey revealed that although there was periodic metals loading due to storm events from small historic mine sites adjacent to the river, the overall river water quality was determined to be good to exceptional. In 1971, the EPA determined the chemical water quality of the river remained good except for contamination resulting from occasional breaks in the tailings pipeline. However, in the same time period, the New Mexico Department of Game and Fish discovered the absence of a once thriving fish population in the reach adjacent to the mine. A 1982 EPA study concluded that the river was substantially impaired from metal loading, but no definitive source was determined. The NMED (March, 1996) reports that in 1984, the Bureau of Land Management documented pollution sources and found a downstream increase of various constituents, which at times exceeded water quality standards, and determined the major impacts on water quality were due to mining activities.

As indicated by Figure 2, there are three National Pollution Discharge Elimination System (NPDES) permitted point sources (outfalls) within the Red River watershed: the town of Red River treatment plant, the trout hatchery at Questa, and one permit for four Molycorp discharges (two outfalls at the tailings ponds (Questa) and two at the mine site). The NMED (March 1996) concluded that only the waste treatment plant discharges upstream of the most impacted reach of the river, with the effluent considered good quality. The hatchery is downstream of the impacted portion of the river, with its effluent apparently improving river water quality through dilution.

2.0 INVESTIGATIVE APPROACH

Molycorp operates within two topographically diverse areas of the Red River watershed. As illustrated by Figures 4 and 5, the mining operations are located within a mountainous region. The tailings ponds are located within the Questa valley, which is an area of low relief (Figure 3). Due to differing depositional environments; aquifers in each area have different relief, intrinsic characteristics (grain size, porosity, etc.) and ground water chemistry. In addition, surface gradient and vertical hydraulic conductivity dictate the percentage of precipitation which will infiltrate to recharge ground water. Therefore, the tailings ponds and mining area were evaluated separately.

Reports on sample studies and historic observations from Molycorp, conservation groups, and the NMED were reviewed to determine if sampling methodology, surface/subsurface geology and historic research were adequate to identify the probable sources for the acidic, high metals Red River seeps in these areas. Available data for this evaluation consisted of 1) pre and post-mining

topographic maps; 2) ground water data (well tests, depth to water, and quality); 3) whole rock and soils geochemistry; 4) water quality analysis of, selected natural spring and Red River seeps (historic data limited); 5) historic and recent Red River water quality data (historic data limited); 6) subsurface lithologic data; and 7) climatological data. Historic and recent aerial photographs were not available for review. The NMED states that aerial surveys are sparse and do not indicate any relevant data. Chemical constituents found in ground water and surface water samples were compared to New Mexico Ground Water Standards (NMGWS) and New Mexico Surface Water Standards (NMSWS) in establishing if ground water or surface water contamination did exist (see Appendix 1 and Appendix 2 for relevant data on NMGWS and NMSWS). In so doing, it was assumed that acceptable sampling methodology was employed and that samples are representative of the immediate area.

The NMED (March, 1996) reports that acidic, high metals seeps at the mine site exist only on the north side of the Red River. The majority of seep and spring discharge and field drainage occurs north of the river at the tailings ponds. Therefore, although a general evaluation was conducted in the Red River watershed to determine the source location, this investigation concentrated on the geology and hydrology north of the river. The following investigative approach was the most appropriate in determining the source for high metals and sulfate buildup within the Red River watershed:

1) Red River water quality was evaluated to determine the general area of the source. Degradation of a particular reach of a drainage system, or a marked decrease (spike) in water quality at a specific sample location along the river would indicate that the source exists in the general area. Degradation of a small portion of the river would indicate a specific source. However, if contamination was discovered to be wide spread, more than one source or a large source could be expected. A concentration of seeps in a particular area was used as an additional indicator of source location.

2) Surface topography, within the general area of the source, was evaluated to define surface water pathways to the Red River. All possible sources within surface flow paths (i.e., subwatersheds) to the river were evaluated to determine their possible metals contribution to the river.

3) Available source leachate quality was evaluated to determine the geochemical fingerprint of each possible source. A geochemical assessment of each source was performed to determine its capability to discharge high metals concentrations to ground water, and in concert with a geochemical assessment of ground water and seep discharge, determine the specific source location.

4) Near-surface geology and subsurface strata and hydrogeology were evaluated to determine if a ground water hydrological connection exists between the probable

source and the river. A knowledge of the local depositional environments leads to a better understanding of an aquifer's capability to deliver ground water to surface water.

5) Spring and seep water quality, monitor well tests, and ground water quality are of particular interest in documenting a hydrological connection between a most probable source and seep discharge. Background surface water and ground water samples were evaluated to determine if only natural sources are the cause of degradation to the water system. Monitor well tests were used to characterize the aquifer's ability to act as a conduit for transport of contaminants from a source to surface water. Spring , seep and ground water samples were utilized to identify a chemical correlation to a particular source.

3.0 TAILINGS PONDS AREA

Documentation for several geologic and hydrologic conclusions were omitted from some of the reports reviewed for this study. Therefore, a concentrated evaluation of pond water and associated metals concentrations (hereafter referred to as leachate), ground water and Red River water quality was considered the principal approach in determining if pond leachate has impacted the ground water and the river. Water samples from pond leachate and ground water down gradient of the ponds were evaluated to determine if a chemical correlation existed, and therefore, establish a tailings pond source for immediate ground water contamination. Seep, spring, field drainage and ground water quality, which are summarized on Table 1 and 2, were evaluated to determine if a correlation existed, and if so, establish a ground water hydrological connection between the source, and seep, spring (artesian) and field drainage (groundwater seeping onto the surface of the ground). Attenuation is a factor in ground water transport. Therefore, utilizing background ground water quality, and seep/spring/field drainage water quality was evaluated to determine if pond leachate still affected the water quality at the seep/spring/field drainage locations.

Ground water data from Molycorp's peizometers and shallow alluvium monitor wells indicated that tailings pond leachate has affected the ground water quality down gradient (towards the Red River) of the ponds. Peizometers have documented infiltration of ponds leachate to the shallow aquifers below the ponds and dams. Although attenuation through ground water transport is a factor in this area, monitor wells document ground water flow from the ponds to the river. As a consequence, Molycorp is presently installing capture wells to intercept ground water between the tailings ponds and the river.

Data concerning the question of whether or not the tailings ponds are hydrologically connected to the Red River were limited to those found in Vail (September 24, 1993) and South Pass Resources, Inc. (April 13, 1995). The South Pass Resources, Inc. (SPRI) report contained monitor well test and ground water quality data and descriptions of the lithology encountered by a select number of

wells. Screened intervals for several wells were not supplied in the report. However, focusing on wells with complete information regarding separate aquifer systems; ground water chemistry, velocity, and direction; and barriers to ground water flow; the shallow aquifers were determined to be the primary conduit to the river. A few monitor well tests discussed within the narrative of the SPRI report were not available within the study for review. Vail conducted a hydrological study of the area using USGS stream data; surface, seep, and monitor well water quality data; and tailings pond leachate quality data. Vail has identified volumes and quality of tailings pond leachate delivered to the Red River, and therefore, has documented a hydrological connection between the ponds and Red River.

In reviewing the previously mentioned investigative approach, more weight was given to a geochemical assessment in determining a ground water hydrological connection to the river. The reason for this is related to several factors which affect the water level and water quality results for all monitor wells, and therefore, the geochemical assessment was deemed to be more reliable. These factors include: 1) ground water chemical reactions with materials used for construction of monitor wells; 2) monitor wells screened in hydraulically separated aquifers, which lead to problems in defining area aquifer systems; 3) location of monitor wells relative to barriers (i.e., faults, etc.), which may re-direct or impede ground water flow; 4) different sample periods (e.g., spring, winter, etc.), which lead to ground water quality and elevation differences; 5) hydraulic head in the ponds relative to the dilution potential of the underlying aquifers; and 8) sampling methodology.

3.1 GENERAL AREA OF SOURCE

As illustrated on Figure 3 and summarized in Table 1 and 2, river water samples, collected by Vail (September 4, 1993), were collected from up to down gradient of the tailings ponds. The permitted discharge from outfall 002 and 003 was considered in evaluating river water quality. No definitive change or spike in sulfate or metals concentrations was observed from up to down gradient of the ponds, which indicated that river water quality could not identify the source location. However, as indicated by Tables 1 and 2, a correlation did exist between seep/spring/field water quality, ground water quality, and pond leachate chemistry; which indicated the tailings ponds as the probable ground water contaminant source.

3.2 POTENTIAL SURFACE PATHWAYS FOR CONTAMINATION

The surface topography is a sloping alluvial plain, with surface gradient being generally to the Red River. It appears that no surface runoff avenues to the Red River exist south of the tailings ponds due to the construction of dams and barriers. Drainage ditches were constructed up gradient of the tailings ponds to divert natural runoff from entering the pond area.

3.3 SOURCE GEOCHEMICAL CHARACTERIZATION

As evidenced by surface discharge and ground water samples collected by SPRI (April 13. 1995), the area's alluvial and volcanic deposits, which include the aquifers considered hydrologically connected to the river, cannot geochemically account for the metals and sulfate concentrations observed in ground water down gradient of the ponds, or the sulfate concentrations observed at the seeps/springs/field discharge. The ground water at monitor well number 10 (MW-10), as seen on Figure 6, is the best water quality within the area (TDS 150 mg/l, sulfate 35 mg/l). Because of this, and the fact that the well is located east of the ponds, where it is evidently outside of the influence of pond infiltrate due to a ground water flow direction to the southwest, samples taken from this well are considered to be indicative of ground water quality before mining activities took place (i.e., background). In comparison to the samples taken at MW-10, several ground water samples south of the ponds show moderately elevated concentrations of sulfate, TDS, manganese and molybdenum. In addition, there exists no natural source for the elevated molybdenum concentrations found in ground water at MW-2 and MW-C; however, tailings are derived directly from the milling operations for molybdenum. Therefore, the elevated sulfate and metals concentrations found in ground water are considered to be from the tailings ponds and not from natural sources.

3.4 SURFACE AND SUBSURFACE GEOLOGY AND HYDROGEOLOGY

Establishing a hydrological connection between a source and contaminated surface water requires the evaluation of several hydrogeological parameters. It must be determined that ground water below the source has been affected by infiltration of source leachate and that conduits exist for the ground water transport of this leachate to surface water.

The surface geology was characterized to determine the erosional and depositional factors which may affect the flow directions within the subsurface aquifers. The subsurface was evaluated through monitor well tests and lithologic samples to determine which aquifers may be conduits for ground water flow from a source to surface water. Monitor well tests and lithologic samples were utilized to define individual aquifers (vertical hydraulic separation), aquifer lateral continuity, and to determine the transport capabilities of the aquifers.

3.4.1 SURFACE AND SUBSURFACE GEOLOGY

Surface topography and subsurface geology characterize the area as one of active structural deformation, deposition, and erosion. The structurally active nature of the area is represented by several faults which displace the shallow alluvial and deeper basaltic aquifer deposits. However, this displacement does not appear to halt ground water flow to the river, which is apparently due to the juxtaposition of different but permeable aquifers or juxtaposed impermeable aquifers redirecting ground water flow to the south (to the river).

SPRI (April 13, 1995) used borehole and geophysical logs to characterize the subsurface. The area consists of volcanic rocks, and sedimentary and lacustrine deposits. The upper alluvial and lacustrine deposits (Santa Fe Group) consist of an Upper Aquifer Unit (UAU), Middle Aquitard Unit (MAU), Lower Aquifer Unit (LAU), and Basal Aquitard Unit (BAU). SPRI states that each unit exhibits vertical variation in lithology; each unit containing clay, gravel and sand lenses. The Santa Fe Group overlies a major regional aquifer which exists in the basalts and volcanics (basalt/andesite unit (BAAU)). The UAU (upper Santa Fe Group) underlies Dam No. 1. However, only 50 feet of the lower Santa Fe Group exists immediately down gradient of Dam No. 4 because of the erosion of some upper Santa Fe Group units.

3.4.2 HYDROGEOLOGY

Monitor well placement and aquifer tests were used to determine several aquifer parameters including ground water gradient, if vertical hydraulic separation exists between aquifer units, if aquifers have lateral continuity, and if barriers exist to redirect ground water flow. Vertical hydraulic separation would indicate that a basal aquitard does exist. An aquitard would indicate no further migration of contaminants into deeper aquifers, and substantiate ground water transport of pond leachate down gradient. The lateral continuity of a hydrologic unit (one aquifer or juxtaposed aquifers) must be determined to define the conduit (i.e., that the hydrologic unit exists from the ponds to the river) for the ground water transport of pond leachate to the Red River. If hydraulic separation or lateral continuity is established at monitor wells, it is assumed that they exist within the general area of the wells.

3.4.2.1 GROUND WATER GRADIENT AND BARRIERS

SPRI (April 13, 1995) conducted aquifer tests on 3 wells (EW-2, EW-3, and MW-7), which are completed (screened) in separate units of the Santa Fe Group (Figure 6). Analyses of well tests indicate good conductivity, recharge and localized barriers to flow. Recharge and barriers to flow may be caused by changes in hydraulic conductivity or faults. Monitor well ground water elevations indicate that the ground water flow direction is generally to the southwest in the UAU and the BAAU. Ground water flow direction for the LAU is unknown; however, it is expected to flow to the southwest because the LAU lies between the UAU and BAAU. SPRI (April 13, 1995) states that USGS stream gage data indicate an overall gain (approximately 30 cfs) between the Questa ranger station and the fish hatchery. Therefore, although faults and juxtaposed units may locally redirect ground water flow, flow is still directed to the river.

SPRI (April 13, 1995) reports that the underdrains (connected to the chimney drains), which were installed to intercept leachate below each dam, would rest on a shallow upper aquifer unit beneath Dam No. 1 and probably on the upper sandy member of the basalt aquifer unit at Dam 4 (Figure 6). Piezometers were installed into the dams to measure the saturated surface to determine the infiltration rate to the underlying aquifers. However, SPRI has only submitted information on the pond leachate infiltration capacity below Dam No. 1. The slope of the saturated surface showed

discharge to the under drain system beneath Dam No. 1. As illustrated on Figure 6 and 7, piezometers within Dam No. 1 and monitoring wells south of the dam document that ground water gradient is to the south from Dam No. 1 to at least MW-7. Because the ponds are unlined, the drain system apparently captures some but not all of the seepage through the dam. The remaining leachate enters the underlying shallow aquifer over the area of the ponds and moves down gradient towards the river, thus bypassing the drain collection system.

Ground water levels from monitor wells located south of Dam No. 1 and 4 were evaluated to determine the ground water elevation relative to the Red River to establish which portions of the river were a gaining or losing stream. MW-11, located south of Dam No. 4, showed water levels below the adjacent Red River level. SPRI (April 13, 1995) states that this situation may indicate river recharge to ground water in this area but not enough to impact the overall gain recorded by stream gages. It must be noted that only one monitor well exists in this area, therefore, ground water gradient in this immediate area cannot be substantiated. For the segment of the Red River between Big Springs and Pope Lake, the water table in the basalt unit appears to be just above river level. MW-1, located south of Dam No. 1, showed water levels above the level of the river, indicating ground water recharge to the river. Ground water elevations do establish ground water flow in a general southwest direction (to the river).

3.4.2.2 VERTICAL HYDRAULIC SEPARATION

Vertical hydraulic separation of aquifers was investigated to determine basal aquitards, and in so doing, define the hydrologic unit capable of transporting contaminants to the river. Separate flow systems (vertical hydraulic separation), due to confining clay beds, occur within the Santa Fe Group (shallow alluvial aquifers) and the underlying basalt aquifer. Monitor wells screened in different aquifers show different depths to water indicating vertical hydraulic separation to some degree. Local vertical hydraulic separation can be supported by a pump test conducted by SPRI (April 13, 1995) at monitor well EW-2, which is illustrated on Figure 6. During the EW-2 (screened in upper portion of LAU) pump test, water levels in MW-7C (screened in lower portion of LAU) were monitored. SPRI reports that only minor water level fluctuations (range of 3.2 inches), which SPRI attributes to barometric changes, were observed in MW-7C, indicating that these wells are apparently screened in hydraulically separated lenses of the LAU.

3.4.2.3 LATERAL CONTINUITY

Lateral continuity must be established to document a continuous conduit for ground water flow from the source to surface water. Establishing lateral continuity over a great distance for a specific hydrologic unit is not possible due to the present monitor well scheme. However, local lateral continuity has been demonstrated by the EW-3 pump test. Water levels within MW-7A were monitored during the EW-3 pump test (both screened in the lower UAU). Observed water level fluctuations in MW-7A established a lateral ground water hydrologic connection between MW-7A and EW-3. These tests indicate good hydraulic conductivity and local lateral continuity. The

perched nature of some aquifers suggests lateral discontinuity most probably caused by juxtaposition, due to fault displacement, of different aquifers with differing conductivity. Although juxtaposition is assumed due to faulting, ground water flow through the fault cannot be documented due to the present monitor well scheme. However, fault trend is north-northeast to south-southwest and ground water gradient is to the river, and therefore, ground water flow direction is to the river. In addition, studies of USGS gage station data indicate the river to be a gaining stream supplied by ground water, which indicates that ground water flow is to the river within a major portion of the tailings area.

3.5 RIVER, SPRING, SEEP AND GROUND WATER QUALITY

Pond, river, spring, seep and ground water quality were evaluated to determine if a water quality correlation existed. In doing so, documentation could be established for a hydrological connection from the ponds to the river via ground water transport.

Vail (September 24, 1993) states that tailings pond water and associated contaminants (leachate) seep to the ground water which flows generally in a southwesterly direction and discharges to Red river. This seepage contains elevated concentrations of sulfates (840+-mg/l), molybdenum (2+-mg/l), manganese (1.4+-mg/l), and total dissolved solids (1700+-mg/l). In his discussion of pond leachate avenues below Dam No. 1, Vail concluded that this seepage flow is generally in the shallow alluvium. Vail believes that a large percentage of the seepage from Pond No. 4 is transported by ground water flow in the volcanic formations and that most of this ground water flow is discharged to Red River at the numerous springs along the Red River Gorge. SPRI (April 13, 1995) reports that the section of the Red River that may be impacted by the tailings ponds is 1.84 miles in length (roughly from the 002/003 Outfall west to the area of the Fish Hatchery)."

3.5.1 RIVER

As illustrated on Figure 3, Vail collected seep/spring and river water samples at several locations between State Road 522 and the Red River State Fish Hatchery. Comparisons of up-river metals concentrations with river water samples adjacent to the ponds suggests that river water quality is not affected by a pond source. For example, river water samples collected from up to down gradient of the ponds show that only a small difference in river metals concentrations, with the most up river sample normally having the greater concentrations. There is a slight influence on river water quality down gradient of outfall 002 and 003 (Figure 3) due to the permitted discharge. This influence was considered in the evaluation of river water quality. Analysis of submitted river water samples, as summarized on Table 1, and conversations with the State of New Mexico and EPA surface water staff, indicate that river water quality is within surface water standards.

3.5.2 SPRINGS

Some Red River springs have sulfate concentrations below NMGWS. Questa Springs, as seen on Figure 6, is most likely due to a north-northeast to south-southwest trending fault which redirects a portion or the total southwesterly flow of ground water to the south (to Questa Springs). Questa Springs water quality has a TDS of 173 mg/l and a sulfate concentration of 80 mg/l, which is just above background (TDS 150 mg/l, sulfate 35 mg/l) and below NMGWS (TDS 1000 mg/l, sulfate 600 mg/l). Questa Springs TDS and sulfate concentrations are lower than ground water concentrations below Dam No. 1, which indicates that attenuation through ground water transport is a factor in concentrations delivered to seeps and springs along the river.

3.5.3 SEEPS

Seep water quality (collected by Vail, September 24, 1993, and summarized in Table 1) was used to some degree as a ground water quality indicator to evaluate the general ground water quality in the immediate area. Two field drainage (field surface seepage) sites immediately south of Dam No. 1 have moderately elevated TDS concentrations; one has elevated sulfate and the other elevated iron concentrations above NMGWS. One field drainage sample, located midpoint of Dam No. 1 and the river, has molybdenum concentrations above NMGWS. These field drainage samples indicate a tailings source. Although sulfate concentrations discharged at Red River seeps are just above ground water background concentrations, which indicate a probable tailings source, they are below NMGWS. These observations are an additional indication that attenuation of pond leachate through ground water transport is a factor in decreasing sulfate and metals concentrations in ground water delivered to seeps and springs along the river.

3.5.4 GROUND WATER QUALITY

Analyses of ground water samples collected below and down gradient of the ponds establishes a correlation between pond leachate, and ground water and seeps/springs/field discharges south of the ponds. Several ground water samples show moderately elevated concentrations of sulfate, TDS, manganese, and molybdenum. The ground water at MW-10 (Figure 6) is the best water quality within the area (TDS 150 mg/l, sulfate 35 mg/l). South of the ponds, the UAU and upper portion of the MAU usually have high TDS and high sulfate concentrations. The highest sulfate concentrations were detected at MW-C (970 mg/l), a shallow piezometer at the toe of the Dam No. 1. The down gradient MW-A has lower sulfate concentrations (560 mg/l) indicating dilution. Piezometer MW-9A, located approximately 1200 feet down gradient (south) of MW-A, has greater sulfate concentrations (680 mg/l) than MW-A. Apparently, inconsistencies between ground water flow direction and ground water quality indicate local attenuation, interflow between aquifer members (dilution), and/or redirection of ground water flow paths. This redirection is most likely due to faults and/or changes in hydraulic conductivity. However, ground water gradient and quality indicate that pond leachate does infiltrate to the UAU and moves down gradient towards the river.

3.6 SUMMARY

A water quality comparison of pond leachate, ground water and seep/spring/field drainage down gradient of the ponds indicates that the only probable source for elevated sulfate and metals concentrations found in ground water are the ponds. However, the available information indicates that ground water discharge via seeps along the river and river water quality are within NMGWS and NMSWS. A complete summary of the tailings ponds and the Molycorp mine site is found at the end of this report.

4.0 MOLYCORP MINE SITE

The mine site is located in a more complex geologic setting than the tailings pond area. The mine property is located in a mountainous region, which is cut by deep canyons. The extreme topographic gradient was formed through erosion of volcanic flows associated with the Questa caldera (a large crater formed by the collapse of a volcanic cone). As indicated by Figures 4 and 5, the surface gradient directs surface water runoff, and shallow ground water, to the Red River.

Historic and recent mining operations and natural sources, within the Molycorp mine area and up-river of the mine, were investigated to determine their potential contribution of metals to the river. Investigations revealed that the possible sources are: 1) historic and recent mine waste rock, 2) naturally occurring erosional scars, 3) remnant deposits of tailings resulting from pipeline breaks, 4) the landfill area at the head of Spring Gulch, 5) the Moly tunnel, (6) the caved area in Goathill Gulch, 7) runoff directed to the underground workings for collection, and 8) the mill site. Of these, the most probable sources are considered to be the WRDs and the erosional scars because of source material and water quality (leachate and ground water) analysis results. An additional indicator of source location is that the acidic seeps and these two sources are wide spread and other possible sources (land fill, Moly tunnel, etc.) are localized.

Approximately 59 historic mine sites exist within seven tributaries of the upper Red River watershed. All of these mines were fairly small operations, with associated waste rock piles being relatively minor. The NMED (March, 1996) states that although these sites contribute some contamination to the river through surface water runoff associated with storm events, none appear to be a significant source of metals loading to ground water or surface water.

4.1 GENERAL AREA OF SOURCE

The most significant water quality degradation occurs within the middle reach of the Red River from Questa to the town of Red River (Figure 2), which contains the Molycorp mine and most of the major scar areas. River surveys have documented declines in river water quality progressing downstream from the town of Red River. The most acceptable method for determining the general

area of the source was the river water analysis for sulfate gain, which used sulfate as a proxy for metals to examine how the loading of metals to the Red River has changed over time.

As illustrated in Figure 8 and summarized in Table 3, Red River water quality data, collected in May 1994 by SPRI (April 21, 1995), indicate a spike in sulfate concentrations. A Red River sample collected just up river of the confluence with Columbine Creek (RR-12) indicates a two-fold gain in sulfates compared to up river samples from Hot-N-Tot Creek to just up river of Portal Springs (RR-5 to RR-10). Sample RR-13 shows a decrease in sulfate concentrations due to inflow from Columbine Creek. However, RR-13 concentrations remain greater than up river samples. Red River sulfate concentrations down river of sample RR-13 are generally the same as the RR-12 sample. This area of increased sulfate concentrations is most probably due to the numerous seeps located within and just down river of the Molycorp boundary.

Seeps are considered the primary and most incessant source for metals loading to the river. Consequently, an additional indicator of source location is that the greater percentage of and most active acidic, high metals seeps exist in the vicinity of the Molycorp mine. Therefore, Red River water quality data and seep locations indicate the source to be within the general area of the Molycorp mine property.

4.2 POTENTIAL SURFACE PATHWAYS FOR CONTAMINATION

Surface avenues to the Red River were evaluated to determine the probability of surface water runoff supplying a portion of or the total metals load and ground water discharge to the river via seeps. The surface topography ranges in elevation from approximately 7600 to 10,800 feet within the mining area. Most of the topography consists of very steep slopes. Major tributary canyons have gradients on the order of 11 to 15 degrees. Due to the topographic gradient, unconsolidated nature of the area alluvium, and storm events; sediment and surface water runoff is directed to the river.

As can be seen by comparing Figures 4, 5 and 9, the steep gradient within the mountainous region facilitates the formation of erosional scars. Erosional scars are so easily eroded that mudflows are produced by heavy precipitation, creating debris aprons where tributaries enter the Red River. Mudflows have at times damned the river. However, the NMED (March, 1996) has determined through water quality analysis that metals loading problems associated with these events are largely temporal, and that in most cases river water quality is restored within a few days.

Molycorp has implemented a water management and sediment collection program at the mine site, which incorporates the majority of the mine property (Figure 4). Surface water within the majority of the mine boundary is redirected to the open pit and caved area (a surface depression within Goathill Gulch canyon caused by the collapse of a portion of the roof of the underground mine) and collected in the underground mine workings. Apparently, due to the collection system,

sediment loading and surface water runoff to the river adjacent to the mine property is not the principal factor in metals loading to this reach of the river.

Molycorp's collection system captures surface water runoff, and spring discharge in unlined catchment basins. The unlined basins undoubtedly allow infiltration to the underlying aquifers. Although a surface system has been installed to intercept surface water runoff and spring discharge, ground water has the potential to bypass the system and flow down gradient to the river. Therefore, the shallow upper valley fill aquifer has the potential to transport high metals concentrations to the Red River. Subwatersheds (canyons), as described below, were individually evaluated to determine if they could function as contamination pathways.

Surface water runoff and seepage from the Capulin Canyon WRDs and erosional scars (Figures 1, 4, and 9) are collected in surface impoundments. However, ground water flow has not been affected by the collection system and has the potential to transport high metals concentrations to the river.

The Goathill Gulch topography indicates surface and ground water flows to the river. However, a sink, the caved area (Figure 1), within Goathill Gulch canyon may restrict surface and ground water flow. Apparently, the caved area is a vertical rubble zone of displaced aquifers and bedrock material, which extends from the surface to the underground mine workings. This rubble zone acts as a conduit between the surface and the underground mine. The caved area may capture most of the surface water runoff from upper Goathill Gulch canyon. The caved area captures and directs surface water to the underground mine, where it is redirected to the mill for milling operations. The caved area may also capture ground water within the immediate area, and in so doing, cause a local cone of depression (not to be confused with the cone of depression caused by the dewatering of the open pit and underground workings).

All Goathill Gulch ground water, up gradient of the caved area, may be captured by the caved area. However, no information is available to indicate whether the shallow aquifers have been sufficiently displaced (due to the collapse of the stratigraphic section) such that all up gradient ground water is captured by this area. SPRI (April 21, 1995) states that mounding of the water table surface may occur due to redirection of surface runoff to the caved area, and that the water mound might extend to the valley fill in Goathill Gulch from which it could more easily reach the river. Surface water runoff down gradient of the caved area is intercepted by the surface water collection system. However, no subsurface collection system exists down gradient of the caved area. Therefore, if up gradient ground water is captured by the caved area, subsurface flow is still probable from the caved area to the river. However, the area of ground water available for discharge to the river would be defined by the location of the down gradient outer rim of the local cone of depression, which forms due to the ground water being captured by the caved area. The location of the outer rim is dependent on the depth to the area's undisturbed basement rock, vertical hydraulic conductivity of the rubble (i.e., discharge rate), hydraulic conductivity of lithologic members, and the canyon gradient within the vicinity of the caved area to the river. Therefore, the area of ground

water available for discharge to the river, and contaminants from sources within that area, would be from the local depression's southern outer rim location to the river. However, no information exists to define the location of the local cone of depression's outer rim, or in fact, indicate that a local cone of depression does exist.

Surface water runoff from the Sugar Shack South and Middle WRDs is collected in unlined catchment basins. Due to the unlined nature of these catchment basins, leachate from these sources, and the erosional scars which underlie these WRDs, has the potential to infiltrate to the shallow alluvial aquifer and move down gradient to the river.

Natural drainage has been drastically altered in the Sulphur Gulch subwatershed by the placement of Spring Gulch WRD, and Spring and Sulphur Gulch WRD. Surface water runoff is assumed to be captured by the Molycorp collection system. However, surface water can potentially migrate down to the shallow aquifers through infiltration.

There are other unnamed tributary canyons which exist within the Molycorp boundary and direct surface and ground water flow to the river. MW- 7 (Figure 1) is located within a tributary valley which extends up gradient to the Capulin Canyon and Sugar Shack West WRDs. MW-11 and 13 are within minor tributary valleys which were overlaid by the Sugar Shack South and Middle WRDs.

As summarized above, surface water runoff to the river, via canyons, has generally been intercepted by the surface water collection system. Therefore, surface runoff is not considered the primary transport mechanism for metals loading to the Red River.

4.3 SOURCE GEOCHEMICAL CHARACTERIZATION

Mining operations were evaluated to determine the most probable source for the high metals concentrations delivered to the river. In addition, the geochemistry of different rock types within the mine area was evaluated to identify the source with the potential to generate the acidic waters necessary for the leaching of metals. The only whole rock, ground water and seep water quality geochemical data available for review were collected by SPRI (April 21, 1995) and Steffen, Robertson and Kirsten (SRK) (April 13, 1995). The geochemical assessment of possible source leachate and ground water chemistry revealed that the most probable source for the generation of acidic, high metals waters (or ARD) is the WRDs and the naturally occurring erosional scars.

ARD is characterized by low pH and elevated concentrations of metals and TDS. The most common mechanism for its formation involves the oxidation and hydration of sulfide minerals (e.g., pyrite, or iron sulfide), resulting in the generation of sulfuric acid. The mine area rhyolite consists primarily of the mineral pyrite. Rhyolite is exposed north of the Red River as erosional scars. The upper Sulphur Gulch erosional scar (rhyolite) and other non-acid generating rock types

were excavated during open pit mining and placed in several WRDs. Therefore, each WRD was evaluated to determine which WRDs contained the rhyolitic material.

A search was conducted to determine if comprehensive WRD disposal records existed to identify WRDs which were composed primarily of rhyolite, and consequently, determine the most acidic, high metals generating WRDs. However, Molycorp has indicated that historical records concerning the development of the WRDs are limited. Generally, mixed volcanic waste rock (rhyolite and andesite) was excavated from the Sulphur Gulch erosional scar area and deposited in the Blind Gulch, Goathill, Sugar Shack South, Sugar Shack West and Middle WRDs and the western portion of Spring and Sulphur Gulch WRD. The remaining waste rock was derived from black andesite, aplite and granite, which are considered to have low potential to generate acidic waters. The majority of this waste rock was placed in the western portion of Spring and Sulphur Gulch, in Spring Gulch and within the pit. SRK (April 13, 1995) states that later in the open pit operations, this waste rock was used to encase the lower faces of the Middle, Sugar Shack South and Spring and Sulphur Gulch WRDs. The rhyolite appears to exist in all WRDs. However, the volume of rhyolite within each WRD could not be determined from the available data.

Other minor waste rock areas were also evaluated for acid generating potential. SRK (April 13, 1995) reports that waste rock from the new underground mine workings, considered non-acid generating, was placed in lower Goathill Gulch, adjacent to the surface facilities. The historic tailings piles at the mine's mill site exhibit acid generating potential, and therefore, have the potential to generate ARD.

The NMED (March, 1996) and SRK (April 13, 1995) conducted a geochemical analysis of waste rock pile, erosional scar, and soils material for metals concentrations. Sugar Shack South WRD has the greatest metals concentrations. ARD from the waste rock is similar in composition to drainage from erosional scar areas. However, leachate analysis, conducted by NMED revealed that average metals concentrations were greater in WRD leachate than scar leachate. SRK states "Over time, ongoing acid generation in the waste rock disposal areas adjacent to the Red River, and the consumption of the neutralizing potential of the waste rock, and consumption of the remaining attenuation capacity in the alluvium in seepage flow paths has the potential to increase sulfate and metal loads in local springs and seeps. Seepage of water impacted by the hydrothermal scars that underlie the waste rock disposal areas will likely continue" (page 35).

SRK's (September 13, 1995) geochemical analysis of soils outside the influence of erosional scars or WRDs indicates that these soils have low metals leaching potential. Therefore, the dissolved metals contribution to the local environment by these soils is low compared to erosional scars and WRDs. SRK collected soil samples from within the mine area and concluded that the alluvium has the potential to contribute sulfate to surface or ground water, however, the potential for acidic waters is low. Mud and debris from erosional scars outside the mine surface water collection system are considered a localized source of intermittent river contamination through surface flows during periods of high runoff.

Most investigators acknowledge that waste rock material and erosional scars have similar geochemical properties, and that weathering of sulfide-rich erosional scars is associated with acidic, high metals storm water runoff. Although an increase in excavation activity (historic and recent mining, unpaved roads, etc.) appears to be related to the metals buildup in the watershed, the natural processes of weathering are the primary cause for the leaching of high metals into the local watershed environment. Natural weathering of sulfide-rich erosional scar material is relatively slow due to its compacted nature. However, when this material is excavated and placed in thick unconsolidated piles (i.e., WRDs), a large sulfide rich surface area is exposed to oxidation. The unconsolidated WRDs undoubtedly allow greater infiltration rates than the more consolidated natural soils or erosional scars. Therefore, the WRDs should have greater acid generation potential, storage capacity, metals transport capability; and consequently, greater recharge to the underlying aquifers than erosional scars. The upper valley fill aquifer should be saturated below and down gradient of the WRDs due to the recharge.

4.4 SURFACE AND SUBSURFACE GEOLOGY AND HYDROGEOLOGY

An evaluation of the surface geology and topography was performed in order to understand the erodibility and depositional factors at work in the area. Surface geology was evaluated to determine the erodibility and infiltration capabilities of differing rock types to define their relative contribution of alluvium within the subwatershed and recharge potential to ground water. The subsurface geology was evaluated to define the limits and avenues to ground water flow. Monitor well tests were used to determine the hydrogeological controls which influence flow direction and volumes delivered to seeps.

4.4.1 SURFACE AND SUBSURFACE GEOLOGY

The mine area geology is characterized as volcanic. Precambrian granite is exposed south of the Red River. The outcrops north of the river are primarily exposed Tertiary rhyolitic intrusive plugs (erosional scars). The primary hydrologic units north of the river are the fractured Tertiary volcanic bedrock (encountered by monitor wells between 60 - 120 feet below surface) and the overlying lower and upper valley fill alluvium. Several studies indicate that the Precambrian, which underlies these units, acts as an aquitard precluding any deeper ground water infiltration.

The rhyolitic erosional scar is a brecciated rock, which is easily eroded due to a lack of cementation and its highly fractured nature. Its erodibility is one source of alluvial deposits down gradient of scars. Molycorp drilled several 90 foot holes into erosional scars within the area (see SPRI April 21, 1995), apparently to determine the scar's discharge, storage and infiltration capacity. Molycorp found that the scars were either dry or produced very little discharge (less than one gallon per minute), which indicated near surface storage, with little to no infiltration at depth. The infiltration rates for the highly unconsolidated WRD material therefore exceeds that of the more consolidated erosional scar material. Thus, due to the similar geochemical properties of erosional scars and WRDs, the unconsolidated WRDs pose a greater ground water contamination potential than scars.

The steep slopes within the area encompass a greater surface area than the canyon floor. Runoff and ground water flow from the slopes are directed to the canyon floor deposits. The canyon aquifers are saturated due to infiltration through the unconsolidated alluvium. The shallow alluvial aquifers presumably have good lateral flow due to their unconsolidated gravel/sand mix and gradient, and less downward flow due to a basal clay aquitard. Therefore, surface water should infiltrate to the shallow aquifer and move down gradient along the clay aquitard to the river.

4.4.2 HYDROGEOLOGY

Twelve monitor wells were installed in July and August of 1994 (Figures 1 and 4). All wells are located within the Molycorp property and between 400 to 700 feet north of the Red River. The wells were installed to determine: 1) aquifer characteristics, 2) ground water gradient and barriers, and 3) ground water quality. A number of these wells indicate separate hydrologic units, and a possible cone of depression created by the dewatering of the open pit and underground mine workings. In addition, studies of USGS gage station data, and ground water elevations (relative to river elevation) obtained from monitor wells and two mine shafts, indicate that the river is supplied by ground water (i.e., gaining stream) throughout most of its length.

It appears that all investigators agree that there are two aquifers in the mine area: a valley fill and an underlying shallow fractured bedrock aquifer. Based on analysis of monitor well data supplied by SPRI (April 21, 1995), EPA believes that at times three different ground water aquifer systems may exist: a shallow fractured bedrock, an overlying lower valley fill, and an upper valley fill aquifer. It must be noted that monitor well tests only determine the hydrologic parameters within the immediate area of the well. However, considering that the alluvial deposits are confined to a relatively small canyon area, an assumption that the hydrologic parameters determined from monitor well tests are indicative of the general lower canyon area is acceptable.

Well tests confirm a weak hydraulic separation between the bedrock and lower valley fill stratigraphic units. Although bedrock and lower valley fill ground water elevations indicate these units may act as one hydrologic unit (one aquifer), well tests also confirm that the valley fill has greater horizontal hydraulic conductivity than the bedrock unit. Therefore, the lower valley fill may act to some degree as an independent aquifer during periods of high recharge. Well tests support some vertical hydraulic separation of the upper valley fill and lower valley fill aquifers by an intermediate clay layer. The clay layer retards further downward flow of upper valley fill ground water. The gradient on the upper surface of the clay layer is apparently to the river due to the depositional environment, and therefore, ground water flow is towards the river.

Monitor well ground water elevations relative to river elevations indicate that a cone of depression, centered on the open pit or underground mine, may exist north of the river. As discussed in Section 4.4.2.1, the cone of depression may affect the bedrock and lower valley fill aquifers between the monitor wells and the open pit and new underground workings, but not the upper valley fill aquifer. Therefore, the upper valley fill has the potential to transport contaminants to the

Red River. The bedrock and lower valley fill ground water located outside the influence of the suspect cone of depression, still has the potential to flow to the river.

The NMED (March, 1996) states that shallow bedrock fractures support preferential ground water flow to Red River seeps. Although geologic observations imply fracture orientation, faults intersecting the shallow bedrock aquifer may redirect ground water flow. Ground water elevations in MW-7 indicate a perched nature to the fractured bedrock aquifer in the immediate area. Therefore, support exists for faults or other geologic impediment to retard or redirect ground water flow.

Monitor well data and the steep surface topography support a distinct ground water flow system to the river via the upper valley fill aquifer. Although monitor well data indicate that a cone of depression may exist in an area north of the river, and that the cone of depression may affect the bedrock and lower valley fill aquifers, ground water south of that area still has the potential to flow to the river via all aquifers. However, the upper valley fill aquifer is a separate system, apparently unaffected by the cone of depression, and therefore, has the potential to transport acidic, high metals concentrations from a large portion of the mine site to the Red River.

4.4.2.1 GROUND WATER GRADIENT AND BARRIERS

Monitor well ground water elevation and river elevation data were compared to establish if the ground water gradient is to the river, which would indicate that ground water would flow to the river, and consequently, transport contaminants to the river. The presence of seeps, in general, indicates that the ground water gradient for at least one of the aquifers is to the river in the immediate area. In addition, studies of USGS gage station data indicate that throughout most of its length, the Red River is a gaining stream supplied by ground water; therefore, the ground water gradient is to the river. A comparison of monitor well ground water and river water elevations, in the eastern portion of the mine site, may imply sporadic recharge to ground water in this area. Therefore, monitor well data and river water levels in this area were evaluated to define the ground water gradient.

Previous investigators have generally compared monitor well ground water elevations to adjacent river elevations in establishing the ground water gradient. Investigators conclude that ground water and river elevations in the eastern portion of the mine property, in the vicinity of MW-13, 14 and 16, indicate ground water to be at or just below the river level. Ground water elevations below river elevation would indicate that the river is recharging ground water, and therefore, contaminants in ground water would not be discharged to the river. Although not stated, these comparisons of ground water elevation to river elevation may have been made in a direction perpendicular from the monitor well to the river. However, due to the Red River gradient (obtained from submitted topographic maps) within the mine area (approximately 1.2/45 feet, east to west), a comparison of monitor well ground water elevation at a right angle to the river may yield inaccurate information by several feet. Ground water flows down gradient along the axis of

the canyon; however, the canyon gradient is not the controlling factor for ground water flow direction in the fan delta deposits. The lower limits of the fan delta deposits conform to the river gradient, which is perpendicular to the canyon gradient. Therefore, ground water flow within the fan delta deposits will not be directly to the river as the canyon gradient would imply; but more along a resultant of the angles of the river and canyon gradients, which is more down-river of the canyon axis. Therefore, a conclusion, based on monitor well water levels, that the river may periodically recharge the ground water in the immediate area may be inaccurate. Although there is insufficient data to document a change in ground water flow direction due to a combination of river and fan delta gradients, it is likely, based on a qualitative examination of the gradient of the river and fan delta deposits, that ground water in fact always flows to the river in the eastern portion of the mine site, and therefore, throughout the mine site. However, because the methodology of the gradient measurements was not supplied, it is not known if this correction was applied. Granted, ground water flow velocity and the size of the fan delta are factors which determine the degree the river gradient would have on diverting the ground water flow direction from the canyon axis.

Subsurface barriers exist which impede or re-direct ground water flow. The ground water elevation in MW-7 indicates a perched natured to the bedrock aquifer, which indicates a barrier to ground water flow, possibly caused by faulting. The low pH and high metals concentrations found in MW-7 indicate a long ground water residence time, which is most probably due to faults. Although barriers may impede flow, ground water does flow to the river.

4.4.2.1.1 CONE OF DEPRESSION

Ground water elevations appear to support a cone of depression (not to be confused with the possible cone of depression caused by the caved area) within the bedrock aquifer which is apparently caused by the dewatering of the open pit and underground mine workings. If the cone of depression does exist, it would indicate that the ground water gradient (ground water flow direction) for a portion of the mine site would be towards the open pit and underground workings (to the north, away from the river). The cone of depression's outer rim, which defines the point at which ground water flows to and from the center of the depression, appears to exist just north of the monitor wells in the eastern portion of the mine site, near the Middle and Spring, and Sulphur Gulch WRDs. Monitor wells in the western and middle portion of the mine site do not appear to have encountered the cone of depression. Ground water elevations and the very active nature of seeps in these areas indicate that the outer rim of the cone of depression should be north of the river, between the new underground workings or open pit and the monitor wells. However, although a cone of depression may exist north of the river and within the mine site, studies of USGS gage station data and seeps indicate that overall the Red River is a gaining stream supplied by ground water; therefore, ground water flow for at least one aquifer is to the river.

An attempt was made to define the outer rim of the suspect cone of depression and its affect on the hydrologic units within the mine area utilizing monitor well/mine shaft data and historic mine dewatering data. There is insufficient historic dewatering information and monitor well data to

define the location of the outer rim of the cone of depression. However, subsequent to the monitor well installations, which are illustrated on Figures 1 and 4, ground water elevations appeared to indicate that the cone of depression may only affect the bedrock aquifer. This interpretation is supported by the following observations:

1) Molycorp contends that the water level within the mine defines the lower limit of the cone of depression at that point. However, there is no indication as to the shallowest elevation ground water is entering the mine. If ground water enters the mine from the shallowest aquifers, the radius of influence of the cone of depression would be closer to the entry point than if water was entering at a deeper point (i.e., less drawdown, less area encompassed by the cone of depression). Therefore, the cone of depression would not have as great an influence on the upper aquifers as the observed mine water levels may suggest. SPRI (April 21, 1995) states that a steep sided cone of depression would probably develop over the deep mine due to the lower hydraulic conductivity at depth. SPRI also concluded that the cone probably did not extend to the river.

2) Ground water elevations, from existing monitor wells, for the period February, 1996, to August, 1997, were obtained from Molycorp to evaluate the effects dewatering of the mine had on aquifers. As summarized in Table 4, observed fluctuations in monitor well ground water elevations show an influence from seasonal infiltration. MW-8, 2, 3, 11 and 10 are outside of the cone of depression. Bedrock wells MW-13, 14 and 16 may define the outer rim of the cone. However, subsequent to SPRI's installation and evaluation of these wells (which can be found in SPRI's April 21, 1995 report), MW-13 showed the valley fill saturated but the bedrock aquifer dry, indicating that the cone of depression may affect the bedrock aquifer but not the shallow alluvial aquifer. Therefore, the valley fill is to some degree unaffected by the cone of depression and has the potential to deliver ground water to the river in the immediate area.

3) Seeps and springs occur at the upper elevations, which are apparently within the cone of depression. Considering that shallow ground water supplies these seeps and springs, the cone of depression does not affect the shallow aquifers to a great extent. Therefore, ground water gradient for the shallow aquifer, throughout a major portion of the mine site, must be to the river.

The cone of depression apparently does not adversely affect the upper valley fill aquifer. Dewatering of the underground workings ceased between 1992 to 1994. SPRI (April 21, 1995) states that during post-1994 dewatering of the new underground mine workings, there was no noticeable effect on the rates of ground water recharge to the Red River in the vicinity of the mine and that most of the ground water recharge to the river may have come from the upper part of the ground water system. Stability of water levels in monitor wells, as post-1994 dewatering

proceeded, supports a steep cone of depression existing over the mine, and that the outer rim of the cone is north of the river. Accepting that the cone of depression exists and that ground water recharge to the Red River is not significantly affected by dewatering of the mine, it is concluded that the shallow upper valley fill aquifer is the most probable conduit between the source and the acidic, high metals discharged to the Red River.

4.4.2.2 VERTICAL HYDRAULIC SEPARATION

Local vertical hydraulic separation between the upper valley fill and underlying aquifers is supported by well test data from MW-2, 11, 13 and 10. MW-13 shows the valley fill aquifer saturated but the bedrock aquifer dry, which establishes vertical hydraulic separation. Aquifer tests at MW-10A (completed in the lower valley fill aquifer) established some vertical hydraulic connection between the lower valley fill aquifer and the underlying bedrock aquifer (MW-10B). However, the aquifer test indicated that the upper valley fill aquifer (MW-10C) appears to be separated from the lower aquifers to some degree due to an intermediate clay layer. This clay layer retards the downward flow of upper valley fill ground water to some degree, allowing two different and sustainable flow systems to exist: the upper valley fill and the lower valley fill/bedrock aquifer. WRD and erosional scar leachate should move downward to the upper valley fill aquifer, along the clay layer, and to the Red River. The lower valley fill and bedrock aquifer may receive some of the leachate over time due to the degree of upper valley fill and lower valley fill hydraulic separation within the immediate area.

4.4.2.3 LATERAL CONTINUITY

Lateral continuity, and good hydraulic conductivity, have been established for the lower valley fill aquifer through pump tests conducted on a select number of monitor wells. However, as previously mentioned, the upper valley fill aquifer is considered the primary conduit for Red River contamination through a ground water hydrological connection. No pump tests have been conducted on the upper valley fill aquifer to determine if lateral continuity exists. However, the upper and lower valley fill deposits (i.e., alluvium) are similar, more so than the bedrock aquifer; and therefore, it is assumed that the hydraulic conductivity and lateral continuity are similar.

SPRI (April 21, 1995) states that most of the bedrock wells went dry during development. This indicates that although lateral conductivity may exist in the fractured bedrock aquifer, the hydraulic conductivity was insufficient to supply recharge to these well. However, the bedrock aquifer well MW-11 was pumped at a rate of approximately 60 gallons per minute (gpm). The MW-10A, lower valley fill well, was pumped at a rate of 140 gpm with little drawdown, indicating recharge balanced discharge. A comparison of these two tests indicates that the lower valley fill aquifer has greater hydraulic conductivity than the bedrock aquifer. The fact that the lower valley fill has good hydraulic conductivity and that it exists above the bedrock aquifer (i.e., nearer the source), the lower valley fill (and consequently, the upper valley fill) has a higher potential than the bedrock aquifer to receive and transport metals to the river in the immediate area of the wells.

4.5 RIVER, SPRING, SEEP AND GROUND WATER QUALITY

Ground water, seep and spring water quality, as shown on Figure 8 and summarized in Table 3 and 5, was evaluated to determine if a water quality correlation exists between WRD or erosional scar leachate and ground water, spring, and Red River seep discharge. Attenuation was considered a factor in water quality delivered to the seeps. However, background samples were compared to all samples evaluated to determine if WRD or erosional scar leachate was present in the seep, spring or ground water samples.

4.5.1 RIVER

Review of the NMED (March, 1996) and Vail (July 9, 1993) studies indicated that although most seep constituent concentrations are usually above NMGWS, mixing of seep and Red River water results in dissolved metals concentrations that are at times diluted below NMSWS. However, during storm events, river metals concentrations are above State standards due to pulse loading. During base flow, river metals concentrations increase due to seep discharge, with some metals precipitating out onto the river bed.

4.5.2 SPRINGS

Although background ground water quality appears to have been excluded from the sampling events, the spring drainage sample CCS-2 (Figure 8) has relatively low metals concentrations and neutral pH. Therefore, the CCS-2 sample was selected as background ground water quality for evaluating ground water within the mine site.

4.5.3 SEEPS

The NMED (March, 1996) has identified more than twenty seeps along the north side of the Red River between the towns of Questa and Red River. Investigations continue to discover additional seeps along the north side of the river. The Portal Springs seep was discovered by an NMED field survey in January 1994, even after numerous earlier surveys. The most recent river survey found the Milk seep (seep at Waldo Curves) approximately one-half mile up river of the mill site. Utilizing the CCS-2 sample as background ground water quality, available Red River seep water chemistry data appear to correlate to WRD and erosional scar leachate chemistry.

The NMED apparently has identified all seeps within the general area of the Molycorp mine property, and has determined that seeps exist only on the north side of the river, with the most active seeps existing within the Molycorp boundary. Both sides of the river have similar topography; therefore, if seeps exist only on the north side of the river, it must be due to other than natural factors which increase recharge to ground water. The major concentrations of erosional scars (Figure 9) and historic and recent mining activity are located on the north side of the river. One iron rich seep was located near the town of Red River (approximately 6 miles up gradient of

the mine), which the NMED (March, 1996) believes is due to anthropogenic factors. If a connection can be substantiated between anthropogenic factors and the formation of seeps, it may be assumed that subsequent excavation activities could add to the contamination of the watershed.

As illustrated on Figures 1 and 2, several seeps exist within and just down river of the Molycorp property. However, the NMED (March, 1996) reports that there are three principal seeps which exhibit concentrated discharge and appear to have the most impact on Red River water quality: Capulin Canyon, Portal Spring, and Cabin Spring. The NMED states that water chemistry varies between seeps. However, all are acidic and contain elevated concentrations of TDS, including sulfates, Al, Fe, Mn, Co, Cu, Ni, Zn, Cd, and F, which exceed NMGWS. The most dominant metals in all seeps are Ca, Al, Mg, and Fe, respectively.

Ground water samples, as summarized on Table 5, were collected from monitor wells and compared to the Portal Springs, Cabin Springs and Capulin Canyon seeps. Portal Springs and Capulin Canyon waters appear to be more similar to ground water in the valley fill aquifer than to the underlying bedrock aquifer. All ground water samples have TDS and sulfate concentrations above the concentrations in the Red River seeps, and exhibit a pH lower than seep discharge. The following is a water quality evaluation of each seep and its possible source location.

Portal Springs seep is characterized as calcium sulfate waters with a pH of 4.5 and TDS of 1800. Some correlation is apparent between this seep and well MW-10C (upper valley fill, calcium sulfate waters, pH of 4.7, TDS 1400). However, the correlation between MW-10C ground water and Portal Springs seep waters is not clearly defined. Ground water within the upper valley fill aquifer is expected to flow southwest in this area, following the surface topography. Therefore, the ground water supplied to the Portal Springs seep may originate further east of MW-10 and 11, in close proximity to the Moly Tunnel. No closure data on this mine drainage tunnel were available to determine if it may be a probable source for the Portal springs seep.

There exists no up gradient monitor well to attempt a correlation between ground water and the Cabin Springs seep. This seep is located southwest of the nearest WRD and may be caused by preferential flow paths within the bedrock aquifer. No Cabin Springs seep water quality analysis was available for review.

The Capulin Canyon seeps are located west of the main mining operations and appear to be out of the influence of any probable source (WRD or erosional scar). However, the Capulin Canyon seeps and MW-2 (completed in valley fill) have similar low pH values, with sulfates and metals concentrations being greater in MW-2. This suggests the source for the seeps to be up gradient of MW-2. The most probable source for the Capulin Canyon seep is the Capulin Canyon WRD and scars located within this canyon.

Molycorp contends that erosional scars are the primary cause for metals loading to the Red River. Therefore, erosional scars and seeps outside the influence of WRD leachate were evaluated to determine their potential for the discharge of high metals concentrations to ground water and surface water. As illustrated on Figure 8, three water samples collected from erosional scars and seeps outside of the Molycorp mine boundary (HTS-1, from an erosional scar; and HCS-1 and 2, from ground water seeps) exhibit low pH, moderate to high TDS values, and high metals concentrations. The upper Hanson Creek seep (HCS-1, near a scar) has lower pH, and higher metals concentrations than the down gradient (HCS-2) seep, indicating attenuation. Although the weathering of excavated rhyolitic material may be a source for high metals buildup within the Red River watershed, the available information does not indicate whether historic mine sites are located near these erosional scars or seeps. Therefore, erosional scars have the potential to release high metals concentrations to the local watershed. Red River samples, down gradient of the Hanson Creek tributary, showed that dilution had decreased metals concentrations and increased pH.

The unconsolidated WRD material appears to deliver greater concentrations of dissolved metals to the ground water than the consolidated erosional scars. The GHS-3 seep (Figure 8) at Goathill Gulch is from an erosional scar and near the Capulin canyon WRD. SPRI (April 21. 1995) states that this erosional scar extends below the Capulin Canyon WRD, and that the GHS-3 chemistry may reflect a mixture of erosional scar and WRD seepage. The HCS-1 and HTS-1 seeps are also within erosional scars. The GHS-3 seep has greater TDS concentrations, and higher metals concentrations; with sulfates, aluminum, and magnesium concentrations being two to nine times greater than the HCS-1 and HTS-1 (erosional scar) seeps. This indicates that the additional WRD material increases the concentrations delivered to the underlying aquifer, well above those concentrations contributed by the erosional scar. Although WRD leachate can supply greater metals concentrations to ground water than erosional scars, erosional scars can also release high metals concentrations to ground water which may discharge to local surface water.

Water samples GHS-1, from Capulin Canyon WRD seepage (considered the worst water quality sample reviewed); GHS-2, from a nearby borehole; and GHS-3 are similar. This correlation supports a hydrological connection between waste rock dump seepage and the immediate ground water.

Hutchison (April 23, 1997) contends that natural factors cause the Red River seeps and if ground water contamination did exist, it would not effect the river due to attenuation. Samples GHS-1, GHS-2 and GHS-3 appear to substantiate ground water contamination from Capulin Canyon WRD infiltration. Red River seep water quality indicates that although attenuation appears to be a factor in seep discharge concentrations, seeps considered hydrologically connected to the probable sources (WRD and erosional scar) discharge high metals concentrations to the river. In addition, ground water samples from monitor wells and anoxic alkaline trenches (located immediately up gradient of seeps) document that ground water has a lower pH and higher concentrations of metals than the hydrologically connected seep discharge, indicating that seep discharge is not a true indication of immediate ground water quality.

4.5.4 GROUND WATER QUALITY

Generally within the valley fill aquifer, ground water acidity, sulfates, and metals concentrations increase down gradient along the river. However, bedrock well MW-7 has the lowest pH and highest sulfate, TDS, and metals concentrations recorded; with much greater values than the other ground water wells. The MW-7 water quality values are similar to the Capulin Canyon and Goathill Gulch (CCS-1 and GHS-1) waste rock seepage concentrations. The perched nature of the bedrock aquifer in the immediate area apparently causes a longer ground water residence time, and therefore, greater concentrations.

The remaining bedrock wells have a pH around 7.0, with the exception of MW-11 (pH 5.6), which is completed below the South Sugar Shack waste rock dump. MW-10B (bedrock well, 7.9 pH) is located immediately down gradient of MW-11 and exhibits lower concentrations of metals than MW-11. The low pH and high metals concentrations for MW-11 is probably a result of infiltration from the WRD. MW-10C (upper valley fill aquifer) water quality (pH 4.7) and ground water level indicate that the upper valley fill aquifer appears to be hydraulically separated from the lower aquifers to some degree. Therefore, there exists support for a ground water flow direction toward the topographic low (the Red River) within the upper valley fill aquifer.

5.0 CONCLUSIONS

The most probable sources for the continuing degradation of the Red River watershed through seep discharge of high metals concentrations are the Molycorp WRDs and the naturally occurring erosional scars. The "most probable" source, indicating that it is the source within a reasonable degree of certainty, has been a defensible argument in the past through specific sampling for verification. Verification of a source requires a comparison of a suspect facility's product or waste stream constituents with contaminants found in ground water and/or surface water. If a correlation exists between facility constituents and contamination, additional support for a hydrological connection is required through water quality, geological and monitor well evidence.

5.1 TAILINGS PONDS

Water quality samples collected from tailings pond leachate, ground water, and Red River seeps indicate that the only probable source for elevated sulfate and metals concentrations found in ground water in this area are the tailings ponds. Ground water samples, which were collected from up and down gradient of the tailings ponds, document infiltration of pond leachate to the underlying shallow alluvial aquifer. A correlation exists between ground water quality below and down gradient of the ponds. Monitor well ground water elevations show a ground water gradient to the river. USGS gage station data indicate the reach adjacent to the tailings ponds is a gaining stream supplied by ground water. Therefore, support exists for a ground water hydrological connection between the ponds and the river. However, although several ground water samples taken

immediately down gradient of the ponds show sulfate and metals concentrations above NMGWS, seeps along the river discharge concentrations below NMGWS and NMSWS. There is insufficient information to document a ground water discharge of metals concentrations above NMGWS and NMSWS to the river in this area.

5.2 MOLYCORP MINE SITE

Naturally occurring erosional scars (exposed and located below some WRDs) and WRDs are the most probable sources of low pH and high metals discharge to the local watershed environment. Red River water quality and a localized concentration of acidic, high metals seeps indicate that the general area of the source is within the Molycorp boundary. Geochemical analysis of erosional scar and WRD leachate indicates similar geochemical signatures. Monitor well ground water samples support a correlation between ground water chemistry and WRD and erosional scar leachate chemistry. USGS gage station data indicate ground water flow to the river. Although attenuation appears to be a factor for seep discharge, a correlation exists between seep and ground water quality. Therefore, verification has been adequately established to support a ground water hydrological connection between the two sources and Red River seep discharge. However, the percentage of constituent concentrations or discharge volume supplied by each probable source to a specific seep could not be determined using the available data.

6.0 REFERENCES

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TABLES

TABLE 1 (1 OF 2) (TAKEN FROM VAIL, October 1994)

WATER QUALITY SURVEY ALONG RED RIVER
BETWEEN STATE ROAD 522 AND FISH HATCERY
APRIL 12, 1993

SAMPLE SOURCE	PH	TOT ALK	F	TDS	SO4	TSS	MO	DIS. AL	CD	SUS. AL	FE	PB	CU	ZN	MN
#1 R/R Below Highway Bridge	7.23	38	0.84	255	119	31	<.03	<.5	<.005	7.8	0.594	<.1	0.036	0.250	[illegible]
#2 Spring N. Side R/R	6.76	90	0.55	247	92	20	<.03	<.5	<.005	0.5	0.543	<.1	0.007	0.021	0.02
#3 Field Drainage to R/R 500'E. of 002	7.44	99	0.60	246	92	7	0.20	<.5	<.005	<.5	0.405	<.1	<.005	0.047	0.05
#4 Field Drainage to R/R 450'E. of 002	8.22	94	0.46	648	172	6	<.03	<.5	<.005	<.5	0.115	<.1	0.008	0.012	0.05
#5 R/R 300'E. of 002	7.60	43	0.90	240	118	22	<.03	<.5	<.005	8.0	0.569	<.1	0.028	0.222	0.88
#6 Outfall 002	7.26	152	1.90	1764	840	2.0	1.80	<.5	<.005	<.5	0.102	<.1	<.005	0.010	1.40
#7 Field Drainage 75'W of 002	7.20	165	0.80	727	228	39	0.20	<.5	<.005	2.7	1.090	<.1	0.009	0.017	0.03
#8 R/R Above Questa Spring	7.14	50	0.88	268	141	21	<.03	<.5	<.005	6.2	0.573	<.1	0.029	0.207	0.88
#9 Near Questa Springs SE of Conc.Box	7.02	158	0.38	1094	504	88	<.03	<.5	<.005	8.5	2.940	<.1	0.016	0.047	0.07
#10 Near Questa Springs End of Old Pipe	7.50	177	0.60	576	210	7	<.03	<.5	<.005	<.5	<.05	<.1	0.005	0.010	0.01
#11 R/R 500'W. of Questa Springs	7.45	54	0.90	269	138	22	<.03	<.5	<.005	3.10	0.618	<.1	0.033	0.215	0.88

TABLE 1 (2 OF 2)

WATER QUALITY SURVEY ALONG RED RIVER
BETWEEN STATE ROAD 522 AND FISH HATCERY
APRIL 12, 1993

SAMPLE SOURCE	PH	TOT ALK	F	TDS	SO4	TSS	MO	DIS. AL	CD	SUS. AL	FE	PB	CU	ZN	MN
#12 Spring–N. Side R/R Sta. 47+20	6.94	82	0.80	271	115	47	<.03	<.5	<.005	1.70	2.36	<.1	0.011	0.046	0.13
#13 R/R Sta. 47+70 Above Hatchery	7.45	51	0.90	259	128	22	<.03	<.5	<.005	3.00	0.590	<.1	0.026	0.206	0.83
#14 Spring S. Side R/R Sta. 36+80	8.14	82	0.80	304	126	<1	<.03	<.5	<.005	<.5	<.05	<.1	<.005	0.005	0.01
#15 Spring N. Side R/R Sta. 36+40	7.26	80	1.10	145	20	<1	<.03	<.5	<.005	<.5	<.05	<.1	<.005	<.005	<.0
#16 R/R Sta.	7.80	49	0.90	247	129	24	<.03	<.5	<.005	3.10	0.527	<.1	0.024	0.191	0.781
#17 Hatchery Inlet Cold Water	7.14	43	0.64	176	80		<.03	<.5	<.005	<.5	0.138	<.1	<.005	<.005	<.0
#18 Hatchery Inlet Warm Water	7.87	77	1.10	284	63		<.03	<.5	<.005	<.5	0.181	<.1	<.005	0.010	<.0
#19 Seep Water in Irrigation Ditch Above 002 Line X @ Road	7.73	174	0.54	1304	660		<.03	<.5	<.005	<.5	0.160	<.1	<.005	0.013	0.05
#20 Molycorp Drain Below Culver Above Ditch	8.10	153	1.90	1702	790		1.70	<.5	<.005	4.00	2.4	<.1	0.016	0.010	2.00

TABLE 2
1994 MONITOR WELL WATER QUALITY DATA FOR TAILINGS AREA
MOLYCORP, INC. - QUESTA, NEW MEXICO

(TAKEN FROM SOUTH PASS RESOURCES, April 13, 1995)

MONITOR WELL	SAMPLE DATE 1994	WELL TD (feet)	Corrected DEPTH TO WATER (feet)	DEPTH TO PUMP INTAKE (feet)	pH (1)	CONDUC-TIVITY (1) (uhmos)	TEMP (1) (°C)	CARBO -NATE (mg/L)	BICARBO -NATE (mg/L)	HYDR-OXIDE (mg/L)	TOTAL ALK (mg/L)	CHLORIDE (mg/L)	FLUORIDE (mg/L)	NITRATE (mg/L)	SUFATE (mg/L)
EW-1	7-Nov	157	83.00	102	7.50	1,460	NA	<1	156	<1	156	23	0.25	0.72	620
EW-2	8-Nov	204	147.91	170	7.48	850	12.9	<1	122	<1	122	4.8	0.49	0.2	96
EW-2	17-Nov	NA	NA	NA	NA	NA	NA	<1	118	<1	118	4.6	0.5	0.38	90
EW-3	8-Nov	78	57.74	70	7.48	1,135	11.4	<1	110	<1	110	17	0.16	0.6	440
EW-3	19-Nov	NA	NA	NA	NA	NA	NA	<1	136	<1	136	18	0.19	0.49	410
EW-4	7-Nov	58	18.49	50	7.78	650	11.6	<1	152	<1	152	26	0.21	0.35	150
EW-4	16-Nov	NA	NA	NA	NA	NA	NA	<1	156	<1	156	26	0.2	0.36	160
MW-1	7-Nov	100	53.17	80	7.28	1,322	NA	<1	136	<1	136	14	0.27	0.45	610
MW-2	7-Nov	80	22.07	60	7.96	1,701	NA	<1	80	<1	80	15	0.96	<0.06	860
MW-3	8-Nov	60	19.97	55	7.38	1,679	12.4	<1	183	<1	183	18	0.44	0.31	780
MW-4	8-Nov	96	40.77	65	7.61	1,157	12.3	<1	184	<1	184	7.3	0.73	0.24	460
MW-7A	7-Nov	90	58.84	80	7.50	1,565	11.9	<1	126	<1	126	16	0.18	0.72	730
MW-7C	9-Nov	146	111.79	135	7.10	2,160	12.4	<1	124	<1	124	16	0.17	0.32	790
MW-9A	8-Nov	44	26.30	35	7.32	1,021	13.1	<1	174	<1	174	20	0.44	0.33	680
MW-10	8-Nov	129	26.23	100	8.16	236	12.3	<1	77	<1	77	1.6	0.36	0.27	35
MW-11	9-Nov	249	191.93	210	7.00	440	19.8	<1	82	<1	82	10.3	1.28	0.39	58
MW-11AB	9-Nov	NA	NA	NA	NA	NA	NA	<1	79	<1	79	10.1	1.29	NA	58
MW-12	7-Nov	234	128.11	210	NA	NA	NA	<1	120	<1	120	5.1	0.46	NA	66
MW-A	7-Nov	38	30.58	NA	7.28	1,332	NA	<1	154	<1	154	14	0.35	0.37	560
MW-C	7-Nov	14.5	1.80	NA	7.24	1,902	NA	<1	185	<1	185	19	1.16	<0.06	970
CH	8-Nov	NA	NA	NA	7.97	539	13.5	<1	206	<1	206	2.3	0.71	0.44	75

NOTES:

(1) pH, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

SOURCE: SAMPLES TAKEN BY SPRI. ANALYTICAL RESULTS FROM MOLYCORP.

NA - NOT AVAILABLE

TABLE 2

1994 MONITOR WELL WATER QUALITY DATA FOR TAILINGS AREA

MOLYCORP, INC. - QUESTA, NEW MEXICO

MONITOR WELL	TDS (mg/L)	SILVER (mg/L)	ALUMINUM (mg/L)	ARSENIC (mg/L)	BARIUM (mg/L)	BERYLLIUM (mg/L)	CALCIUM (mg/L)	CADMIUM (mg/L)	COBALT (mg/L)	CHROMIUM (mg/L)	COPPER (mg/L)	IRON (mg/L)	MERCURY (mg/L)
EW-1	1,200	<0.10	<0.05	<0.005	0.053	<0.004	240	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-2	240	<0.10	<0.05	<0.005	0.068	<0.004	59.4	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-2	290	<0.010	<0.05	<0.005	0.065	<0.004	57.8	0.0036	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-3	830	<0.10	<0.05	<0.005	0.074	<0.004	179	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-3	750	<0.010	<0.05	<0.005	0.054	<0.004	158	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-4	440	<0.10	<0.05	<0.005	0.065	<0.004	101	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
EW-4	450	<0.010	<0.05	<0.005	0.068	<0.004	104	<0.0005	<0.010	<0.010	0.012	<0.050	<0.0002
MW-1	1,100	<0.10	<0.05	<0.005	0.025	<0.004	207	<0.0005	<0.010	<0.010	<0.010	0.068	<0.0002
MW-2	1,400	<0.10	<0.05	<0.005	0.022	<0.004	241	<0.0005	<0.010	<0.010	<0.010	4.6	<0.0002
MW-3	1,400	<0.10	<0.05	<0.005	0.032	<0.004	264	<0.0005	<0.010	<0.010	<0.010	0.07	<0.0002
MW-4	890	<0.10	<0.05	<0.005	0.084	<0.004	166	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-7A	1,300	<0.10	<0.05	<0.005	0.028	<0.004	273	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-7C	1,300	<0.10	<0.05	<0.005	0.028	<0.004	279	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-9A	1,200	<0.10	<0.05	<0.005	0.061	<0.004	247	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-10	150	<0.10	<0.05	<0.005	0.038	<0.004	28.2	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-11	200	<0.10	<0.05	<0.005	0.014	<0.004	28.6	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-11AB	220	<0.10	<0.05	<0.005	0.015	<0.004	28.5	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-12	260	<0.10	<0.05	<0.005	0.096	<0.004	47.1	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MW-A	1,000	<0.10	<0.05	<0.005	0.03	<0.004	214	<0.0005	<0.010	<0.010	<0.010	0.066	<0.0002
MW-C	1,700	<0.10	<0.05	<0.005	0.04	<0.004	334	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
CH	340	<0.10	<0.05	<0.005	0.059	<0.004	48.5	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002

NOTES:

(1) pH, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

SOURCE: SAMPLES TAKEN BY SPRI. ANALYTICAL RESULTS FROM MOLYCORP.

NA - NOT AVAILABLE

TABLE 2

1994 MONITOR WELL WATER QUALITY DATA FOR TAILINGS AREA

MOLYCORP, INC. - QUESTA, NEW MEXICO

MONITOR WELL	POTASSIUM (mg/L)	MAGNESIUM (mg/L)	MANGANESE (mg/L)	MOLYBDENUM (mg/L)	SODIUM (mg/L)	NICKEL (mg/L)	LEAD (mg/L)	ANTIMONY (mg/L)	SELENIUM (mg/L)	SILICON (mg/L)	THALLIUM (mg/L)	VANADIUM (mg/L)	ZINC (mg/L)
EW-1	3.7	47.9	0.017	<0.02	41.7	<0.020	<0.002	<0.05	<0.005	13.8	<0.005	<0.010	<0.050
EW-2	3.3	10.4	0.169	<0.02	20.0	<0.020	<0.002	<0.05	<0.005	15.7	<0.005	<0.010	<0.050
EW-2	3.6	10	0.138	<0.02	19.6	<0.020	<0.002	<0.05	<0.005	17.3	<0.005	<0.010	0.091
EW-3	2.6	31.8	0.056	<0.02	28.6	<0.020	<0.002	<0.05	<0.005	12.4	<0.005	<0.010	<0.050
EW-3	2.2	27.8	0.036	<0.02	28.9	<0.020	<0.002	<0.05	<0.005	11.9	<0.005	<0.010	0.364
EW-4	1.5	17.8	<0.010	<0.02	15.5	<0.020	<0.002	<0.05	<0.005	12.4	<0.005	<0.010	<0.050
EW-4	2.1	18.1	0.019	<0.02	16	<0.020	<0.002	<0.05	<0.005	12.7	<0.005	<0.010	0.364
MW-1	3.0	41.2	0.035	0.04	55.4	<0.020	<0.002	<0.05	<0.005	11.9	<0.005	<0.010	<0.050
MW-2	3.1	52.2	0.37	1.7	95.6	<0.020	<0.002	<0.05	<0.005	1.8	<0.005	<0.010	<0.050
MW-3	1.5	48.6	0.032	<0.02	71.6	<0.020	<0.002	<0.05	<0.005	10.3	<0.005	<0.010	<0.050
MW-4	1.1	32.7	<0.010	0.21	64.2	<0.020	<0.002	<0.05	<0.005	10.3	<0.005	<0.010	<0.050
MW-7A	2.6	47.1	<0.010	<0.02	39.5	<0.020	<0.002	<0.05	<0.005	12.3	<0.005	<0.010	<0.050
MW-7C	3.9	48.4	<0.010	<0.02	45.1	<0.020	<0.002	<0.05	<0.005	12.1	<0.005	<0.010	<0.050
MW-9A	1.7	45.5	0.111	<0.02	66.0	<0.020	<0.002	<0.05	<0.005	10.5	<0.005	<0.010	<0.050
MW-10	1.3	4.4	<0.010	<0.02	14.7	<0.020	<0.002	<0.05	<0.010	10.8	<0.005	<0.010	<0.050
MW-11	2.8	8.6	<0.010	0.06	25.8	<0.020	<0.002	<0.05	<0.005	15.5	<0.005	<0.010	<0.050
MW-11AB	2.6	8.6	<0.010	0.06	25.7	<0.020	<0.002	<0.05	<0.005	15.5	<0.005	0.01	<0.050
MW-12	2.9	8.5	<0.010	0.02	24.5	<0.020	<0.002	<0.05	<0.005	13.6	<0.005	<0.010	<0.050
MW-A	2.8	35.7	0.04	0.63	50.6	<0.020	<0.002	<0.05	<0.005	10.9	<0.005	<0.010	<0.050
MW-C	2.1	56.1	0.774	1.12	82.2	<0.020	<0.002	<0.05	<0.005	11.6	<0.005	<0.010	<0.050
CH	1.2	9.4	<0.010	<0.02	57.8	<0.020	<0.002	<0.05	<0.005	9.8	<0.005	<0.010	0.946

NOTES:

(1) pH, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

SOURCE: SAMPLES TAKEN BY SPRI. ANALYTICAL RESULTS FROM MOLYCORP.

NA - NOT AVAILABLE

TABLE 3

WATER QUALITY DATA FOR THE RED RIVER - (SPRI, MAY 1994)

MINE AREA - MOLYCORP, INC. - QUESTA, NEW MEXICO

(TAKEN FROM SOUTH PASS RESOURCES, April 21, 1995)

Sample ID	Sample Description	pH Meter	pH Strip	Temp (F°)	Conduc-tivity (uhmos)	Total Alkalinity (mg/L)	TDS (mg/L)	TSS (mg/L)	Aluminum Susp. (mg/L)	Aluminum Dis. (mg/L)	Fluoride (mg/L)	Iron (mg/L)
BC-1	BC 75' N of High St. bridge	6.40	5.0	44.9	49.8	20	82	26	0.75	0.60	0.15	2.70
BC-2	BC 500' S of Spring flow from BCS-1	6.55	5.5	43.6	66.2	18	78	10	<.5	0.60	0.12	1.00
BCS-1	Spring, 1.2 mi. N High St.	4.42	5.0	44.7	478.0	0	530	<1	<.5	5.20	0.30	<.01
BOS-1	Spring, W side of Bobita Campground		6.0	61.0	605.0	44	737	8	<.5	<.5	0.32	0.16
CCS-1	Middle sump Capulin Canyon		3.0	50.9	13,440	0	24,950	8	1.00	1,310	53.30	258.30
CCS-2	Spring drainage W side Capulin Canyon		7.0	56.9	260.0	54	416	107	2.80	2.2	0.62	11.72
CCS-3	Adit W side Capulin Canyon		4.0	45.1	2,960	0	2,686	295	1.60	53.6	12.00	25.20
CCS-4	Seep, Capulin Canyon S of adit		4.0	48.2	1,775	0	1,193	12.7	<.5	23.2	5.70	2.35
CCS-5	Culvert drain W side of Capulin Canyon		4.0	66.7	1,700	0	1,896	3.7	<.5	74.8	9.80	0.21
CCS-6	Seep, 200' E Capulin Canyon		3.0	73.7	2,430	0	2,673	6.4	<.5	116.2	13.00	7.68
CLB-1	Columbine Creek-200' up from confluence		6.5	57.7	134.0	49	70	3	<.5	<.5	0.18	0.34
ECCS-1	Seep near river, E of Capulin Canyon		6.5	60.5	580.0	26	413	8	<.5	<.5	1.50	0.32
ECCS-2	Seep S of Hwy 38, E of Capulin Canyon		4.0	62.0	1,752	0	913	1	<.5	73	5.20	0.79
EGHS-1	Seep, S of Hwy 38, E of Goathill		7.0	55.6	810.0	47	843	1.2	<.5	<.5	0.47	0.15
GHS-1	Seepage Goat Hill dump		2.0	69.1	11,140	0	23,890	39	0.97	1,183	36.70	257.00
GHS-2	Seep from bore hole +GHS1		2.0	73.0	11,350	0	17,623	29	1.70	1,125	43.30	252.00
GHS-3	Natural seep from volcanic rock					0	11,980	94	1.30	645	26.00	250.00
HCS-1	seeps, Upper Hanson Creek Canyon		2.5	44.2	5,520	0	6,493	13.6	<.5	185.4	15.00	177.90
HCS-2	seep, downgradient from HCS-1		2.5	50.6	5,390	0	6,230	7.6	<.5	154	15.60	164.80
HCS-3	Seep S of Hwy 38, W Hanson Creek		4.0	77.0	1,232	0	1,773	<1	<.5	2.6	1.40	0.43
HTS-1	Upper Hot-N-Tot Canyon	2.86	2.3	48.2	2,670	0	2,610	43	<.5	97.8	2.30	212.80
MC-1	Mallette Creek-Alpine Lodge	6.86	6.0	52.2	80.4	22	96	16	0.65	0.60	0.25	1.20
PC-1	Pioneer Creek, Arrowhead Lodge	7.34	7.0	45.1	107.0	43	94	15	<.5	0.50	0.10	0.70
POS-1	seep, Portal Springs W of mine portal		4.5	54.4	1,900	10	1,800	34	<.5	21.3	153.00	8.24
RR-1	RR W of confluence w/BitCrk	7.40	6.0	43.8	99.3	43	82	4	<.5	0.50	0.86	1.10
RR-2	RR 50' E of BC Confluence	7.58	6.5	45.9	108.0	70	88	18	<.5	0.50	0.08	0.80
RR-3	RR behind Alpine Lodge	7.53	6.0	48.2	93.7	51	92	22	0.5	0.50	0.10	2.10
RR-4	RR, Goose Lake Rd/East RR	7.73	7.0	43.5	130.0	47	98	13	<.5	<.5	0.10	0.70
RR-5	RR, Hot-N-Tot Creek/upstream	7.45	7.0	47.0	144.0	59	100	32	0.75	0.50	0.11	2.20

TABLE 3

WATER QUALITY DATA FOR THE RED RIVER - (SPRI, MAY 1994)

MINE AREA - MOLYCORP, INC. - QUESTA, NEW MEXICO

Sample ID	Sample Description	pH Meter	pH Strip	Temp (F°)	Conduc-tivity (uhmos)	Total Alkalinity (mg/L)	TDS (mg/L)	TSS (mg/L)	Aluminum Susp. (mg/L)	Aluminum Dis. (mg/L)	Fluoride (mg/L)	Iron (mg/L)
RR-6	RR, Hot-N-Tot Creek/dwnstream	7.52	6.5	48.0	145.0	43	92	34	0.60	<.5	0.11	1.90
RR-7	RR down from Sulpher Gulch	7.48	7.0	62.0	122.0	48	108	49	0.75	<.5	0.16	2.10
RR-8	RR upstream from mill gate	7.53	6.5	57.0	129.0	56	106	57	0.50	0.60	0.12	2.14
RR-9	RR, 200' up from Hanson Creek confluence	7.46	7.0	54.5	144.0	53	104	31.2	<.5	<.5	0.13	1.70
RR-10	RR, downstream of Portal Springs	7.46	7.0	54.5	196.0	48	112	61.2	1.60	<.5	0.20	2.41
RR-11	RR, Down from Hanson Creek confluence	7.51	6.5	51.5	177.0	61	104	17.6	<.5	<.5	0.11	1.29
RR-12	RR 100' E of Columbine Creek Confluence		6.5	55.5	196.0	48	213	58	0.54	0.6	0.30	2.35
RR-13	RR, highway bridge W of Columbine Creek		6.5	55.5	196.0	50	163	54	0.54	<.5	0.20	1.80
RR-14	RR up from Goathill Gulch		6.5	58.1	241.0	42	123	52	0.72	<.5	0.32	2.05
RR-15	RR down from Goathill Gulch		7.0	57.0	224.0	52	130	62	0.83	<.5	0.32	2.24
RR-16	RR Questa Ranger Station		6.5	54.0	171.0	41	150	106	0.83	<.5	0.35	2.72
SGS-1	Sulpher Gulch-spring pond	6.65	7.0	75.5	753.0	83	620	6.5	<.5	<.5	1.30	0.75
SSC-1	seep, S of west end Sugar Shack South		5.0	55.0	2,350	33	2,017	214	2.20	5.3	92.00	<.01

NOTES:

Sampling by SPRI; analytical results from Molycorp. Inc.

(1) - pH Strip, Temperature and Conductivity were measured field measurements.

All samples are total metals except Alum. Suspended and Alum. Dissolved

< symbols are detection limits.

TABLE 3

WATER QUALITY DATA FOR THE RED RIVER - (SPRI, MAY 1994)

MINE AREA - MOLYCORP, INC. - QUESTA, NEW MEXICO

Sample ID	Ferrous Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Zinc (mg/L)	Copper (mg/L)	Molybdenum (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Silica (mg/L)	Chlorine (mg/L)	Cadmium (mg/L)	Sulfate (mg/L)
BC-1		0.003	0.041	0.025	0.03	<.02	2.5	<1.0	6	1.6	20	2.5	<.005	12
BC-2		0.002	0.034	0.025	0.02	<.02	2.7	<1.0	12.5	3.5	22	3	<.005	13.7
BCS-1		<.002	1.360	0.491	0.18	<.02	9.4	1.5	48.9	27.2	46	5	0.005	171
BOS-1		<.002	<.01	0.060	0.01	<.02	13.1	1.2	85.2	21.5	20	20	<.005	217
CCS-1	7.0	<.002	416.20	146.00	15.3	<.02	23.7	<1.0	504	1,032	92.4	30	0.75	11,996
CCS-2		0.036	0.213	0.149	0.024	<.02	9.5	2.6	20.2	4.2	46.6	7.5	<.005	56.8
CCS-3	<1.0	0.078	12.600	6.960	0.162	<.02	70.3	9.6	348	84	76	14.5	0.021	1,736
CCS-4		<.002	10.300	2.620	0.21	<.02	30.9	2	145	38.5	52	9.5	0.007	541.7
CCS-5		0.004	28.900	7.600	1.21	<.02	19.1	1.7	118	76.9	112	9.5	0.036	1,152
CCS-6		0.003	13.600	4.470	0.998	<.02	30	3.5	233	65	62	35	0.017	1,649
CLB-1		<.002	<.01	0.022	0.008	<.02	1.5	<1.0	17	1.8	14	2.5	<.005	1.7
ECCS-1		<.002	<.01	0.115	0.01	<.02	9.8	1.2	52.8	12.7	28	18.5	<.005	128.3
ECCS-2		0.003	8.740	2.820	0.921	<.02	55.7	3.5	138	41	28	95	0.015	669
EGHS-1		<.002	<.01	0.042	0.009	<.02	9.5	1.7	104.4	23.1	18	10.5	<.005	190
GHS-1	8.0	<.010	239.50	82.70	8.6	<.02	11.7	<1.0	444	760	104	37	0.381	13,312
GHS-2	10.0	<.010	263.80	86.40	8.5	<.02	18.4	<1.0	432	704	96.7	40	0.409	11,667
GHS-3	1.0	0.017	22.00	4.22	1.58	<.02	32.6	<1.0	504	405	102	15	<.005	7,763
HCS-1	2.0	0.004	20.300	3.740	0.512	<.02	17.8	<1.0	504	274	63.5	10	0.012	3,876
HCS-2		<.002	17.100	3.880	0.629	<.02	17.2	<1.0	454	199	75.9	16	0.013	3,436
HCS-3		0.004	0.445	0.183	0.025	<.02	48	2.6	156	18	22	90	<.005	377
HTS-1	7.0	0.009	6.250	2.960	1.14	<.02	2.1	<1.0	55.9	43.5	100	16	0.012	848
MC-1		<.002	0.054	0.043	0.02	<.02	3.9	1.4	8.2	3.1	32	4.5	<.005	16.4
PC-1		<.002	0.036	0.014	0.02	<.02	2	<1.0	19.8	2.4	15	5	<.005	20
POS-1		<.002	6.830	2.490	0.05	<.02	26.2	3.4	206	16.6	32	27	0.01	622
RR-1		<.002	0.033	0.048	0.02	<.02	2.2	<1.0	15	2.5	14	4	<.005	7
RR-2		<.002	0.039	0.012	0.01	<.02	2	<1.0	17.7	2.4	14	2.5	<.005	3
RR-3		0.004	0.086	0.018	0.02	0.03	2.3	<1.0	15.7	2.5	17	4	<.005	13.8
RR-4		<.002	0.030	0.006	0.01	<.02	1.9	<1.0	17	2.2	12	5	<.005	2.2
RR-5		0.003	0.065	0.022	0.02	<.02	2.3	<1.0	17	2.5	14	5	<.005	17.4

TABLE 3

WATER QUALITY DATA FOR THE RED RIVER - (SPRI, MAY 1994)

MINE AREA - MOLYCORP, INC. - QUESTA, NEW MEXICO

Sample ID	Ferrous Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Zinc (mg/L)	Copper (mg/L)	Molybdenum (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Silica (mg/L)	Chlorine (mg/L)	Cadmium (mg/L)	Sulfate (mg/L)
RR-6		0.003	0.080	0.034	0.02	<.02	2.3	<1.0	16.6	2.4	14	5	<.005	17.7
RR-7		0.004	0.080	0.030	0.02	<.02	2.8	<1.0	20	3.1	16	5	<.005	15.9
RR-8		0.004	0.082	0.027	0.02	<.02	2.8	<1.0	19.1	3	24	4.5	<.005	19.5
RR-9		0.003	0.064	0.202	0.01	<.02	2.6	<1.0	18.6	3.4	14	5	<.005	14.5
RR-10		0.004	0.109	0.018	0.02	<.02	2.9	<1.0	20.4	3.9	17	5	<.005	17.4
RR-11		0.004	0.048	<.005	0.02	<.02	2.6	<1.0	18.5	3.3	20	4	<.005	11.4
RR-12		0.004	0.126	0.042	0.018	<.02	3	<1.0	21.4	4.6	64	2.5	<.005	33.6
RR-13		0.004	0.078	0.031	0.016	<.02	2.9	<1.0	21	4.4	18	3	<.005	23.5
RR-14		0.006	0.242	0.067	0.02	<.02	3	1	23	5	18	3	0.007	29.7
RR-15		0.004	0.213	0.062	0.018	<.02	3	<1.0	22.8	4.9	20	3.5	<.005	34.7
RR-16		0.014	0.290	0.073	0.024	<.02	2.7	<1.0	22.1	4.5	14	6.5	<.005	28.9
SGS-1		<.002	0.252	0.099	0.01	0.19	17.6	4	119	17.7	24	22.5	<.005	160
SSC-1		0.026	12.300	2.920	0.213	0.88	58.7	5.3	298	13.5	30	72.5	0.02	679.8

TABLE 4
MINE SITE MONITOR WELL GROUND WATER ELEVATIONS
(FROM MOLYCORP)

MOLYCORP, INC. - QUESTA DIVISION
MMW WATER ELEVATIONS

WELL	REFERENCE ELEVATION	H20 ELEV 2/22/96	H20 ELEV 3/13/96	H20 ELEV 4/18/96	H20 ELEV 5/23/96	H20 ELEV 6/21/96	H20 ELEV 7/25/96	H20 ELEV 8/21/96	H20 ELEV 9/20/96	H20 ELEV 1/27/97	H20 ELEV 2/17/97	H20 ELEV 3/7/97	H20 ELEV 3/31/97	H20 ELEV 4/26/97	H20 ELEV 5/21/97	H20 ELEV 6/25/97	H20 ELEV 7/22/97	H20 ELEV 8/20/97
MMW-2	7700.05	7665.59	7665.60	7665.47	7665.10	7665.52	7665.10	7665.52	7665.73	7665.41	7665.49		7665.95	7665.88	7665.92	7665.26	7665.04	7665.28
MMW-3	7701.07	7669.10	7669.14	7669.10	7668.69	7669.08	7668.69	7669.08	7669.17	7668.79	7668.89		7669.44	7669.24	7669.36	7668.78	7668.50	7668.72
MMW-7	8090.16	8028.41	8028.58	8028.80	8028.26	8029.00	8029.00	8028.26	8028.69	8028.71	8028.59		8028.46	8028.59	8028.74	8028.58	8028.46	8028.66
MMW-8A	7858.22	7761.69	7761.8	7761.77	7762.06	7762.60	7762.06	7762.60	7762.77	7762.07	7761.80		7761.99	7761.41	7762.56	7762.62	7762.05	7761.91
MMW-8B	7859.47	7763.73	7763.84	7763.87	7764.14	7764.51	7764.14	7764.51	7764.63	7763.76	7763.57		7763.75	7764.14	7764.53	7764.72	7763.52	7763.88
MMW-10A	7939.33	7917.58	7917.37	7917.36	7918.19	7917.55	7918.19	7917.55	7916.64	7911.40	7909.49	7907.48	7907.17	7906.45	7907.87	7915.41	7916.10	7914.09
MMW-10B	7939.20	7917.52	7917.32	7917.31	7918.05	7917.53	7918.05	7917.53	7916.57	7911.25	7909.32	7907.26	7906.9	7905.85	7905.60	7915.20	7916.00	7913.90
MMW-10C	7939.44	7917.18	7916.99	7916.99	7917.75	7917.23	7917.75	7917.23	7916.31	7911.29	7909.48	7907.47	7907.1	7906.29	7907.72	7914.94	7915.99	7914.00
MMW-11	8004.93	7917.50	7915.3	7915.28	7916.11	7915.57	7916.11	7915.57	7914.64	7909.74	7908.07	7906.09	7905.61	7904.77	7906.05	7913.82	7914.43	7912.50
MMW-13	8072.45	7963.75	7963.32	7963.25	7965.05	7965.19	7965.05	7965.19	7961.17	7947.13	7945.30	7942.75	7941.86	7941.35	7942.41	7954.32	7956.64	7953.50
MMW-14	8166.50	0	0				0	0	0	8106.14	8106.28	8106.28	8106.28	8106.25	8106.27	8106.27	8106.28	8106.27
MMW-16	8139.66	8057.03	8056.86	8056.66	8057.32	8056.05	8057.32	8056.05	8053.86	8053.33	8053.24	DRY	DRY	MUD	MUD	MUD	MUD	MUD
P-1	7827.08										7805.43		7804.46	7805.08		7804.08	7806.80	7807.56
P-2	7822.34										7806.24		7805.56	7805.88		7804.99	7807.34	7807.95
P-3	7842.71										7811.46		7810.86	7811.44		7816.15	7813.77	7813.78
P-4A	7834.36										7810.72		7810.23	7810.41		7814.36	7812.21	7812.45
P-4B	7834										7809.89		7809.27	7809.74		7813.89	7811.58	7811.85
P-5A	7840.37										7872.07		7818.86	7819.68		7823.82	7822.07	7821.43
P-5B	7840.18										7817.68		7817.65	7818.28		7821.83	7820.08	7819.69
P-5C	7840.29										7816.19		7816.26	7816.79		7819.66	7818.17	7817.83

TABLE 5

1994 MONITOR WELL WATER QUALITY DATA FOR MINE AREA

MOLYCORP, INC. - QUESTA, NEW MEXICO

(TAKEN FROM SOUTH PASS RESOURCES, April 21, 1995)

MONITOR WELL	SAMPLE DATE 1994	WELL TD (feet)	Corrected DEPTH TO WATER (feet)	DEPTH TO PUMP INTAKE (feet)	pH (1)	CONDUC-TIVITY(1) (uhmos)	TEMP.(1) (°C)	CARBO -NATE (mg/L)	BICARBO -NATE (mg/L)	HYDR-OXIDE (mg/L)	TOTAL ALK (mg/L)	CHLORIDE (mg/L)	FLUORIDE (mg/L)	SULFATE (mg/L)
MMW-2	8-Nov	68	31.69	50	4.90	3,680	7.9	<1	<1	<1	<1	6.8	24.0	2,100
MMW-3	7-Nov	140	27.76	80	7.50	3,970	10.9	<1	222	<1	222	5.8	2.59	1,700
MMW-7	7-Nov	161	61.11	120	4.40	9,490	17.2	<1	<1	<1	<1	21	1.12	10,400
DUP-11A (2)	7-Nov	NA	NA	NA	NA	NA	NA	<1	<1	<1	<1	21	0.98	10,500
MMW-8A	8-Nov	178	96.77	140	7.00	2,860	8.4	<1	165	<1	165	8.7	2.72	1,300
MMW-8B	8-Nov	129	96.03	112	6.40	1,780	7.1	<1	19	<1	19	5.6	1.83	730
MMW-10A	8-Nov	144	21.70	100	5.80	2,400	7.8	<1	<1	<1	<1	27	11.2	1,100
DUP-12B (3)	8-Nov	NA	NA	NA	NA	NA	NA	<1	<1	<1	<1	26	7.96	1,100
MMW-10A (4)	19-Nov	NA	NA	NA	NA	NA	NA	<1	<1	<1	<1	26	8.28	1,200
MMW-10B	7-Nov	189	21.57	140	7.90	2,250	10.1	10	<1	66	76	28	12.2	1,100
MMW-10C	8-Nov	50	21.80	40	4.70	2,000	11.8	<1	<1	<1	<1	20	15.4	880
MMW-11	7-Nov	184	86.71	150	5.60	2,450	15.7	<1	<1	<1	<1	22	17.6	1,300
MMW-13	8-Nov	145	105.98	130	7.90	2,280	8.9	<1	200	<1	200	14	1.67	770

NOTES:

(1) pH, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

(2) - Dup 11A = DUPLICATE SAMPLE FOR MMW-7

(3) - Dup 12B = DUPLICATE SAMPLE FOR MMW-10A

(4) - SAMPLED AFTER AQUIFER TEST

NA - Not Available

SOURCE: SAMPLES TAKEN BY SPRI, ANALYTICAL RESULTS FROM MOLYCORP.

TABLE 5

1994 MONITOR WELL WATER QUALITY DATA FOR MINE AREA

MOLYCORP, INC. - QUESTA, NEW MEXICO

MONITOR WELL	TDS (mg/L)	SILVER (mg/L)	ALUMINUM (mg/L)	ARSENIC (mg/L)	BARIUM (mg/L)	BERYLLIUM (mg/L)	CALCIUM (mg/L)	CADMIUM (mg/L)	COBALT (mg/L)	CHROMIUM (mg/L)	COPPER (mg/L)	IRON (mg/L)	MERCURY (mg/L)
MMW-2	3,400	<0.10	63.5	<0.005	<0.010	0.015	501	0.024	0.280	<0.010	0.088	50.8	<0.0002
MMW-3	2,900	<0.10	0.75	<0.005	0.047	<0.004	567	0.0024	0.089	<0.010	<0.010	0.076	<0.0002
MMW-7	16,000	<0.50	943	<0.05	0.108	0.104	544	0.096	4.91	0.193	4.84	384	<0.0002
DUP-11A (2)	16,000	<0.50	961	<0.05	0.074	0.122	534	0.092	4.99	0.17	5.04	375	<0.0002
MMW-8A	2,200	<0.10	<0.05	<0.005	0.103	<0.004	466	0.002	<0.010	<0.010	<0.010	2.84	<0.0002
MMW-8B	1,100	<0.10	0.44	<0.005	0.016	<0.004	206	<0.0005	<0.010	<0.010	<0.010	<0.050	<0.0002
MMW-10A	1,700	<0.10	33.4	<0.005	<0.010	0.008	275	0.028	0.148	<0.010	0.558	<0.050	<0.0002
DUP-12B (3)	1,700	<0.10	34.2	<0.005	<0.010	0.008	270	0.024	0.137	<0.010	0.58	<0.050	<0.0002
MMW-10A (4)	1,700	<0.010	31.6	<0.005	<0.010	0.006	245	0.0224	0.141	<0.010	0.534	0.086	<0.0002
MMW-10B	1,800	<0.10	8.74	<0.005	0.034	0.007	347	0.025	0.074	<0.010	0.179	0.101	<0.0002
MMW-10C	1,400	<0.10	31.1	<0.005	0.014	0.007	204	0.026	0.106	<0.010	0.38	<0.050	<0.0002
MMW-11	2,000	<0.10	56.3	<0.005	0.016	0.013	276	0.036	0.266	0.036	0.919	0.129	<0.0002
MMW-13	1,400	<0.10	<0.05	<0.005	0.036	<0.004	316	<0.0005	0.013	<0.010	<0.010	0.198	<0.0002

NOTES:

(1) pH, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

(2) - Dup 11A = DUPLICATE SAMPLE FOR MMW-7

(3) - Dup 12B = DUPLICATE SAMPLE FOR MMW-10A

(4) - SAMPLED AFTER PUMP TEST

SOURCE: SAMPLES TAKEN BY SPRI, *ANALYTICAL RESULTS FROM MOLYCORP.*

TABLE 5

1994 MONITOR WELL WATER QUALITY DATA FOR MINE AREA

MOLYCORP, INC. - QUESTA, NEW MEXICO

MONITOR WELL	POTASSIUM (mg/L)	MAGNESIUM (mg/L)	MANGANESE (mg/L)	MOLYBDENUM (mg/L)	SODIUM (mg/L)	NICKEL (mg/L)	LEAD (mg/L)	ANTIMONY (mg/L)	SELENIUM (mg/L)	SILICON (mg/L)	THALLIUM (mg/L)	VANADIUM (mg/L)	ZINC (mg/L)
MMW-2	10.8	137	52.1	<0.02	64.6	0.61	<0.002	<0.05	<0.05	20.3	<0.005	<0.010	9.48
MMW-3	7.5	96.2	34.5	<0.02	103	0.236	<0.002	<0.05	<0.005	7.6	<0.005	<0.010	1.36
MMW-7	12.0	1250	72.1	<0.10	175	10.5	0.10	<0.25	<0.025	22.7	<0.005	0.104	11.7
DUP-11A (2)	12.1	1230	73.3	<0.10	178	10.7	0.06	<0.25	<0.025	22.6	<0.005	0.106	11.9
MMW-8A	3.8	85.6	7.15	<0.02	41.5	<0.020	<0.002	<0.05	<0.005	11.1	<0.005	<0.010	<0.050
MMW-8B	2.9	55.5	0.202	<0.02	33.9	0.059	<0.002	<0.05	<0.005	17.3	<0.005	<0.010	0.211
MMW-10A	2.8	77.9	13.8	<0.02	26.5	0.325	<0.002	<0.05	<0.005	14.3	<0.005	<0.010	2.29
DUP-12B (3)	2.5	76.7	12.8	<0.02	26.4	0.293	<0.002	<0.05	<0.005	14.0	<0.005	<0.010	2.07
MMW-10A (4)	3.7	69.7	13.1	<0.02	25.6	0.279	0.004	<0.05	<0.005	14.1	<0.005	<0.010	2.68
MMW-10B	3.5	80.3	8.55	<0.02	25.8	0.201	0.021	<0.05	<0.05	12.8	<0.005	<0.010	1.5
MMW-10C	2.8	75.2	16.3	<0.02	20.2	0.0347	<0.002	<0.05	<0.005	9.9	<0.005	<0.010	3.2
MMW-11	3.4	133	31.7	<0.02	25.5	0.593	0.086	<0.05	<0.005	14.2	<0.005	<0.010	5.0
MMW-13	5.4	38.7	1.02	0.05	30	<0.020	<0.002	<0.05	<0.005	8.8	<0.005	<0.010	0.222

NOTES:

(1) Ph, CONDUCTIVITY AND TEMPERATURE WERE RECORDED WHEN SAMPLED.

(2) - Dup 11A = DUPLICATE SAMPLE FOR MMW-7

(3) - Dup 12B = DUPLICATE SAMPLE FOR MMW-10A

(4) - SAMPLED AFTER PUMP TEST

SOURCE: SAMPLES TAKEN BY SPRI, ANALYTICAL RESULTS FROM MOLYCORP.

FIGURES

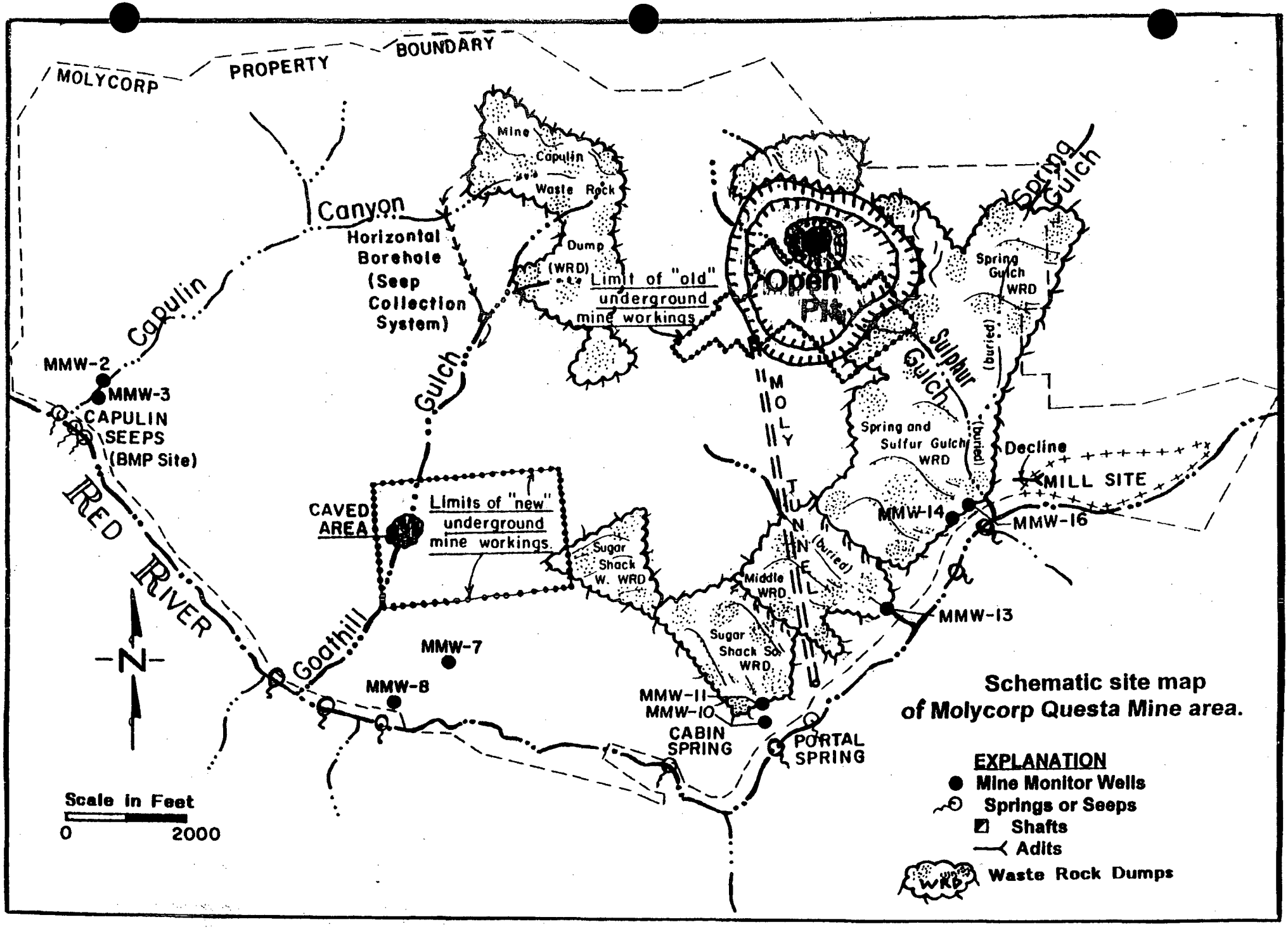
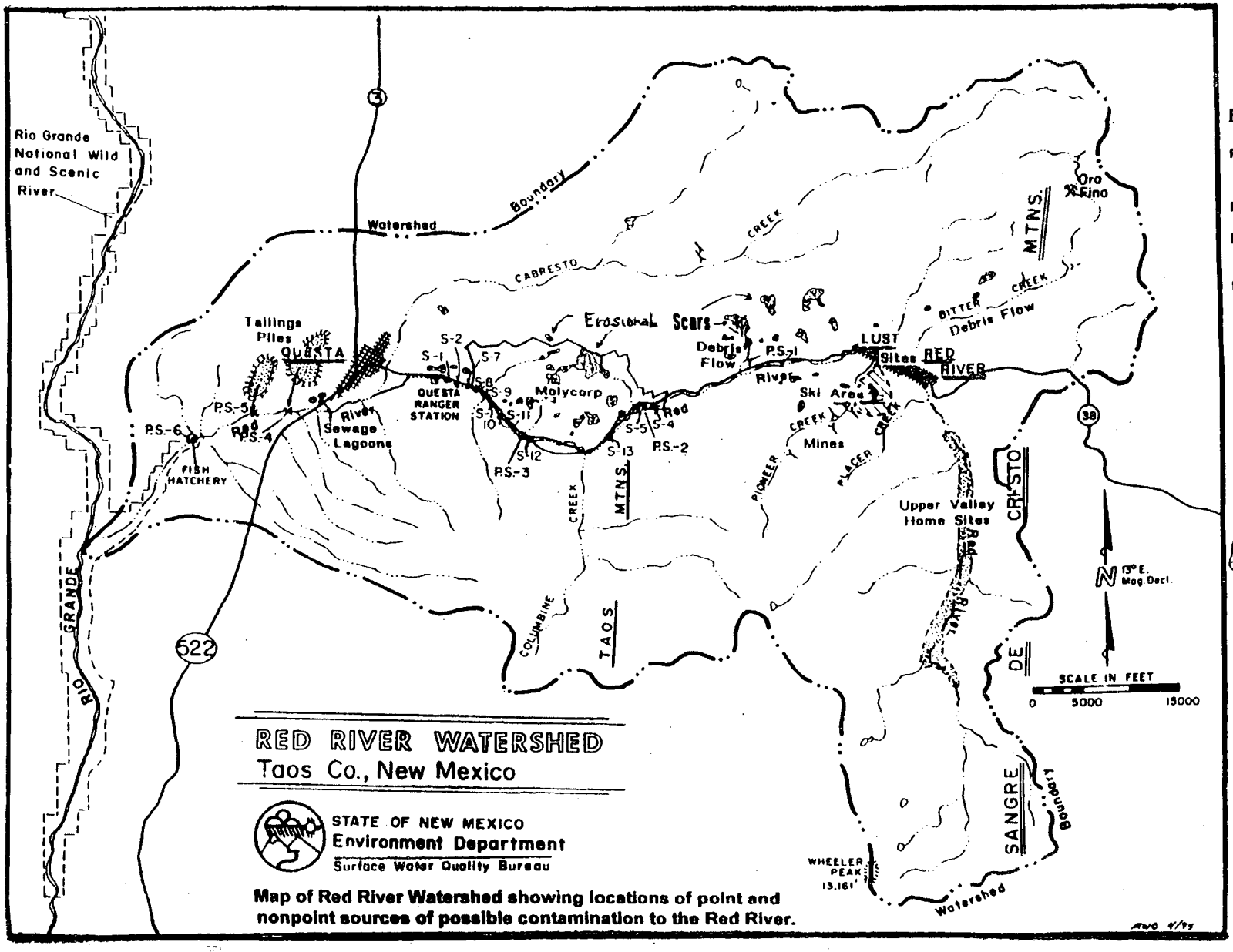


FIGURE 1

(MODIFIED FROM NMED, March 1996)

FIGURE 2

(MODIFIED FROM NMED, March 1996)



Map of Red River Watershed showing locations of point and nonpoint sources of possible contamination to the Red River.

EXPLANATION

POINT SOURCE POLLUTION:

PS-1: Town of Red River Wastewater Treatment Plant

PS-2: Molycorp Mill Site Outfall #005

PS-3: Molycorp Mine, Goathill Gulch Outfall #004

PS-4: Molycorp East Tailings Pile Outfall #002

PS-5: Molycorp Pope Lake/W.Tailings Outfall #001

PS-6: Red River Fish Hatchery (NMDG&F)

NONPOINT SOURCE POLLUTION:

S-1 to S-13: Red River Groundwater Seeps (ARD)

Hydrothermally Altered Volcanic Rock Scars

Molycorp Mine

Scattered Abandoned Mine and Mill Sites (Esp. Pioneer and Bitter Creeks)

Upper RR Valley Home Sites: septic tanks, leach fields

Town of Red River: Leaking Underground Storage Tanks (LUST)

Red River Ski Area

Town of Questa Sewage Lagoons

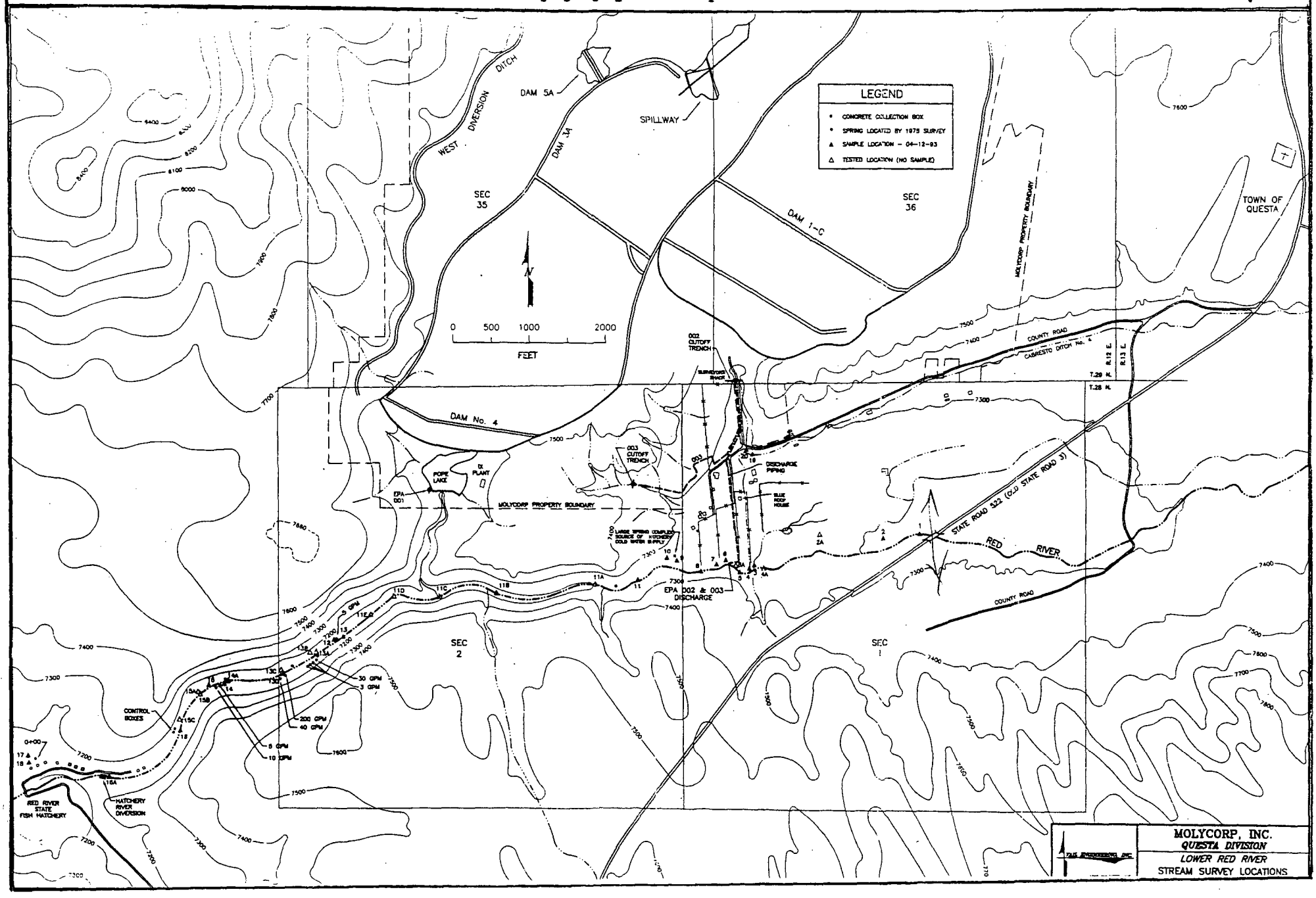
Landslide/ Debris Flow Gravels and Sediment (Bitter, Hansen and Hotentot Creeks)

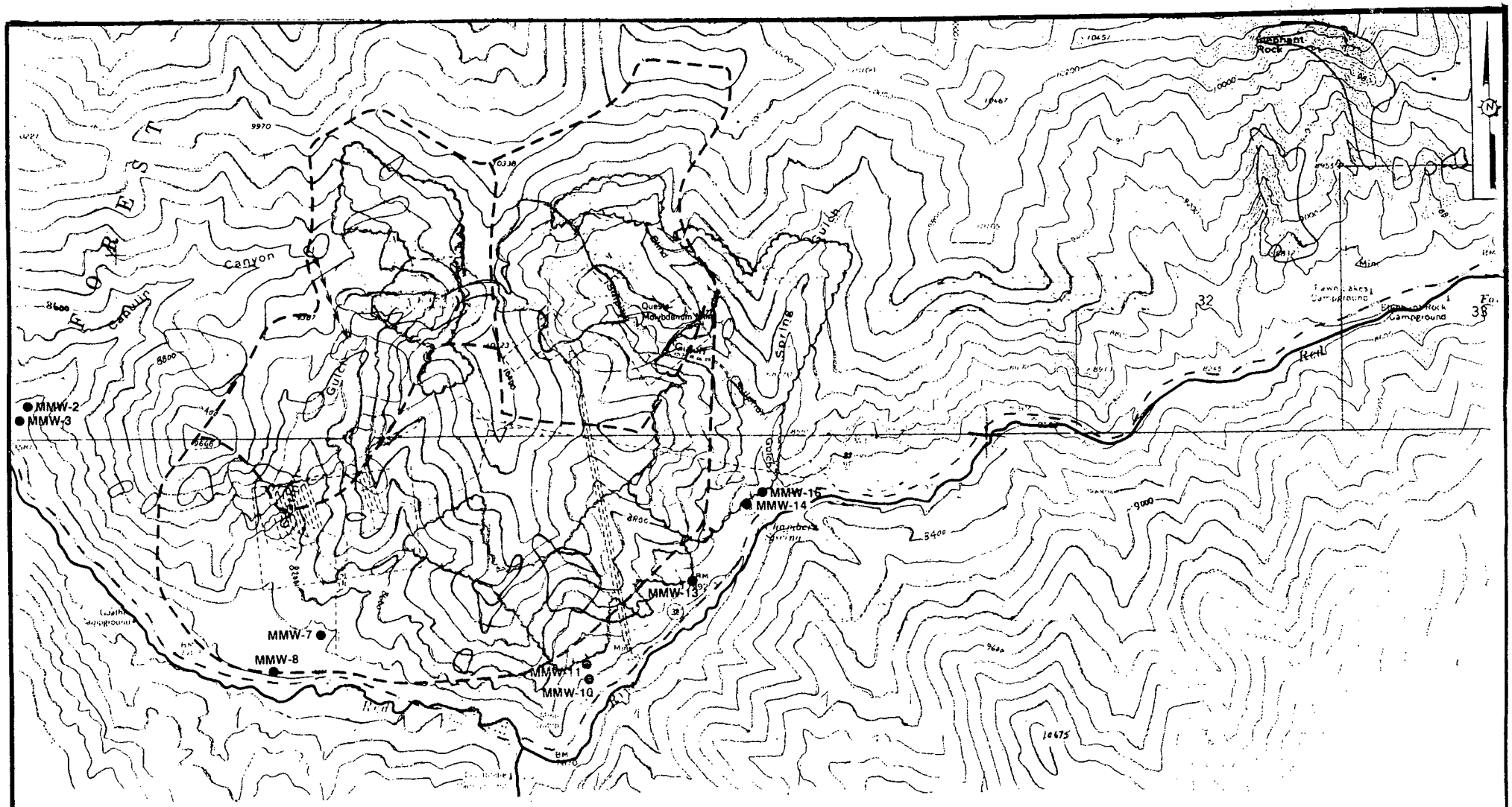
FIGURE 3

TAILINGS PONDS

Topography and Sample Locations

(TAKEN FROM VAIL, October 1994)





(MODIFIED FROM NMED, March 1996)

Approximate Surface Water Collection System Boundary

SCAR AREAS (SRK, 1995)

OVERBURDEN DISPOSAL PILES (SRK, 1995)

0 2000 4000 FEET

SCALE

REFERENCE U.S.G.S. TOPOGRAPHIC MAPS OF QUESTA AND RED RIVER, NEW MEXICO DATED 1963.

FIGURE 4

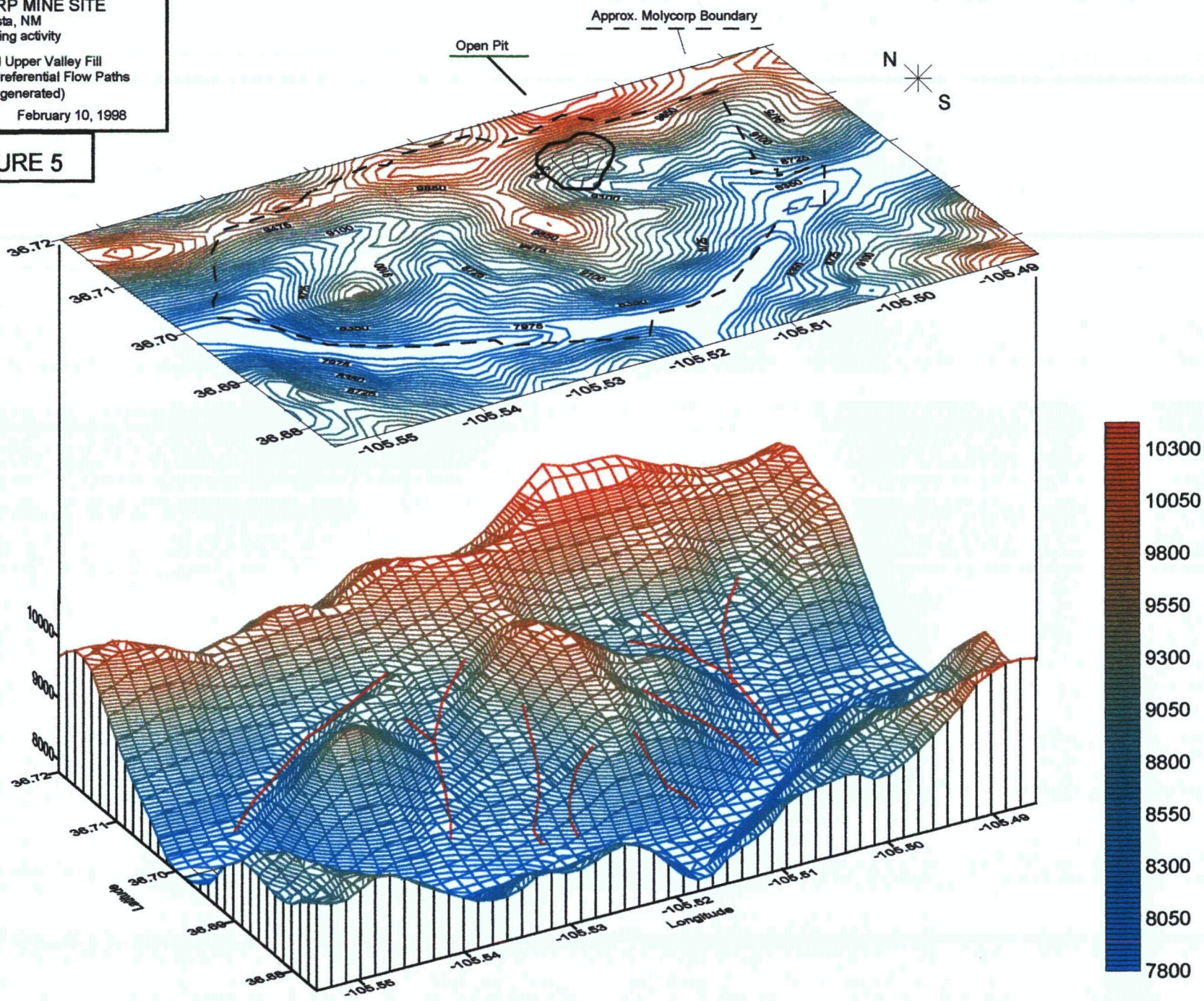
MINE SITE TOPOGRAPHY
Erosional Scars and WRDs

MOLYCORP MINE SITE
Questa, NM
Pre-mining activity

Surface and Upper Valley Fill
Groundwater Preferential Flow Paths
(Surfer generated)

USEPA February 10, 1998

FIGURE 5



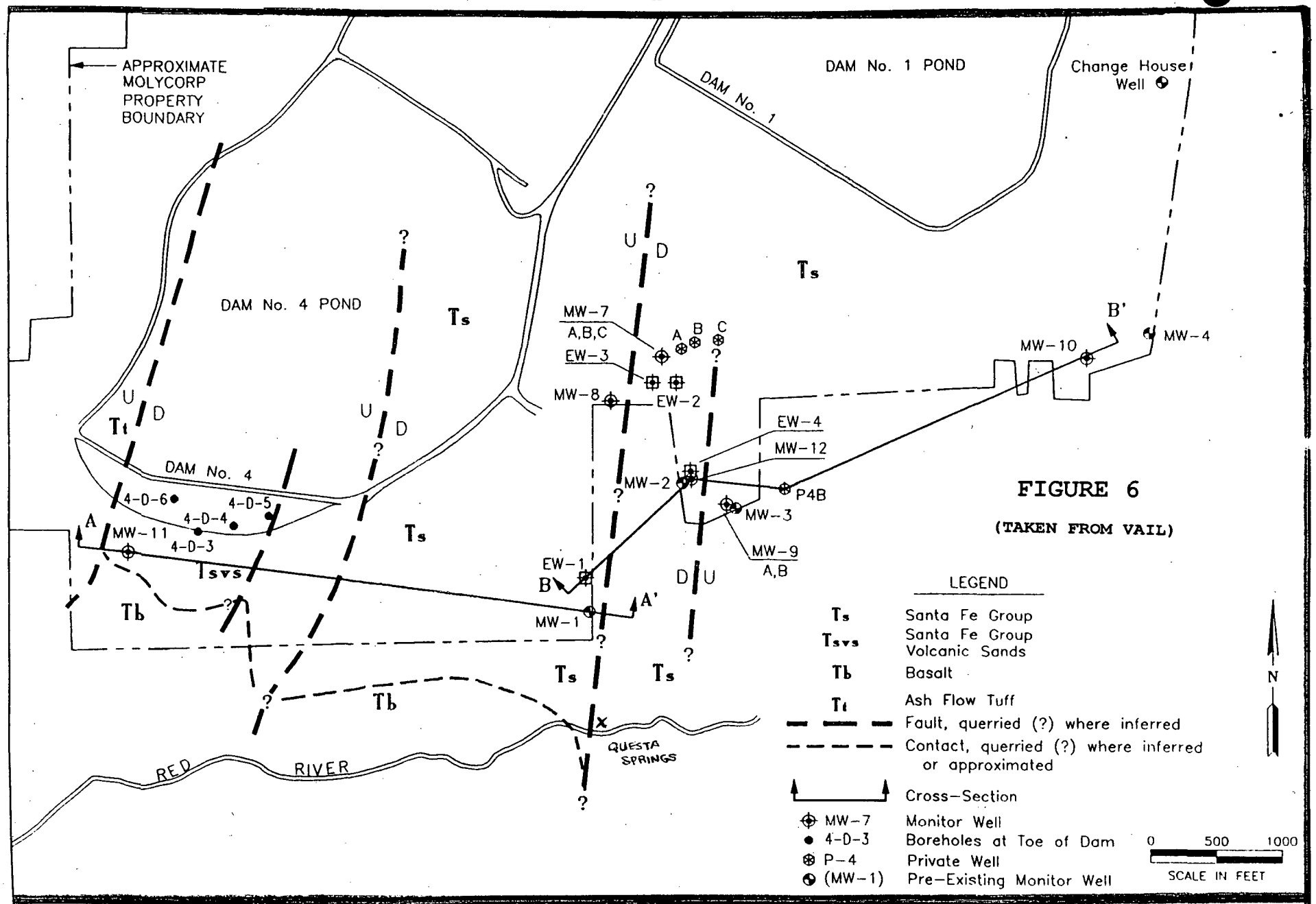


FIGURE:

SOUTH PASS RESOURCES, Inc.

PROJECT No:	DATE:	AUTHOR:	DRAWN BY:
001-06	3/31/95		M.O'M.

GEOLOGIC MAP – TAILINGS AREA
Molycorp, Inc.
Questa, New Mexico

XSEC-15

UPPER PORTION OF UAU AT DAM No. 1

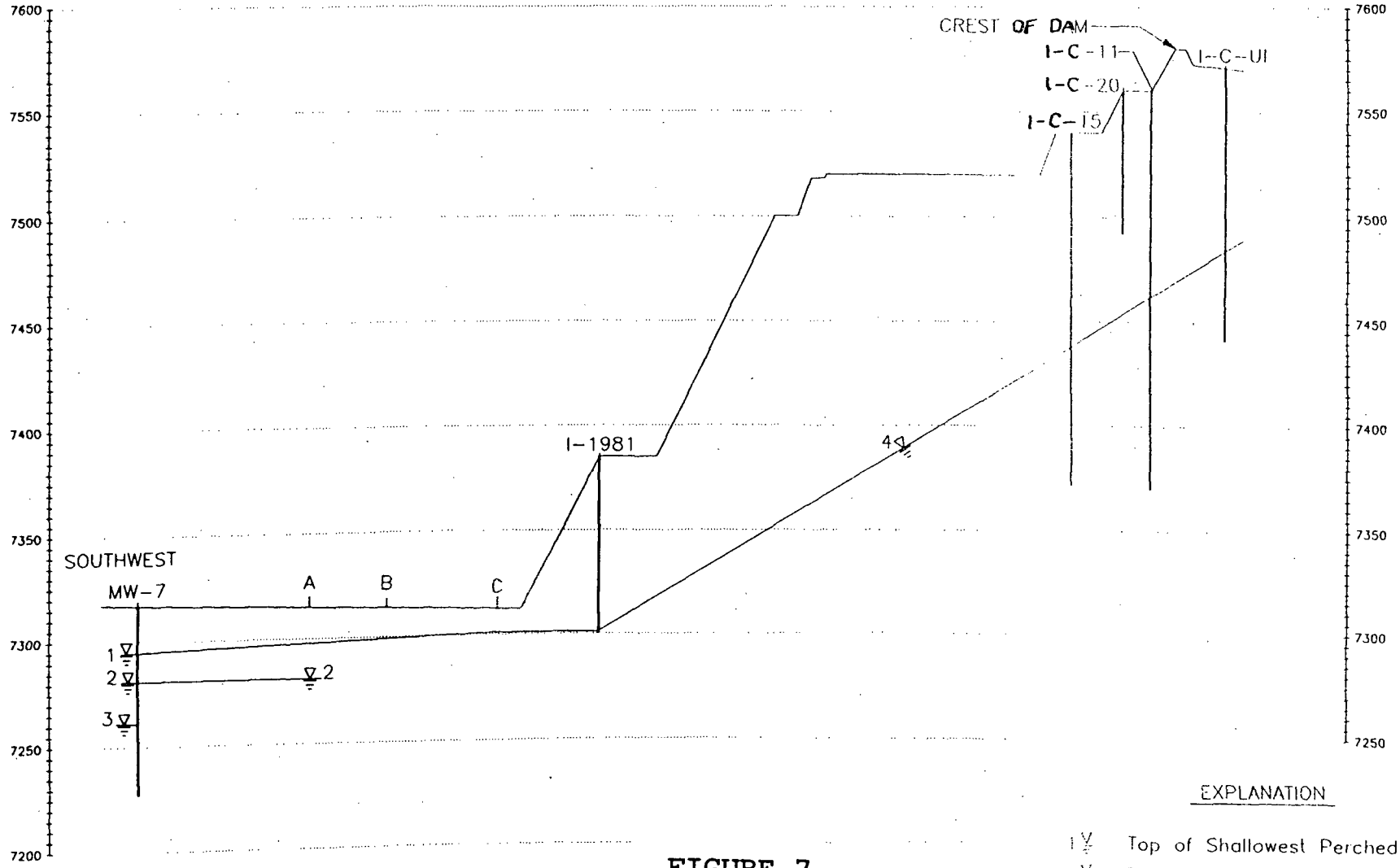


FIGURE 7

0 37.5 75
VERTICAL SCALE IN FEET

0 150 300
HORIZONTAL SCALE IN FEET

(TAKEN FROM SOUTH PASS RESOURCES, April 13, 1995)

EXPLANATION

1	Top of Shallowest Perched Zone
2	Top of Intermediate Perched Zone
3	Top of Main Perched Zone
4	Water Level in Tailings Dam
A,B,C	Piezometers projected into line of section

FIGURE:

SOUTH PASS RESOURCES, Inc.

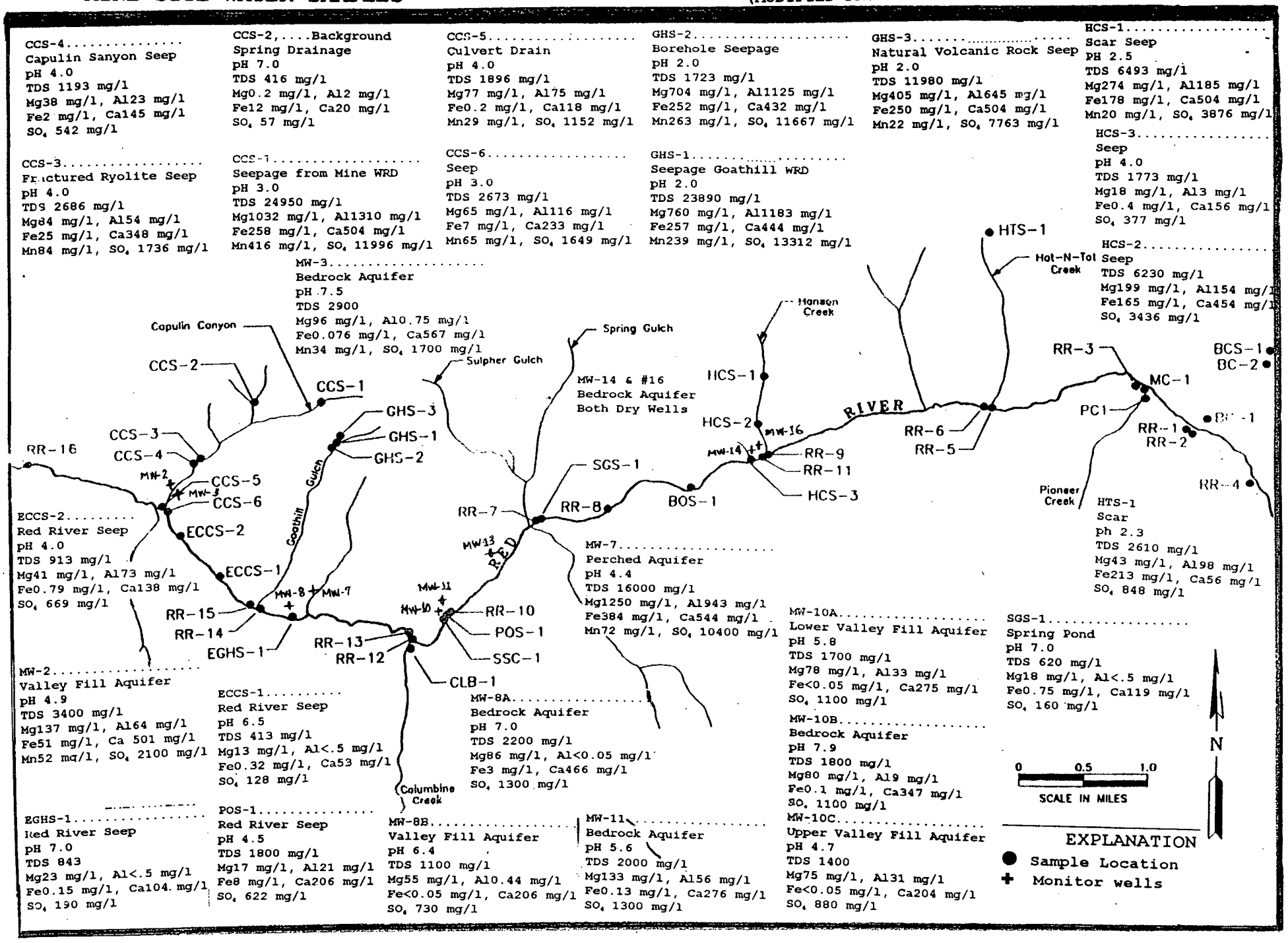
PROJECT No.:	DATE:	AUTHOR:	DRAWN BY:
001-06	3/31/95		M.O'M.

WATER LEVELS FOR PERCHED ZONES (APRIL 1993)
Tailings Area – Molycorp, Inc.
Questa, New Mexico

MINE SITE WATER SAMPLES

FIGURE 8

(MODIFIED FROM SOUTH PASS RESOURCES, April 21, 1995)



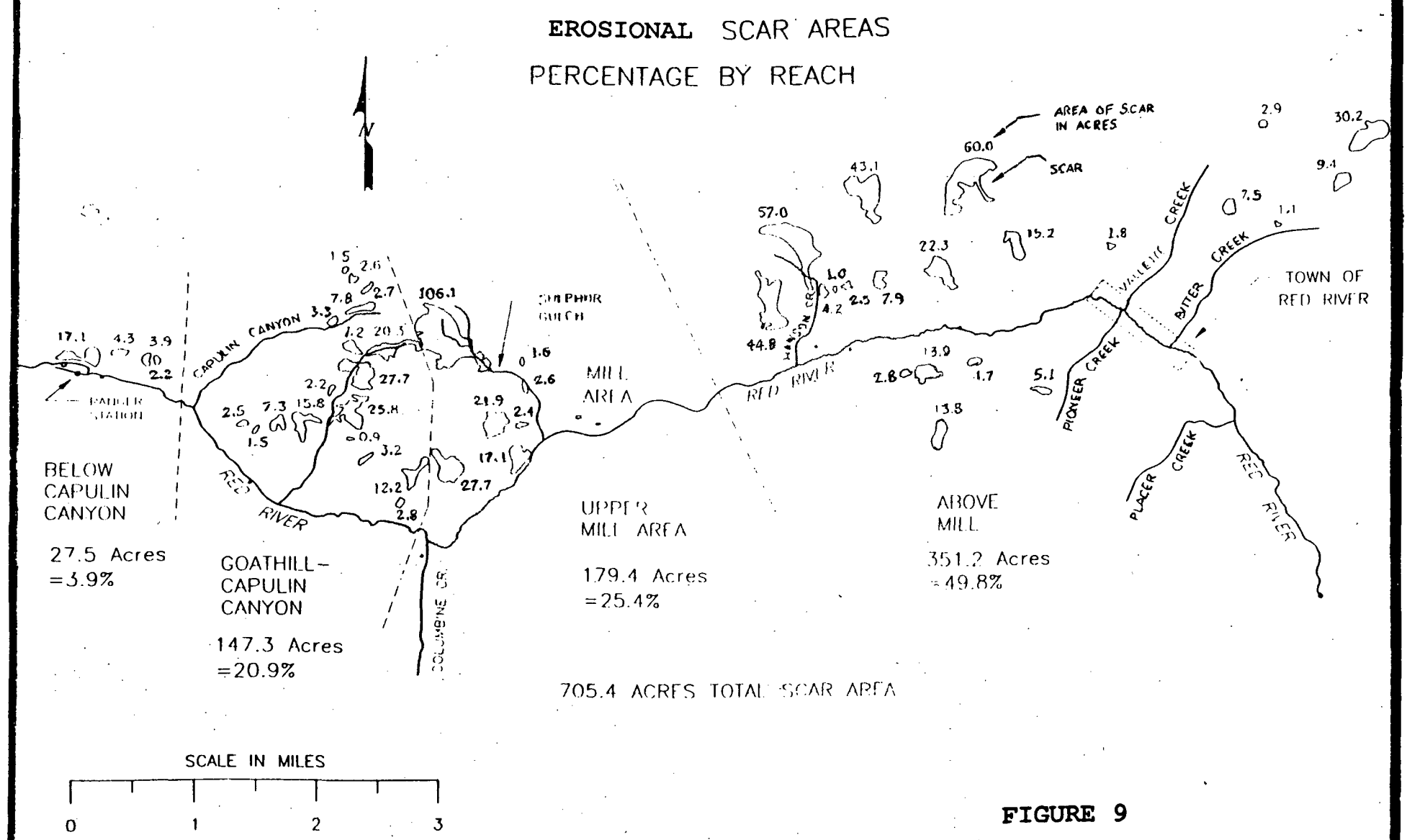


FIGURE 9

EROSIONAL SCAR AREAS

(MODIFIED FROM VAIL, July 9, 1993)

APPENDIX 1

APPENDIX 1

Appendix 1 is an excerpt from the State of New Mexico Standards for Interstate and Intrastate Streams [effective January 23, 1995].

B. Standards:

1. In any single sample: conductivity shall not exceed 300 μmhos, pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20 C (68 F), and turbidity shall not exceed 10 NTU. The use-specific numeric standards set forth in Section 3101 are applicable to the designated uses listed above in Section 2118.A.

2. The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see Section 1103.B).

2119. The main stem of the Rio Grande from Taos Junction Bridge upstream to the New Mexico-Colorado line, the Red River from its mouth on the Rio Grande upstream to the mouth of Placer Creek, and the Rio Pueblo de Taos from its mouth on the Rio Grande upstream to the mouth of the Rio Grande del Rancho.

A. Designated Uses: coldwater fishery, fish culture, irrigation, livestock watering, wildlife habitat, and secondary contact.

B. Standards:

1. In any single sample: pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20 C (68 F), and turbidity shall not exceed 50 NTU. The use-specific numeric standards set forth in Section 3101 are applicable to the designated uses listed above in Section 2119.A.

2. The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see Section 1103.B).

2120. The Red River upstream of the mouth of Placer Creek, all tributaries to the Red River, and all other perennial reaches of tributaries to the Rio Grande in Taos and Rio Arriba counties unless included in other segments.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater fishery, irrigation, livestock watering, wildlife habitat, and secondary contact.

B. Standards:

1. In any single sample: conductivity shall not exceed 400 μmhos (500 μmhos for the Rio Fernando de Taos), pH shall be within the range of 6.6 to 8.8, temperature shall not exceed 20 C (68 F), and turbidity shall not exceed 25 NTU. The use-specific numeric standards set forth in Section 3101 are applicable to the designated uses listed above in Section 2120.A.

2. The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 ml; no single sample shall exceed 200/100 ml (see Section 1103.B).

2200. PECOS RIVER BASIN.

2201. The main stem of the Pecos River from the New Mexico-Texas line upstream to the mouth of the Black River.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact, and warmwater fishery.

B. Standards:

1. In any single sample: pH shall be within the range of 6.6 to 8.8 and temperature shall not exceed 32.2 C (90 F). The use-specific numeric standards set forth in Section 3101 are applicable to the designated uses listed above in Section 2201.A.

2. The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see Section 1103.B).

3. At all flows above 50 cfs: TDS shall not exceed 20,000 mg/l, sulfate shall not exceed 3,000 mg/l, and chloride shall not exceed 10,000 mg/l.

2202. The main stem of the Pecos River from the mouth of the Black River upstream to Lower Tansil Dam,[1] including the Black River, the Delaware River and Blue Spring.

A. Designated Uses: industrial water supply, irrigation, livestock watering, wildlife habitat, secondary contact, and warmwater fishery.

B. Standards:

1. In any single sample: pH shall be within the range of 6.6 to 9.0, and temperature shall not exceed 34 C (93.2 F). The use-specific numeric standards set forth in Section 3101 are applicable to the designated uses listed above in Section 2202.A.

2. The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 ml; no single sample shall exceed 400/100 ml (see Section 1103.B).

3. At all flows above 50 cfs: TDS shall not exceed 8,500 mg/l, sulfate shall not exceed 2,500 mg/l, and chloride shall not exceed 3,500 mg/l.

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[1]Diversion for irrigation frequently limits summer flow in this reach to that contributed by springs along the watercourse.

3101. STANDARDS[1] APPLICABLE TO ATTAINABLE OR DESIGNATED USES UNLESS OTHERWISE SPECIFIED IN SUBPART II OF THESE STANDARDS (SECTIONS 2100 through 2805).

A. Coldwater Fishery: Dissolved oxygen shall not be less than 6.0 mg/l, temperature shall not exceed 20 C (68 F), and pH shall be within the range of 6.6 to 8.8. The acute and chronic standards set out in Section 3101.J are applicable to this use. The total ammonia standards set out in Section 3101.N are applicable to this use.

B. Domestic Water Supply: Waters designated for use as domestic water supplies shall not contain substances in concentrations that create a lifetime cancer risk of more than one cancer per 100,000 exposed persons. The following numeric standards shall not be exceeded:

Dissolved arsenic	0.05	mg/l
Dissolved barium	1.	mg/l
Dissolved cadmium	0.010	mg/l
Dissolved chromium	0.05	mg/l
Dissolved lead	0.05	mg/l
Total mercury	0.002	mg/l
Dissolved nitrate (as N)	10.	mg/l
Dissolved selenium	0.05	mg/l
Dissolved silver	0.05	mg/l
Dissolved cyanide	0.2	mg/l
Dissolved uranium	5.0	mg/l
Radium-226 + radium-228	30.0	pCi/l
Tritium	20,000	pCi/l
Gross alpha	15	pCi/l

C. High Quality Coldwater Fishery: Dissolved oxygen shall not be less than 6.0 mg/l, temperature shall not exceed 20 C (68 F), pH shall be within the range of 6.6 to 8.8, total phosphorus (as P) shall not exceed 0.1 mg/l, total organic carbon shall not exceed 7 mg/l, turbidity shall not exceed 10 NTU (25 NTU in certain reaches where natural background prevents attainment of lower turbidity), and conductivity (at 25 C) shall not exceed a limit varying between 300 μmhos/cm and 1,500 μmhos/cm depending on the natural background in particular stream reaches (the intent of this standard is to prevent excessive increases in dissolved solids which would result in changes in stream community structure). The acute and chronic standards set out in Section 3101.J are applicable to this use. The total ammonia standards set out in Section 3101.N are applicable to this use.

D. Irrigation: The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 ml; no single sample shall exceed 2,000/100 ml. The following numeric standards shall not be exceeded:

Dissolved aluminum	5.0	mg/l
Dissolved arsenic	0.10	mg/l
Dissolved boron	0.75	mg/l
Dissolved cadmium	0.01	mg/l
Dissolved chromium	0.10	mg/l
Dissolved cobalt	0.05	mg/l
Dissolved copper	0.20	mg/l
Dissolved lead	5.0	mg/l
Dissolved molybdenum	1.0	mg/l
Dissolved selenium	0.13	mg/l
Dissolved selenium in presence of >500 mg/l SO_4	0.25	mg/l
Dissolved vanadium	0.1	mg/l
Dissolved zinc	2.0	mg/l

E. Limited Warmwater Fishery: Dissolved oxygen shall not be less than 5 mg/l, pH shall be within the range of 6.5 to 9.0, and on a case by case basis maximum temperatures may exceed 32.2 C. The acute and chronic standards set out in Section 3101.J are applicable to this use. The total ammonia standards set out in Section 3101.M are applicable to this use.

F. Marginal Coldwater Fishery: Dissolved oxygen shall not be less than 6 mg/l, on a case by case basis maximum temperatures may exceed 25 C and the pH may range from 6.6 to 9.0. The acute and chronic standards set out in Section 3101.J are applicable to this use. The total ammonia standards set out in Section 3101.N are applicable to this use.

G. Primary Contact: The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 ml, no single sample shall exceed 400/100 ml, pH shall be within the range of 6.6 to 8.8 and turbidity shall not exceed 25 NTU.

H. Warmwater Fishery: Dissolved oxygen shall not be less than 5 mg/l, temperature shall not exceed 32.2 C (90 F), and pH shall be within the range of 6.5 to 9.0. The acute and chronic standards set out in Section 3101.J are applicable to this use. The total ammonia standards set out in Section 3101.M are applicable to this use.

I. Fish culture, secondary contact, and municipal and industrial water supply and storage are also designated in particular stream reaches where these uses are actually being realized. However, no numeric standards apply uniquely to these uses. Water quality adequate for these uses is ensured by the general standards and numeric standards for bacterial quality, pH, and temperature which are established for all stream reaches listed in Subpart II of these standards (Sections 2100 through 2805).

J. The following schedule of numeric standards and equations for the substances listed shall apply to the subcategories of fisheries identified in Section 3101 of these standards:

1. Acute Standards[2]

Dissolved aluminum	750	µg/l
Dissolved beryllium	130	µg/l
Total mercury	2.4	µg/l
Total recoverable selenium	20.0	µg/l
Dissolved silver[4]	e(1.72[ln(hardness)]-6.52)	µg/l
Cyanide, amenable to chlorination	22.0	µg/l
Total chlordane	2.4	µg/l
Dissolved cadmium	e(1.128[ln(hardness)]-3.828)	µg/l
Dissolved chromium[5]	e(0.819[ln(hardness)]+3.688)	µg/l
Dissolved copper	e(0.9422[ln(hardness)]-1.464)	µg/l
Dissolved lead	e(1.273[ln(hardness)]-1.46)	µg/l
Dissolved nickel	e(0.8460[ln(hardness)]+3.3612)	µg/l
Dissolved zinc	e(0.8473[ln(hardness)]+0.8604)	µg/l
Total chlorine residual	19	µg/l

2. Chronic Standards[3]

Dissolved aluminum	87.0	µg/l
Dissolved beryllium	5.3	µg/l
Total mercury	0.012	µg/l
Total recoverable selenium	2.0	µg/l
Cyanide, amenable to chlorination	5.2	µg/l
Total chlordane	0.0043	µg/l
Dissolved cadmium[4]	e(0.7852[ln(hardness)]-3.49)	µg/l
Dissolved chromium[5]	e(0.819[ln(hardness)]+1.561)	µg/l
Dissolved copper	e(0.8545[ln(hardness)]-1.465)	µg/l
Dissolved lead	e(1.273[ln(hardness)]-4.705)	µg/l
Dissolved nickel	e(0.846[ln(hardness)]+1.1645)	µg/l
Dissolved zinc	e(0.8473[ln(hardness)]+0.7614)	µg/l
Total chlorine residual	11	µg/l

K. Livestock Watering: The following numeric standards shall not be exceeded:

Dissolved aluminum	5.0	mg/l
Dissolved arsenic	0.2	mg/l
Dissolved boron	5.0	mg/l
Dissolved cadmium	0.05	mg/l
Dissolved chromium[5]	1.0	mg/l
Dissolved cobalt	1.0	mg/l

Dissolved copper	0.5	mg/l
Dissolved lead	0.1	mg/l
Total mercury	0.01	mg/l
Dissolved selenium	0.05	mg/l
Dissolved vanadium	0.1	mg/l
Dissolved zinc	25.0	mg/l
Radium-226 + radium-228	30.0	pCi/l
Tritium	20,000	pCi/l
Gross alpha	15	pCi/l

L. Wildlife Habitat: The following narrative standard shall apply:

1. Except as provided below in Paragraph 2 of this section, no discharge shall contain any substance, including, but not limited to selenium, DDT, PCB's and dioxin, at a level which, when added to background concentrations, can lead to bioaccumulation to toxic levels in any animal species. In the absence of site-specific information, this requirement shall be interpreted as establishing a stream standard of 2 μg/l for total recoverable selenium and of 0.012 μg/l for total mercury.

2. The discharge of substances that bioaccumulate in excess of levels specified above in Paragraph 1, is allowed if, and only to the extent that, the substances are present in the intake waters which are diverted and utilized prior to discharge, and then only if the discharger utilizes best available treatment technology to reduce the amount of bioaccumulating substances which are discharged.

3. Discharges to waters which are designated for wildlife habitat uses, but not for fisheries uses, shall not contain levels of ammonia or chlorine in amounts which reduce biological productivity and/or species diversity to levels below those which occur naturally, and in no case shall contain chlorine in excess of 1 mg/l nor ammonia in excess of levels which can be accomplished through best reasonable operating practices at existing treatment facilities.

4. A discharge which contains any heavy metal at concentrations in excess of the concentrations set forth in Section 3101.J.1 of these standards shall not be permitted in an amount, measured by total mass, which exceeds by more than 5 percent the amount present in the intake waters which are diverted and utilized prior to the discharge, unless the discharger has taken steps (an approved program to require industrial pretreatment; or a corrosion program) appropriate to reduce influent concentrations to the extent practicable.

APPENDIX 2

APPENDIX 2

NEW MEXICO GROUND WATER STANDARDS AND U.S. EPA DRINKING WATER STANDARDS FOR ALUMINUM, MANGANESE, MOLYBDENUM, AND SULFATE

Christopher A. King
U.S. EPA Region 6 Ground Water/UIC Section
November, 1997

Currently there are no national ambient ground water quality standards. The United States Environmental Protection Agency (U.S. EPA) drinking water Maximum Contaminant Levels (MCL's) are frequently used as a reference by State and federal agencies when determining clean up levels for individual contaminated sites. The MCL's are for finished drinking water quality, not for raw water quality. States have the authority to develop their own ground water standards related to ambient water quality. Some State ground water standards are the same as U.S. EPA MCL's for finished drinking water. If a U.S. EPA primary or secondary MCL does not exist, a health advisory limit is often used. The State of New Mexico has developed ambient ground water standards for certain inorganic and organic contaminants. These standards represent the maximum allowable concentration of contaminants in the ground waters of New Mexico.

U.S. EPA Drinking Water Standards:

In March 1975 the U.S. EPA proposed the National Interim Primary Drinking Water Regulations under provisions of the Public Health Service Act as amended by the Safe Drinking Water Act. Based in part on Public Health Service regulations developed in 1946 and 1962 and later modified, the interim regulations became final in June 1977, but are continually under review. These federal regulations specify MCL's for finished drinking water supplies and apply to all public water systems. At the recommended maximum contaminant levels, no adverse health effects are known to exist.

MCL's were established for finished drinking water by the Safe Drinking Water Act in two different categories: primary and secondary. Primary MCL's are federally enforceable and based on health risk. The secondary MCL's represent reasonable goals for drinking water quality, but are not federally enforceable. Instead, states are encouraged to implement these standards. Contaminants covered by secondary MCL's are those which may adversely affect the aesthetic qualities of drinking water such as taste, odor, color, and appearance and which thereby may deter public acceptance of drinking water provided by public water systems. Contaminants found at concentrations considerably higher than the secondary MCL may also be associated with adverse health implications (Driscoll, 1989).

New Mexico Ground Water Standards:

Aluminum:

The State of New Mexico maximum allowable concentration for aluminum in ground water is 5.0 mg/l. The U.S. EPA currently does not have a primary MCL for aluminum in drinking water, but instead has a secondary MCL of 0.05 to 0.2 mg/l.

Manganese:

The State of New Mexico maximum allowable concentration for manganese in ground water is 0.2 mg/l. The U.S. EPA secondary MCL for manganese is 0.05 mg/l, in order to avoid manganese staining. Stains caused by manganese in plumbing fixtures and laundry are more objectionable and harder to remove than those from iron.

Molybdenum:

The State of New Mexico maximum allowable concentration for molybdenum in ground water is 1.0 mg/l. The U.S. EPA currently does not have a primary or secondary MCL for molybdenum in drinking water, but has issued a health advisory limit of 0.05 mg/l.

Sulfate:

The State of New Mexico maximum allowable concentration for sulfate in ground water is 600.0 mg/l. The U.S. EPA secondary MCL for sulfate is currently 250 mg/l, based upon the laxative effects of sulfate in high concentrations. The secondary MCL for sulfate is under debate, and the U.S. EPA has proposed a primary MCL of 500 mg/l (Federal Register, December 20, 1994).

Sulfate in ground water is derived principally from the evaporite minerals gypsum and anhydrite; it may also come from the oxidation of pyrite, which is an iron sulfide mineral. Ground water in igneous or metamorphic rocks generally contains less than 100 mg/l sulfate (Davis and DeWiest, 1966).

Table 1: Comparison of New Mexico Ground Water Standards and U.S. EPA's Drinking Water Standards for Finished Water Quality (note: concentrations in mg/l).

CONTAMINANT	New Mexico Standard for Ground Water	U.S. EPA Primary MCL	U.S. EPA Secondary MCL
Aluminum	5.0	none	0.05 - 0.2
Manganese	0.2	none	0.05
Molybdenum	1.0	none	none
Sulfate	600.0	none	250

References:

Davis, S.N., and DeWiest, R.J.M., 1966. Hydrogeology. John Wiley Sons, Inc., New York, NY, 463 p.

Driscoll, F.G., 1989. Ground Water and Wells, Second Edition. Johnson Filtration Systems, St. Paul, MN, pp. 99 - 109.

Fetter, C.W., 1993. Contaminant Hydrogeology. Macmillan Publishing, New York, NY, pp. 11 - 14.

New Mexico Quality Control Commission, December, 1995. State of New Mexico Ground and Surface Water Quality Protection Regulations (20 NMAC 6.2) and Utility Operator Certification Regulations (20 NMAC 7.4). pp. 23 - 25.

One Hundred Fourth Congress, United States of America, 1996. Safe Drinking Water Act Amendments of 1996, Section 109.

U.S. Environmental Protection Agency Region 6 Drinking Water Section, May 1997. Current and Proposed National Primary and Secondary Drinking Water Regulations & Health Advisories for Other Contaminants.

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FALL 1997 DATA ADDENDUM

RED RIVER AQUATIC BIOLOGICAL ASSESSMENT

FEBRUARY 1998

CHADWICK

ECOLOGICAL

CONSULTANTS, INC.

FALL 1997 DATA ADDENDUM

RED RIVER AQUATIC BIOLOGICAL ASSESSMENT

Prepared for:

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Questa, New Mexico

FEBRUARY 1998

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APPENDIX A - Benthic Invertebrate Data

INTRODUCTION

A previous report assessed the aquatic biological conditions in the Red River in the vicinity of the Molycorp, Inc. Questa Molybdenum Mine (Chadwick Ecological Consultants, Inc. 1997). That report evaluated the impact of the open pit mine and waste rock piles on the fish and benthic invertebrate populations of the Red River over a 30-year period. The conclusions of that report indicated that negative impacts to fish and benthic invertebrates in the Red River were likely caused by naturally occurring thermal scars downstream of the town of Red River. This pattern was evident during baseline (pre-1966) conditions and present (1995-1997) conditions. The open pit mine and waste rock piles did not appear to have measurably impacted the suitability of the Red River to support aquatic biota.

The purpose of this report is to briefly update the information in our previous report with additional fish and benthic invertebrate data collected in September 1997 by Chadwick Ecological Consultants, Inc (CEC). Also included in this report is a brief evaluation of fish data collected in August 1997 by the New Mexico Department of Game and Fish (NMDGF 1997). The most recent data are used to further evaluate the trends identified in the previous report, and to further evaluate the impact of the open pit mine and waste rock piles on the fish and benthic invertebrate populations of the Red River.

The approach and scope of our evaluation are described in detail in the previous report (CEC 1997) and are not repeated here. For the purpose of this addendum, present conditions refers to fish data collected in spring and fall 1997 by CEC and in August 1997 by NMDGF. Present benthic invertebrate conditions are described by data collected in September 1997 by CEC (presented in this report) and data collected in December 1995 by New Mexico Environmental Department (NMED) personnel, and analyzed for Molycorp by Woodward-Clyde (1996).

Baseline conditions refer to the period prior to 1966. This includes fish data collected in 1960 by NMDGF (NMDGF 1960) and benthic invertebrate data collected in 1965 by the U.S. Department of Health, Education, and Welfare (USDHEW 1966). A detailed listing of all available data for baseline conditions, historic conditions in the intervening years (data collected 1970-1992), and present conditions (through spring 1997) is contained in our previous report (CEC 1997).

STUDY AREA

The study area includes the Red River from its headwaters to its confluence with the Rio Grande (Fig. 1). In order to organize the available baseline, historical, and present data, the Red River was segmented into six reaches (CEC 1997). These reaches were used to group the data into biologically significant sections of the river to allow a more focused interpretation of the data. The six reaches are:

- Upstream of Red River,
- Red River to Hansen Creek,
- Hansen Creek to Molycorp Boundary,
- Molycorp Boundary to Capulin Canyon,
- Capulin Canyon to Questa, and
- Questa to Rio Grande.

Detailed descriptions of these reaches are presented in CEC (1997).

METHODS

Fall 1997 Fish Data Collection

Fish populations were quantitatively sampled by CEC at ten sites on September 8-11, 1997. These same ten sites were previously sampled in April 1997. Sampling was conducted with three- or four-pass electrofishing as described in our previous report (CEC 1997). This sampling provides species lists, estimates of abundance (#/mile, #/acre), and biomass (lbs/acre).

Fish populations were quantitatively sampled by NMDGF at four sites on August 11-12, 1997. The first site was in the special trout water section of the Red River upstream of Goose Creek. This site roughly corresponds to the CEC site upstream of the Town of Red River (Fig. 1). The next site downstream sampled by NMDGF corresponds to the site downstream of Hansen Creek. The remaining two sites sampled by NMDGF correspond to the site upstream of the Questa Ranger Station and upstream of the fish hatchery diversion. Sampling was conducted with two- or three-pass electrofishing, apparently similar to the methods used by CEC.

Fall 1997 Benthic Invertebrate Data Collection

Benthic invertebrates were quantitatively sampled at the same ten sites by CEC during September 1997. Sampling was conducted concurrently with the fish sampling. The sampling methods were similar to those used in 1995 by NMED (Woodward-Clyde 1996) and are briefly described below.

Benthic invertebrates were quantitatively sampled at the ten sites by taking five replicate samples from similar riffle habitats. A modified Hess sampler, which encloses $0.1 m^2$ and has a net mesh size of 500 μm (Canton and Chadwick 1984), was used to collect the invertebrate samples. Five replicate Hess samples were also collected in 1995 by NMED (Woodward-Clyde 1996).

Collected organisms were preserved in the field with 95% ethanol and returned to Chadwick & Associates, Inc. laboratory for analysis. In the lab, organisms were sorted from the debris, identified to the lowest practical taxonomic level (depending upon the age and condition of each specimen), and counted. Chironomids were mounted and cleared prior to identification and counting.

This analysis provided species lists, estimates of density ($\#/m^2$), and the total number of taxa present at each site. Further analysis included calculation of the Shannon-Weaver Diversity Index (H′), which the EPA recommends as a measure of the effects of stress on invertebrate communities (Klemm *et al.* 1990). This index generally has values ranging from 0 - 4, with values greater than 2.5 indicative of a healthy invertebrate community. Diversity values less than 1.0 indicate a stream community under severe stress (Wilhm 1970, Klemm *et al.* 1990).

In mountain streams, such as those near the Molycorp Molybdenum Mine, the presence of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa (referred to as the EPT taxa) can be used as an indicator of water quality. These insect groups are considered to be sensitive to a wide range of pollutants (Wiederholm 1989, Plafkin *et al.* 1989, Klemm *et al.* 1990, Lenat and Penrose 1996, Wallace *et al.* 1996). Stress to aquatic systems can be evaluated by comparing the number of EPT taxa and the percent of EPT taxa (expressed as the percent of the number of EPT taxa relative to the number of total taxa) between unimpacted and potentially impacted sites. Impacted sites would be expected to have fewer EPT taxa and lower percent EPT taxa compared to unimpacted sites.

To assess potential statistical differences in benthic invertebrate population parameters between study sites, one-way analysis of variance (ANOVA) was performed on the replicate Hess samples. For the parameters of density, number of taxa, and number of EPT taxa, ANOVA was performed using the means of the individual sample replicates. Benthic invertebrates are often found in "clumped" or negative binomial distributions. Therefore, in order to fulfill the assumptions needed to use ANOVA, the density data were transformed ($\log_{10}$) prior to analysis (Elliott 1977). The statistical analyses were conducted on the mean and variance of the transformed density data for the five replicates. The summary data table in this report presents composite mean density values (untransformed). However, for the other parameters analyzed (number of taxa, number of EPT taxa, % EPT taxa, diversity), the summary data table presents the results of pooled numbers from the total of the five replicates.

RESULTS AND DISCUSSION

Fish Populations

Chadwick Ecological Consultants, Inc.

Four different trout species were collected in the Red River and its tributaries during sampling in September 1997 (Table 1). Brown and rainbow trout were the most common species collected. Brown trout were collected at all ten sites sampled; rainbow trout were collected at eight of the ten sites. Hybrids between rainbow and cutthroat trout were present at three sites and were the most common fish in Cabresto Creek, as was also true in spring 1997 (CEC 1997).

Multiple size classes of cutthroat, brook, brown, and hybrid trout were collected. This indicates the presence of resident, self-sustaining populations of these species in the Red River and its tributaries. However, rainbow trout collected were 5.5 inches in length or greater, with most in the 8 to 11 inch size group. This corresponds to the lengths of fish regularly stocked by NMDGF and the Town of Red River (CEC 1997). As was true in the spring of 1997, the rainbow trout collected during sampling in fall 1997 are probably stocked fish. One white sucker was collected at the Elephant Rock Campground site. This species has occasionally been collected by NMDGF over the years, and is native to the drainage (CEC 1997).

TABLE 1: Fish population parameters for collection sites on the Red River and tributaries. Data collected during September 8-11, 1997, by Chadwick Ecological Consultants, Inc. Data from three or four electrofishing passes (CUT = cutthroat trout, BRK = brook trout, RBT = rainbow trout, BRN = brown trout, HYBRID = cutthroat-rainbow cross, WS = white sucker).

			Density		Biomass
Site	Species	# Collected	#/Mile	#/Acre	Lbs./Acre
Red River					
Upstream of Town of Red River	CUT	2	34	16	3.6
	BRK	8	135	62	2.4
	RBT	4	68	31	32.4
	BRN	10	169	78	1.5
	HYBRID	10	169	78	14.7
	Total	34	575	265	54.6
June Bug Campground	BRK	1	18	8	1.0
	RBT	62	1,153	507	202.4
	BRN	10	183	81	5.9
	HYBRID	1	18	8	0.9
	Total	74	1,372	604	210.2
Downstream of Elephant Rock Campground, upstream of Hansen Creek	BRK	3	59	25	5.0
	RBT	9	177	75	23.5
	BRN	45	926	390	73.1
	WS	1	20	8	0.6
	Total	58	1,182	498	102.2
Downstream of Hansen Creek, upstream of mill	RBT	7	116	42	16.9
	BRN	10	166	61	2.5
	Total	17	282	103	19.4
Downstream of mill, upstream of Columbine Creek	RBT	1	17	7	3.3
	BRN	19	331	130	27.4
	Total	20	348	137	30.7
Goathill Campground	BRN	8	169	72	6.8
Upstream of Questa Ranger Station	CUT	1	12	4	1.7
	RBT	1	12	4	1.9
	BRN	9	109	37	1.1
	Total	11	133	45	4.7
Upstream of hatchery diversion	RBT	28	490	189	52.6
	BRN	41	788	303	52.2
	Total	69	1,278	492	104.8

TABLE 1: Continued.

Site, Date	Species	# Collected	Density #/Mile	Density #/Acre	Biomass Lbs./Acre
Tributaries					
Columbine Creek	CUT	1	23	14	1.8
	BRN	20	460	282	21.4
	Total	21	483	296	23.2
Cabresto Creek	CUT	1	31	20	2.6
	BRK	10	309	204	5.1
	RBT	18	556	367	135.5
	BRN	15	464	306	2.4
	HYBRID	57	1,792	1,183	82.9
	Total	101	3,152	2,080	228.5

The fish population data from the fall of 1997 indicate a distinct pattern of trout distribution along the length of the Red River (Fig. 2). Both total trout and resident trout (excluding stocked rainbow trout) have relatively higher numbers at sites upstream of Hansen Creek. The density of resident trout at the three sites upstream of Hansen Creek ranged from 219 to 985 trout per mile (Table 1, Fig. 2), and averaged 570 trout per mile. At the four sites from Hansen Creek downstream to the Questa Ranger Station, resident trout density ranged from 121 to 331 trout per mile, averaging 197 trout per mile. There was a decrease of 83% in resident trout density between the Elephant Rock Campground site and the site downstream of Hansen Creek.

The density of resident trout reached a minimum of 121 trout per mile at the site near the Questa Ranger Station, downstream of Capulin Canyon (Table 1). At the next site downstream, the site near the fish hatchery, resident trout density increased over 500% to a level that is within the range of the sites upstream of Hansen Creek.

As concluded in our previous report (CEC 1997), the single most important impact in the Red River appears to be the effects of Hansen Creek. Capulin Canyon is also apparently having a negative impact to the river as lowest trout density was found at the site downstream of Capulin Canyon, near the Questa Ranger Station. The large increase in resident trout density at the fish hatchery site appears to be due, in part, to the input of relatively clean water from Cabresto Creek. The density of resident trout in Cabresto Creek (2,596 trout per mile) was higher than at any of the eight sites on the Red River (Table 1).

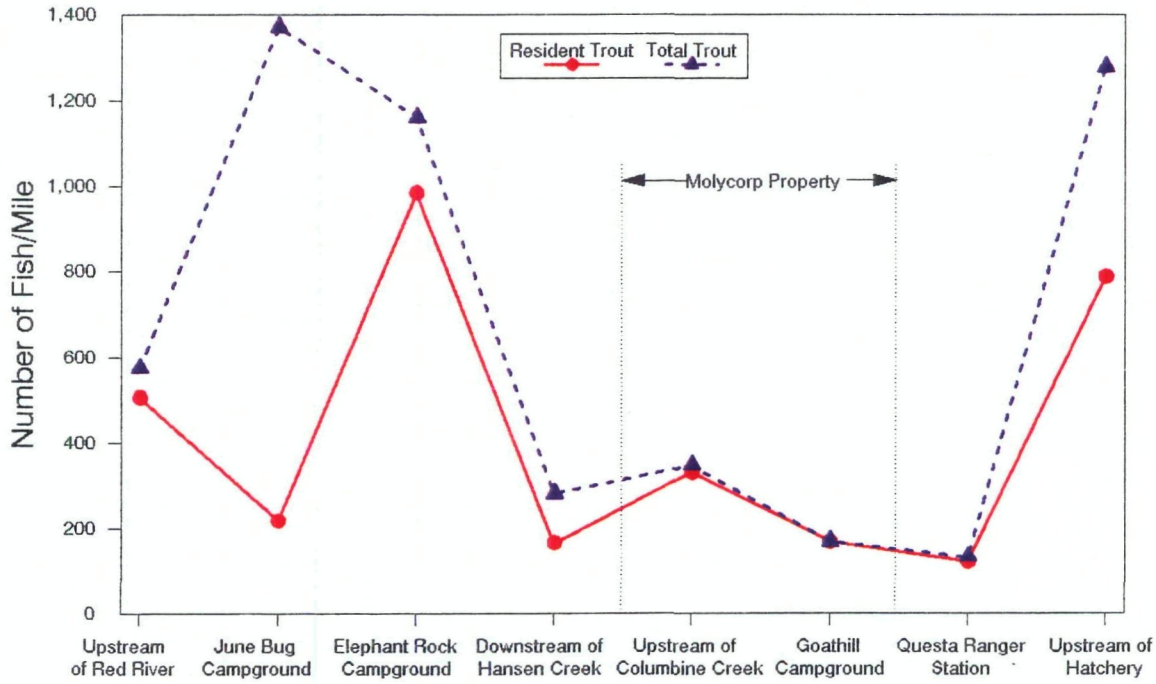

FIGURE 2: Trend in the number of trout per mile for data collected in fall, 1997. Data represent results of all electrofishing passes. Resident trout excludes rainbow trout.

At the June Bug Campground site, the density of resident trout was lower than at the other two sites in the section of the Red River upstream of Hansen Creek (Table 1, Fig. 2). There was a decrease of 57% in the density of resident trout between the site upstream of the Town of Red River and the site at the June Bug Campground, downstream of Red River. This suggests an impact to trout populations is occurring in or near the Town of Red River.

The density of resident trout in fall 1997 at the June Bug Campground site was 219 fish per mile (Table 1), approximately one-third of the density in spring 1997 (666 resident fish per mile). The relatively high density of total trout at the June Bug Campground (Table 1, Fig. 2) was due to the stocking of rainbow trout at the campground by NMDGF on the morning prior to sampling (Campground Monitor, pers. comm.). This may be responsible, in part, for the low density of resident trout at this site in fall. There is some evidence that stocked rainbow trout may cause a decline in the number of resident trout (Griffith 1993). The June Bug section of the Red River has been routinely stocked with rainbow trout for years, and the fall

stocking does not represent a change in management of the stream. However, there may have been at least a temporary decline in resident brook and brown trout density at the campground at the time of sampling.

New Mexico Department of Game and Fish

Sampling by NMDGF in August 1997 was conducted at four sites on the Red River that roughly correspond to sites sampled by CEC. Brown and rainbow trout were the most common species collected, along with brook trout, several rainbow-cutthroat hybrids, and one "sucker" (possibly a white sucker). Brown and rainbow trout were collected at all four sites. Brook trout and hybrids were collected only at the site upstream of the Town of Red River (Table 2).

TABLE 2: Fish population parameters for collection sites on the Red River. Data collected August 11-12, 1997, by NMDGF. Data from two or three electrofishing passes (species abbreviations the same as in Table 1). NC = sucker biomass not calculated by NMDGF.

			Density		Biomass
Site	Species	# Collected	#/Mile	#/Acre	Lbs./Acre
Red River					
Upstream of Town of Red River	BRK	26	435	180	10.2
	RBT	35	580	240	118.4
	BRN	12	209	87	26.6
	HYBRID	5	81	33	3.4
	Total	78	1,305	540	158.6
Downstream of Hansen Creek, upstream of mill	RBT	5	81	31	17.5
	BRN	5	81	31	10.9
	Total	10	162	62	28.4
Upstream of Questa Ranger Station	RBT	1	16	6	5.3
	BRN	1	16	6	1.0
	Total	2	32	12	6.3
Upstream of hatchery diversion	RBT	28	564	146	34.5
	BRN	50	902	234	17.8
	WS	1	16	4	NC
	Total	79	1,482	384	52.3

The results of the NMDGF sampling generally are consistent with the results of the CEC sampling at corresponding sites. Multiple size classes of brook, brown, and hybrid trout were collected, indicating resident, self-sustaining populations of these species. Most rainbow trout were larger than 5.5 inches, with many larger than 8 inches. This again indicates that rainbow trout populations are sustained by stocking. Several smaller rainbow trout (3 - 5 inches) were collected at the site upstream of Red River indicating that a low level of natural reproduction may be occurring in this section of the Red River. However, rainbow trout continue to be maintained almost entirely by stocking.

The longitudinal trend in density of resident trout for the NMDGF data (Fig. 3) is similar to the trend for the data collected by CEC (Fig. 2). Relatively high density of resident trout is present upstream of the Town of Red River, with much lower density at the site downstream of Hansen Creek. There was a decrease of 89% in resident trout density between the NMDGF site upstream of the Town of Red River and the site downstream of Hansen Creek. Lowest density of resident trout with both data sets was present at the site upstream of the Questa Ranger Station, with a substantial increase in density near the fish hatchery.

Benthic Invertebrate Populations

Upstream of the Town of Red River, a healthy population of benthic invertebrates was present in September 1997. This is indicated by a moderate density of invertebrates, the presence of multiple EPT taxa (Appendix A) and a diversity of 3.30 (Table 3). Downstream of the Town of Red River, at the June Bug Campground site, most population parameters are similar to those at the site upstream of Red River. However, density is substantially reduced at this site. The reduction in invertebrate density is significant (ANOVA $p = 0.006$), and this indicates some impact to benthic invertebrate populations is occurring near the Town of Red River. The data on fish populations in fall 1997 also exhibited this trend.

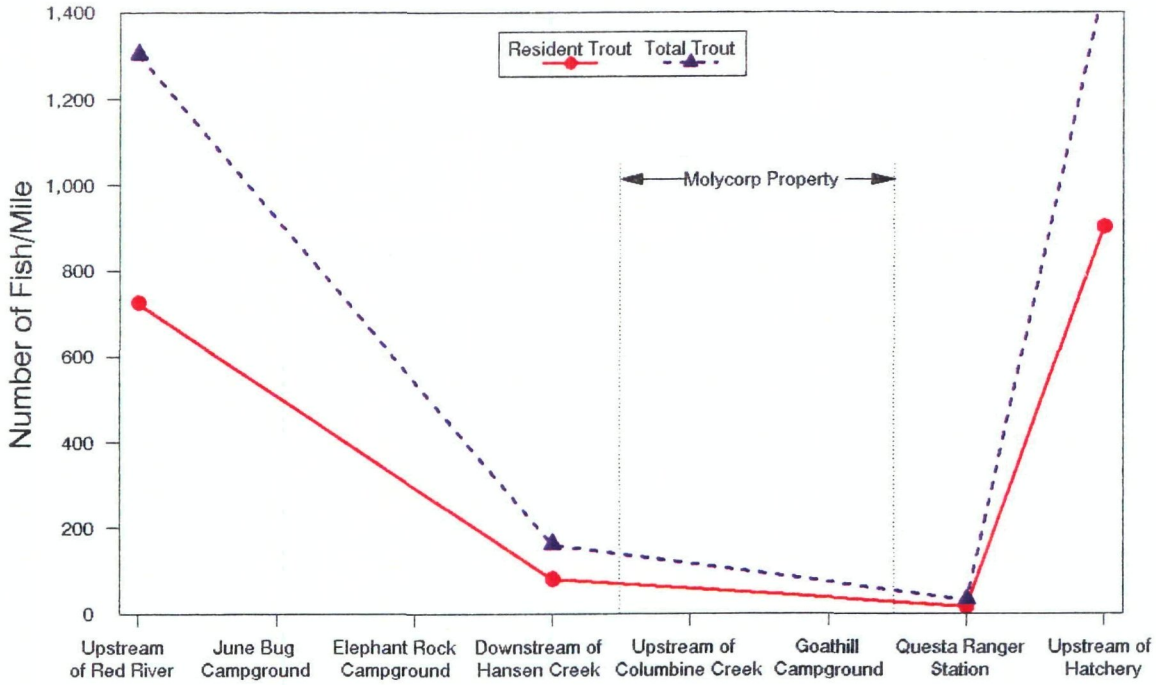

FIGURE 3: Trend in the number of trout per mile for data collected in August 1997 by NMDGF. Data represents results of all electrofishing passes. Resident trout excludes rainbow trout.

TABLE 3: Benthic invertebrate population parameters for collection sites on the Red River and tributaries. Data collected during September 8-11, 1997, by Chadwick Ecological Consultants, Inc.

Site	Density (#/m^2)	Total # of Taxa	# EPT Taxa	EPT Taxa as % Total Taxa	Diversity Index (H')
Red River					
Upstream of Town of Red River	1,550	22	9	41	3.30
June Bug Campground	528	23	11	48	3.38
Downstream Elephant Rock Campground, upstream of Hansen Creek	3,170	21	10	48	2.85
Downstream of Hansen Creek, upstream of mill	4,232	24	12	50	2.63
Downstream of mill, upstream of Columbine Creek	1,682	23	13	57	3.21
Goathill Campground	1,150	20	10	50	2.84
Upstream of Questa Ranger Station	548	15	10	67	2.59
Upstream of hatchery diversion	1,606	21	9	43	2.68
Tributaries					
Columbine Creek	748	32	17	53	3.68
Cabresto Creek	3,450	36	21	58	3.84

Further downstream of the Town of Red River, near the Elephant Rock Campground, the density of invertebrates increased significantly ($p = 0.03$) as compared to the site upstream at the June Bug Campground. However, the diversity was reduced, although not significantly ($p > 0.05$). This combination of increased density and decreased diversity is often indicative of the effects of organic enrichment (Hynes 1971). This pattern was also present in data from 1995, and was attributed to a slight enrichment effect of the wastewater treatment plant that discharges to the Red River between the June Bug and Elephant Rock Campgrounds (CEC 1997). The number of total taxa, the number of EPT taxa, and the percentage of EPT taxa at the Elephant Rock Campground site are similar to those at the site upstream of Red River (Table 3), indicating that the enrichment effect is not severely impairing the suitability of this section of the Red River to sustain some of the more sensitive forms of aquatic invertebrates.

At the sampling site downstream of Hansen Creek, the density of benthic invertebrates was higher than at all other sites sampled (Table 3), although not significantly higher ($p = 0.32$) than at the next site upstream, the Elephant Rock Campground site. The total number of taxa and the EPT parameters were slightly higher at the site downstream of Hansen Creek than at the three sites upstream. Diversity was significantly ($p < 0.05$) lower at this site as compared to upstream sites, primarily as a result of the abundance of two diptera (true fly) larvae, *Cricotopus tremulus* and *Pagastia* sp. This pattern may also reflect a slight nutrient enrichment effect, as at the Elephant Rock Campground site. These data contrast with the data from 1995 (Woodward-Clyde 1996), which indicated that lower densities were present in this reach of the river in 1995, as compared to upstream reaches.

At sites downstream of the Molycorp mill and at the Goathill Campground, densities of invertebrates were significantly lower ($p = 0.026$, $p = 0.007$, respectively) than at the site downstream of Hansen Creek. Other population parameters were similar among these three sites. Diversity, however, was significantly higher ($p < 0.05$) at the sites downstream of the mill and at the Goathill Campground as compared to the site downstream of Hansen Creek (Table 3). This pattern of reduced density and increased diversity compared to the sites immediately upstream is consistent with a reduction in the enrichment effects of wastewater treatment plant effluent that appeared to be affecting the benthic invertebrates at the site near the Elephant Rock Campground and the site downstream of Hansen Creek. The population parameters in the reach of the Red River adjacent to the Molycorp property (Fig. 1) have returned to levels similar to those present

upstream of the Town of Red River (Table 3). There was no significant difference in density or diversity between the site upstream of the Town of Red River, and the sites downstream of the Molycorp mill and at the Goathill Campground.

The site near the Questa Ranger Station had the second lowest density, lowest number of taxa, and lowest diversity of all sites sampled. However, the number of EPT taxa was comparable to most other sites on the Red River, and the percentage of EPT taxa was higher than at all other sites (Table 3). The values for these population parameters were very similar at this site in December 1995 (CEC 1997). This indicates a continuing impact downstream of Capulin Canyon leading to reduced density and number of taxa of benthic invertebrates of the Red River.

The most downstream site on the Red River, the site upstream of the hatchery diversion, showed a recovery from the low levels of density and number of taxa present at the previous site upstream, the site near the Questa Ranger Station (Table 3). For most population parameters, the values at this site were comparable to those found upstream of the Town of Red River. In fact, there were no significant differences in density, number of EPT taxa, or percent of EPT taxa between these two sites. This recovery is probably due to the input of clean water from Cabresto Creek.

The benthic invertebrate populations in Cabresto Creek are healthy and exhibit significantly higher diversity, number of taxa, and number of EPT taxa than all other sites sampled (Table 3). The other tributary sampled, Columbine Creek, also has a healthy population of benthic invertebrates. The number of taxa, the number of EPT taxa, and diversity were all relatively high in Columbine Creek (Table 3). However, density was relatively low compared to most other sites. These two sites may give an indication of the natural background variability in invertebrate density of relatively unimpacted streams in the region.

The overall longitudinal trend in benthic invertebrate population parameters along the Red River shows little variation in the total number of taxa, with the exception of relatively low taxa at the site near the Questa Ranger Station (Fig. 4). This trend suggests that conditions along the length of the Red River are suitable to sustain at least a moderate level of benthic invertebrate taxa. Although impacts are occurring, these impacts do not render the river unsuitable to benthic invertebrates.

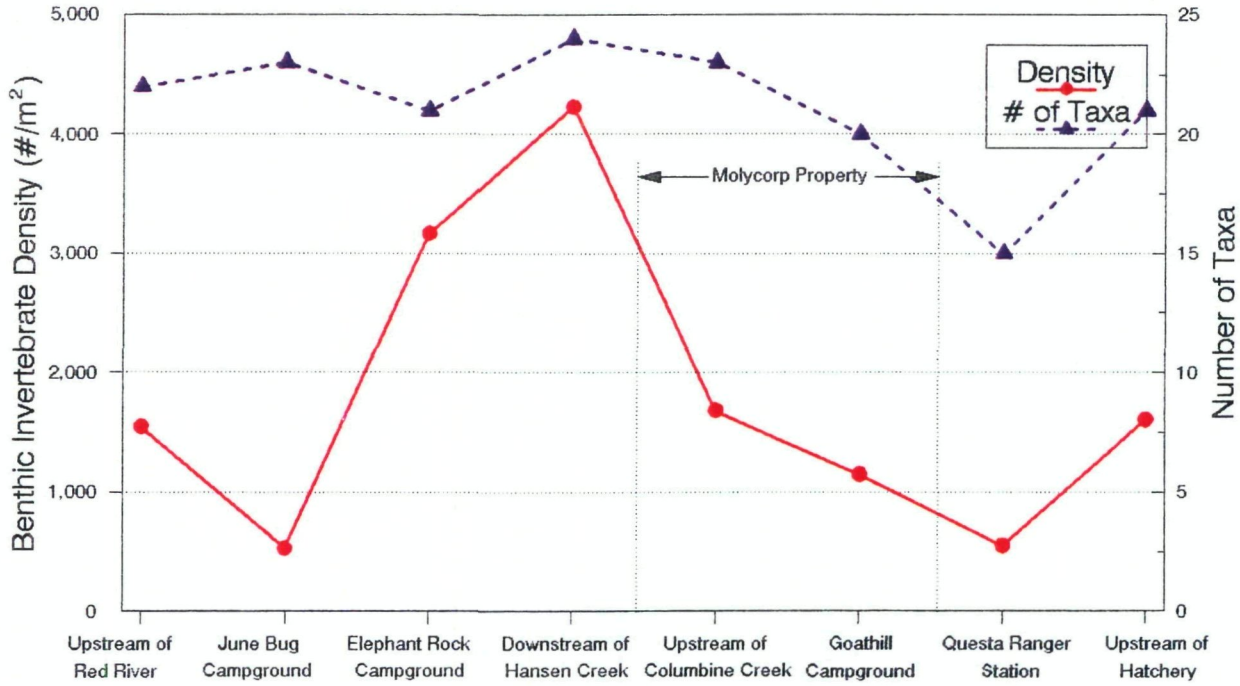

FIGURE 4: Trend in benthic invertebrate density and number of taxa for data collected in fall, 1997.

The trend in benthic invertebrate density in the Red River is much more variable than that for number of taxa (Fig. 4). Four of the eight sites sampled contained densities of invertebrates between 1000-2000/m^2, including the site upstream of the Town of Red River. However, densities at the other four sites varied considerably. The two sites with highest density are immediately downstream from the wastewater treatment plant effluent discharge and appear to be exhibiting enriched conditions due to the effluent.

The two sites with lowest density, the June Bug Campground site and the site near the Questa Ranger Station, indicate impacts are occurring to the Red River upstream of these two sites. At the June Bug Campground site, the impact may be occurring near the Town of Red River. As the number of taxa and diversity remained relatively high at this site, the impact is apparently not severe. A more severe impact appears to be occurring downstream of Capulin Canyon as the number of taxa, diversity, and density were reduced at the site near the Questa Ranger Station (Table 3, Fig. 4).

TEMPORAL PATTERNS OF AQUATIC BIOTA

Fish Populations

The longitudinal pattern of fish density in Figure 5 is plotted for three different time periods. Data from 1960 were collected prior to the initiation of open pit mining, and represent baseline data. Present conditions are represented by data collected in spring 1997 and in fall 1997 by CEC and in summer 1997 by NMDGF. Data collected during the intervening period of open pit mine operation (1974-1988) are also plotted.

In order to make the data sets for the three periods comparable, only first-pass electrofishing data were used, since this was the primary sampling method during the earlier studies (CEC 1997). Also, since rainbow trout are largely maintained by stocking, and are not as directly controlled by habitat and water quality conditions as are resident fish, rainbow trout numbers have been omitted from the comparison.

The longitudinal trends in fish density (number of fish/mile) are similar during all three time periods. The trends all indicate relatively high fish density upstream of the Town of Red River, decreasing density downstream of Hansen Creek, and increasing density downstream of Questa (Fig. 5). This trend holds for baseline conditions (1960 data), present conditions (spring, summer, and fall 1997 data), and during the intervening period of open pit mine operation (1974-1988).

The trends in trout density in all three periods indicate that impacts are occurring to the suitability of the Red River to support trout near the Town of Red River. The trend in trout density in all three periods also indicate further impacts to trout downstream of Hansen Creek (Fig. 5). Downstream of Hansen Creek and through the section of the Red River adjacent to the Molycorp property, trout density remains low.

Downstream of Capulin Canyon, trout density reached its lowest level during spring, summer, and fall 1997. During all three sampling periods, there was also a substantial increase in resident trout density in the reach of the Red River downstream of Questa. In this lower reach of the river, trout density returned to levels comparable to or higher than those found in the reach upstream of the Town of Red River (Fig. 5).

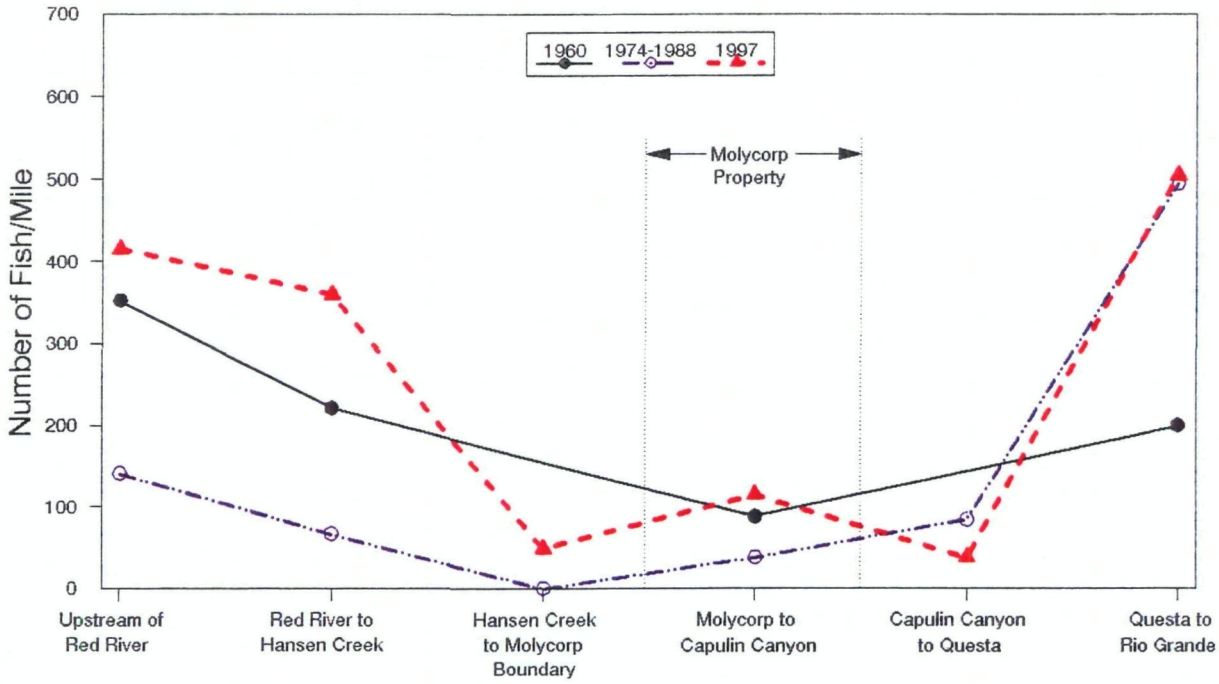

FIGURE 5: Longitudinal trends in fish density (#/mile) for baseline conditions (1960 data), open pit mine operation (1974-1988 data), and present conditions (spring, summer, and fall 1997 data). First pass data only, rainbow trout excluded.

Benthic Invertebrate Populations

For benthic invertebrates, the collected data also were divided into three time periods. Baseline conditions were represented by data collected in 1965, apparently prior to the initiation of open pit mining. Benthic invertebrate data collected in 1995 and in fall 1997 represent present conditions. Data available from the intervening period (1970-1992) represent conditions during open pit mining. Comparisons are made between the two population parameters of density (#/m^2) and number of taxa.

The longitudinal trends in density for the three sampling periods (1965, 1970-1992, and 1995-1997) show a similar pattern of decreasing density downstream from the headwaters of the Red River with low levels of benthic invertebrates downstream of Hansen Creek (Fig. 6). In the remainder of the Red River from the Molycorp property downstream past Questa, the data from the three sampling periods also have a similar trend (Fig 6). Low densities occur adjacent to the Molycorp Mine, and lowest densities are found near the

Questa Ranger Station in the reach of the river downstream of Capulin Canyon. This is followed by an increase in density in the reach downstream of Questa, after Cabresto Creek inputs relatively clean water into the Red River. This general trend has not changed since 1965.

The trend in number of taxa for three sampling periods (1965, 1970-1992, and 1995-1997) indicates a gradual decrease in taxa along the length of the Red River to the reach downstream of Capulin Canyon (Fig. 7). This is followed by an increase in number of taxa downstream of Questa for two of these periods (1970-1992, 1995-1997)

In all six reaches for data collected in 1995-1997, densities and number of taxa are substantially higher than during the baseline period (1965) and the period of open pit mine operation (Figs. 6, 7). As mentioned in our earlier report, this may be partly due to different methods of data collection and analysis. However, this suggests that the Red River is at least as suitable for sustaining benthic invertebrates at present as it was prior to open pit mine operations.

CONCLUSIONS

Our previous report concluded that the primary impacts to the suitability of the Red River to sustain aquatic biota were occurring near the Town of Red River, downstream of Hansen Creek and downstream of Capulin Canyon (CEC 1997). Downstream of the confluence of Cabresto Creek, conditions improved for both fish and benthic invertebrates. The cause of these impacts appeared to be the input of excess sediment from a number of sources and, possibly, decreased water quality. That report further concluded that baseline data indicated these impacts were present prior to the initiation of open pit mining at the Molycorp Questa Mine, and in reaches of the Red River upstream of the mine. That report also concluded that present population levels of fish and benthic invertebrates are higher than during baseline conditions, suggesting that there have been improvements in the suitability of the Red River to support aquatic biota since the 1960s (CEC 1997).

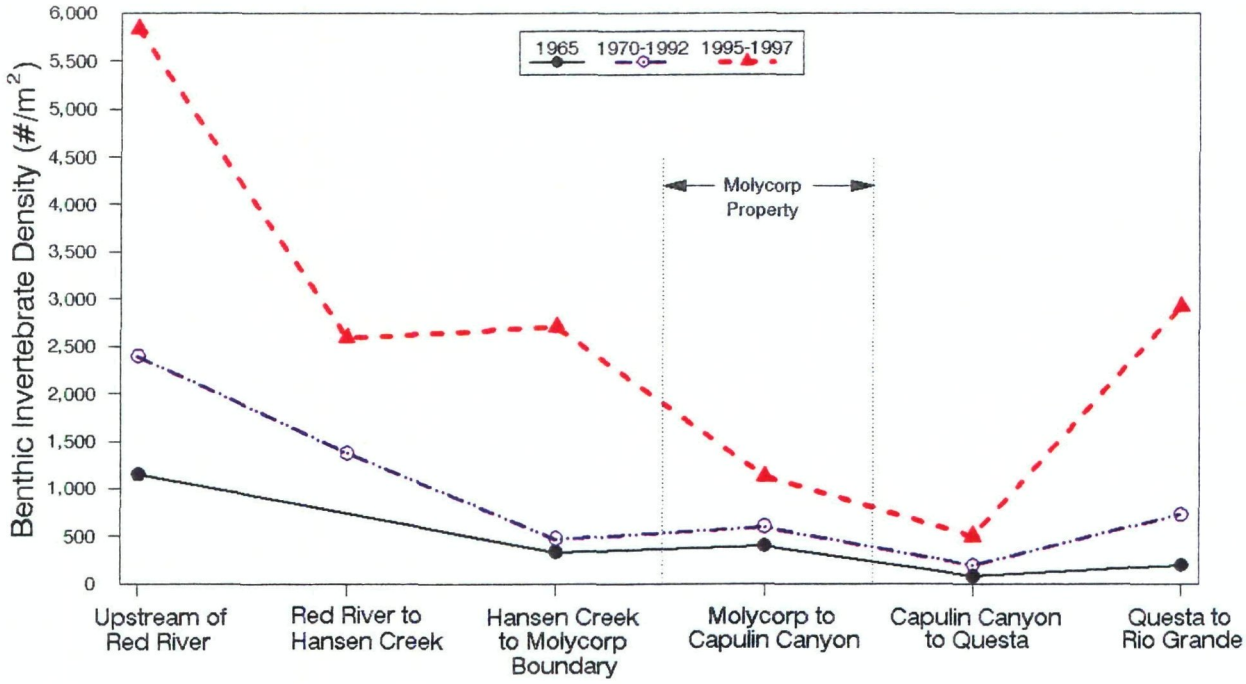

FIGURE 6: Longitudinal trends in benthic invertebrate density (#/m^2) for baseline conditions (1965 data), open pit mine operation (1970-1992 data), and present conditions (fall 1995 and fall 1997 data)

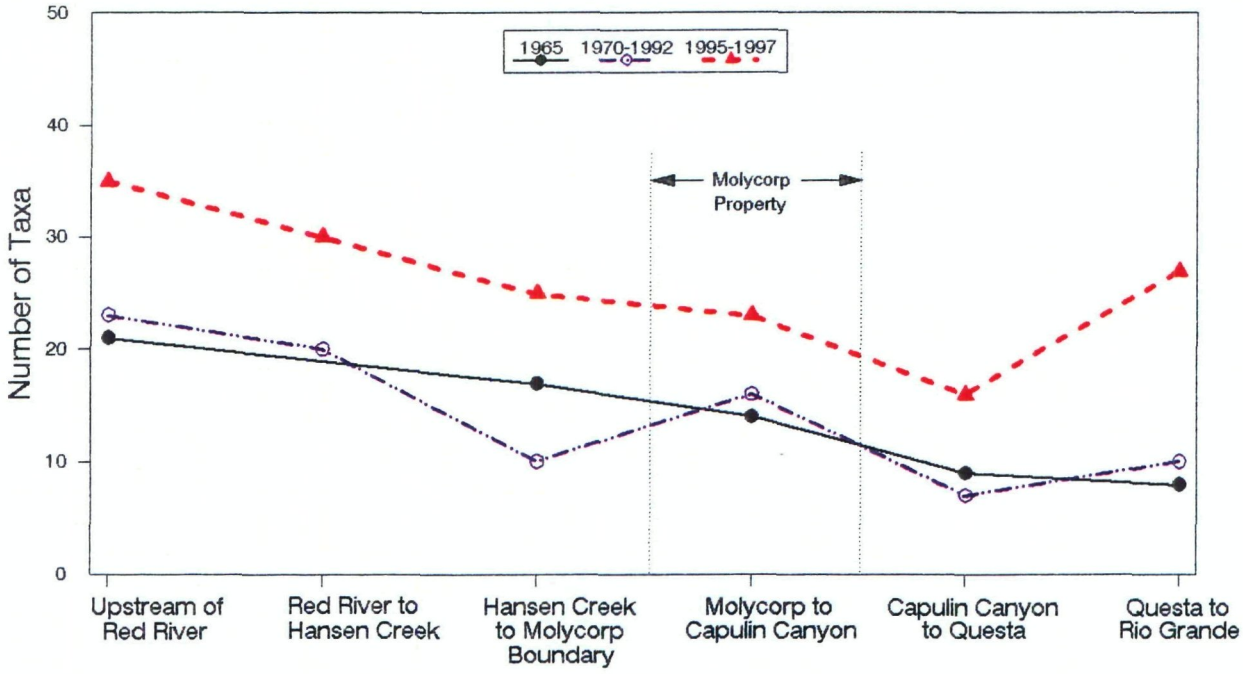

FIGURE 7: Longitudinal trends in benthic invertebrate taxa for baseline conditions (1965 data), open pit mine operation (1970-1992 data), and present conditions (fall 1995 and fall 1997 data).

The fish data collected in summer and fall 1997 exhibit nearly the same trend in density as that found for baseline conditions (1960), the period of open pit operation (1974-1988), and in spring 1997. The most recent data from summer and fall 1997 support the conclusions of our previous report.

The trends in benthic invertebrate population parameters from data collected in the fall of 1997 were similar in most respects to the trends from the baseline (1965) and open pit mine operation periods (1970-1992). However, there were differences in the trend in 1997, especially in the section of the Red River near the Elephant Rock Campground and downstream of Hansen Creek. The densities of benthic invertebrates at the two sites in this section of the river were significantly higher than at the next site upstream, the June Bug Campground site. These higher densities, coupled with relatively low diversities at these two sites, suggest nutrient enrichment of the Red River downstream of the wastewater treatment plant.

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APPENDIX A

Benthic Invertebrate Data

MACROINVERTEBRATE DATA SUMMARY

	Red River									
	Upstream of Red River	June Bug Campground	Elephant Rock Campgound	Downstream of Hansen Creek	Upstream of Columbine Creek	Goathill Campground	Questa Ranger Station	Upstream of Hatchery	Columbine Creek	Cabresto Creek
TAXA										
INSECTA										
PLECOPTERA	70	6	4	4	6	2	16	8	192	378
Capnia sp.									2	
Claassenia sabulosa									6	2
Cultus sp.										68
Megarcys signata	4	2	2	2						14
Perlodidae		4								
Pteronarcella badia					2		16	2		
Sweltsa sp.	66		2	2				4	52	246
Taeniopterygidae					2	2		2	120	34
Zapada cinctipes										4
Zapada frigida					2					
Zapada haysi									12	10
EPHEMEROPTERA	478	252	674	1114	770	668	172	824	328	1234
Acentrella insignificans		2								
Baetis bicaudatus					68		2			
Baetis tricaudatus	4	66	236	596	398	314	68	732	194	580
Cinygmula sp.				8						16
Drunella coloradensis	10	130	382	4		8				
Drunella doddsi	458	40	40	20	6	6	2		22	146
Drunella grandis				474	210	44	6	8	2	4
Epeorus deceptivus		2		12	6	14			6	
Epeorus longimanus	4								38	
Ephemerella infrequens									8	484
Rhithrogena hageni	2	12	16		82	282	78	84	56	4
Rhithrogena robusta									2	
Serratella micheneri							16			
TRICHOPTERA	128	42	264	118	160	180	84	260	84	460
Arctopsyche grandis		18	8	20	106	106	50	14	20	4
Brachycentrus americanus	18	22	244	76	38	72	30	46		
Hydropsyche sp.				18	10			200		6
Lepidostoma sp.			2							50
Micrasema bactro									2	8
Oligophlebodes sp.										276
Rhyacophila betteni gr.				4						
Rhyacophila brunnea gr.									6	4
Rhyacophila harmstoni					6	2	4		56	110

Continued

TAXA	Red River: Upstream of Red River	June Bug Campground	Elephant Rock Campgound	Downstream of Hansen Creek	Upstream of Columbine Creek	Goathill Campground	Questa Ranger Station	Upstream of Hatchery	Columbine Creek	Cabresto Creek
TRICHOPTERA (Cont.)										
Rhyacophila sibirica gr.	110	2	10							
Wormaldia sp.										2
COLEOPTERA	106	6	16	10		4		8	46	162
Cleptelmis ornata			8							
Heterlimnius corpulentus	106	6	8	10		4		8	46	158
Narpus concolor										4
DIPTERA	734	180	1532	2604	730	286	268	504	88	1136
Atherix pachypus		2	18		2	2	6	32		
Bibiocephala grandis	2									
Chelifera sp.			16	8			2	4	8	4
Cricotopus tremulus	204	66	824	1194	318	206	248	190	30	124
Dicranota sp.				8	4	4			2	2
Empididae				2	2			4		4
Hemerodromia sp.									2	
Hexatoma sp.								10		58
Limonia sp.			2							
Mallochohelea sp.	34	4						20		46
Micropsectra sp.	30	2		90	92	2		8	14	452
Pagastia sp.	12	50	582	1262	220	54	12	78	10	160
Parorthocladius sp.			6							
Pericoma sp.	188	2	18	20	2				10	286
Polypedilum sp.		2								
Prosimulium sp.	4									
Rhabdomastix sp.				4	2	4				
Rheotanytarsus sp.	34								8	
Simulium sp.	50	4	66	16	88	14		154	2	
Thienemanniella sp.	166	48							2	
Thienemannimyia gr. sp.								4		
Tipula sp.	10									
TURBELLARIA						2			2	46
Phagocata sp.						2				
Polycelis coronata									2	46

Continued

	Red River									
	Upstream of Red River	June Bug Campground	Elephant Rock Campgound	Downstream of Hansen Creek	Upstream of Columbine Creek	Goathill Campground	Questa Ranger Station	Upstream of Hatchery	Columbine Creek	Cabresto Creek
TAXA										
ANNELIDA										
OLIGOCHAETA	34								2	
Lumbricidae									2	
Rhynchelmis sp.	34									
NEMATODA				2					2	12
Unid. Nematoda				2					2	12
HYDRACARINA		42	680	380	16	8	8	2	4	22
Gehypochthoniidae		2								
Lebertia sp.		40	680							
Sperchon/Sperchonopsis				380	16	8	8	2	4	18
Wandesia sp.										4
TOTAL (#/sq. meter)	1550	528	3170	4232	1682	1150	548	1606	748	3450
NUMBER OF TAXA	22	23	21	24	23	20	15	21	32	36
DIVERSITY (H')	3.30	3.38	2.85	2.63	3.21	2.84	2.59	2.68	3.68	3.84
TOTAL EPT TAXA	9	11	10	12	13	10	10	9	17	21
EPT INDEX (% of Total Taxa)	41	48	48	50	57	50	67	43	53	58
EPHEMEROPTERA ABUNDANCE (% of Total Density)	31	48	21	26	46	58	31	51	44	36

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MOLYCORP

NPDES
Permit Renewal

April 1998

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SECTION I

SUMMARY AND EXHIBITS

SUMMARY OF MOLYCORP NPDES PERMIT ISSUES

Fluoride Limitations - *Molycorp requests that fluoride limitations at discharge points 001 and 002 be modified to reflect those concentrations achievable by the application of Best Available Technology (BAT), 19.9 mg/l monthly average and 35.0 mg/l daily maximum or a more appropriate Best Professional Judgement ("BPJ") limitation.*

Throughout the 1980s, EPA developed an extensive Combined Metals Data Base (CMDB) that characterized the treatability levels achievable by the application of BAT. Specifically related to fluoride removal, EPA chose lime and settle technology as Best Practical Technology (BPT), and lime, settle, and filter (LS&F) as BAT. From the CMDB and supplemental data specific to fluoride, EPA determined that the discharge levels achievable via BAT are 35 mg/l as a daily maximum and 19.9 mg/l as a monthly average. The specific reference to calculation of BAT for fluoride can be found in EPA Development Document, EPA 440/1-89-019.2, Vol. II, as presented in Exhibit I-1 of Section I.

In the CMDB, EPA did not specifically address the treatability of fluoride via LS&F, but did examine 47 samples from two electronics manufacturing plants. The electronics plants had similar waste water concentrations of fluoride as those waste waters of the CMDB; therefore, they were used as the basis of BAT. To derive the daily maximum limitation and the monthly average limitation, EPA multiplied the long-term treatment effectiveness values by a variability factor. EPA has determined that the long-term average fluoride concentration that can be achieved with lime and settle (BPT) is 14.5 mg/l, and that the pooled variability factors are:

- one-day maximum: 4.100;
- ten-day average: 1.821; and
- 30-day average: 1.618.

Further, EPA assumed that the addition of filtering to the lime and settle process will reduce all pollutants by one-third. This one-third reduction was defined as BAT. Therefore, if one were to calculate the daily maximum BAT limitation for fluoride, the long-term average treatment concentration would be multiplied by the variability factor of 4.1 and then times the 33 percent reduction attributed to filtration, which would yield a value of 35 mg/l. EPA utilized the 10-day average for establishing the monthly average limitation, which yields 19.9 mg/l.

The current permit contains a limitation for fluoride at both 001 and 002 of 3.0 mg/l as both the 30-day average and daily maximum. This limitation, which is apparently based upon Best Professional Judgment (BPJ), dates back to the issuance of Molycorp's first NPDES permit on January 28, 1975.

In 1976 and in 1980, an area of the orebody being mined and milled contained higher than normal fluoride minerals, fluorite and biotite. We believe that we are currently mining in an area that similarly has higher than normal fluoride mineralization. For example, current mine water fluoride concentrations are slightly greater than 10 mg/l. The mine water is used in the mill circuit and is

mixed with both supply well and river water, all of which serve as the total process water stream. Currently, only 14 percent of the mill process water is from the mine, therefore, the fluoride in the final tailings pool is diluted considerably.

As mentioned above, BAT for fluoride removal is lime, settle, and filter. The Questa Mill water treatment system currently employs lime addition for pH control and extended settling in the tailings pond. We believe that our system represents BAT, and, in general, exceeds BAT performance due to the extended settling times in the tailings ponds. Assuming standard wastewater treatment plant design practices, we estimate our tailings system provides 145 times the settling time of the standard LS&F system. However, the historic variation noted in the 001 and 002 fluoride concentrations are more an artifact of the mine water and fluoride mineralization than a result of performance of our process water treatment system. At the current time, the tailings pool water contains about 4.7 mg/l fluoride, which is above the 3.0 mg/l permit limit but significantly below BAT at 19.9 mg/l. The achievability, on a consistent basis, of discharge concentrations of less than 3.0 mg/l has never been demonstrated, as the feed fluoride concentrations going to the tailings system have been generally less than 3.0 mg/l, i.e., 3.0 mg/l is beyond what can be achieved via BAT. Having said this, until the water pool in our tailings dam increases to the level of discharge, we will not be able to take representative samples for fluoride. Molycorp is confident, however, that the overall mine and mill water management and treatment system is fully capable of meeting BAT limits for fluoride.

As noted above, Molycorp's 1993 fluoride limit was based on BPJ. The "anti-backsliding" requirement of the Clean Water Act does not prohibit a less stringent effluent limitation for fluoride than is in the existing permit, so long as one of the exceptions to the rule contained in §402(o) of the Act applies. 33 U.S.C. §1342(o).

One exception to the anti-backsliding rule arises when "a less stringent effluent limitation is necessary because of events over which the permittee has no control and for which there is no reasonably available remedy." 33 U.S.C.§1342(o)(2)(C); 40 C.F.R.§122.44(1)(2)(i)(C)(1997). Since the Questa facility has reopened, new data suggest that, as in 1976 and 1980, greater fluoride mineralization has been encountered, which has resulted in increased fluoride loading to the tailings water system. Since Molycorp has no control over fluoride concentrations found in the ore body it mines, and since there is no reasonably available remedy for the increased fluoride loadings to the tailings water because BAT cannot achieve these limits, the exception to the anti-backsliding rule in § 402(o)(C) of the Clean Water Act clearly applies. Molycorp's current fluoride limits are thus based on "a technical mistake" EPA made in 1977 in predicting EPA's subsequent BAT limitations for fluoride. In addition, the exception in § 402(o)(B)(i) applies, because information that was not available in 1975 would have justified less stringent limits at the time of permit issuance.

Although exceptions to the anti-backsliding rule are subject to two limitations found at § 402(o)(3) of the Clean Water Act, neither limitation applies to Molycorp's fluoride limit. The proposed effluent limitation of 19.9 mg/l for fluoride is no less stringent than required by any effluent guideline in effect because the applicable effluent guidelines do not limit fluoride. Furthermore, the proposed limit does not violate a water quality standard because New Mexico has no water quality

standard for fluoride. See 33 U.S.C. §1342(o)(3); 40 C.F.R. § 122.44(1)(2)(ii) and Subpart III, Section 3101 of the New Mexico Standards for Interstate and Intrastate Streams (20 NMAC 6.1).

Molybdenum Concentration Limitations - *Molycorp requests that the molybdenum limitation at 001 be changed to represent those concentrations achievable by the application of BAT, 3.3 mg/l monthly average and 5.03 mg/l daily maximum, and that the monitor-only requirement at 002 remain the same.*

We believe that these limitations of 3.3 mg/l monthly average and 5.03 mg/l daily maximum are fully protective of the new, 1994 molybdenum stream standard in Segment 2-119 of the Red River system and meet what EPA has established as BAT for comparable industry subcategories.

The current permit has ~~one~~ a molybdenum limitation that appears to be based upon stream standards and another molybdenum limitation based upon an estimated BAT performance. The current mass limitation of 25 lbs/day appears to be based upon a water quality consideration to protect agricultural uses, which has become outdated, as explained below, due to the adoption of a new water quality standard in 1994. The concentration limitation at discharge point 001 was based upon what EPA believed would be achievable with the application of BAT. Each approach is discussed separately below.

Molybdenum Water Quality-Based Limitation

The present mass-based limit appears to be based upon protection of water quality utilized for agricultural purposes. The standard, as originally developed in 1977, established a mass discharge limit of no more than 176 lbs/day; however, it was changed to 25 lbs/day in the 1977 stipulated agreement with EPA. It is not clear as to what standard was being protected, but it is clear that the procedure used to develop the standard was prior to the adoption of the current State water quality standards regulation and prior to the adoption in 1994 of an agricultural standard for molybdenum in Segment 2-119.

Molycorp's permitted discharge is into Segment 2-119 of the Red River system. This segment has been classified for agricultural uses (irrigation) and as such, is subject to Subpart III, Section 3101 of the New Mexico Standards for Interstate and Intrastate Streams (20 NMAC 6.1). Section 3101.D, which lists water quality standards for irrigation, includes a stream standard for molybdenum of 1.0 mg/l. This water quality standard for molybdenum was adopted in 1994 and, due to this timing, that standard was not incorporated into the current permit limits.

Integrating the 1994 Segment 2-119 molybdenum stream standard into the Molycorp permit would be carried out in the same manner that other stream standards have been integrated into the permit. When one calculates the applicable molybdenum concentration limitation utilizing the current 1.0 mg/l agricultural standard in Segment 2-119, and utilizing EPA's mass balance equation, the resultant permit limitation is 4.55 mg/l, which is comparable to the 5.03 mg/l concentration referenced above as the BAT daily maximum for Outfall 001. This limitation of 4.55 mg/l equates to 178.5 lb/day molybdenum as the maximum permissible mass discharge.

Given the recent addition of molybdenum as a regulated parameter for the protection of agricultural uses, the permit should be updated to incorporate this new standard. Furthermore, Molycorp believes the agricultural use standards (Section 3101.D) may actually be chronic standards. This is in view of the fact that the standards listed in Section 3101.D as adopted by the New Mexico Water Quality Control Commission are intended by the Commission to protect the agricultural use designation. This implies that these standards are chronic standards. Molycorp is currently verifying this issue with the New Mexico Environment Department.

The present mass-based molybdenum limit was originally established in 1975. The 1975 permit established an interim discharge limit for molybdenum of 78 lbs/day daily average, and 156 lbs/day daily maximum. The interim limit was to be replaced in 1977 by a final limit of 25 lbs/day daily average, and 50 lbs/day daily maximum. Pursuant to a 1977 stipulation, the deadline for achieving this limit was extended to 1983.

The basis for calculating these molybdenum limits is explained in neither the 1975 permit documentation, the 1977 stipulation, nor in any other 1977 permit documentation. It is unknown to Molycorp. Although the 1977 stipulation indicated that the limits were intended to protect Red River water quality for irrigation usage, the State of New Mexico had no water quality standard for molybdenum in the Red River in 1975 and 1977. In fact, as of 1977 EPA had no published water quality criterion for molybdenum. Moreover in 1977, the State of New Mexico had recommended to EPA a revision of Red River stream segment boundaries to eliminate irrigation as a recognized use of the stream segment bordering Molycorp.

Molycorp's permitted discharge flows into Segment 2-119 of the Red River system. The New Mexico State water quality standards that govern this segment today include a new stream standard for molybdenum of 1.0 mg/l, which was adopted in 1994 and is therefore not incorporated into the current permit limits. To integrate this modified 1994 molybdenum stream standard into Molycorp's permit, EPA can calculate the applicable molybdenum concentration limitation by applying the 1.0 mg/l 1994 standard to EPA's mass balance equation. This calculation results in a permit limitation of 4.55 mg/l, which is more stringent than the 5.03 mg/l concentration referenced below as the BAT-equivalent daily maximum limit for Outfall 001. This limitation of 4.55 mg/l equates to 178.5 lbs/day of molybdenum as the maximum permissible mass discharge.

Because the basis of the current 25 lbs/day molybdenum limit is unclear, it is doubtful that the anti-backsliding prohibition of § 402(o) of the Clean Water Act applies. This prohibition specifically forbids the reissuance of a permit containing less stringent effluent limitations than the previous permit if the basis of those permit limitations is either (a) "best professional judgment" technology-based effluent limitations under § 402(a)(1)(B) of the Act, or (b) standards promulgated under §§ 301(b)(1)(C) or 303(d) or (e). 33 U.S.C. § 1342(o)(1). None of these types of limitations could have served as the basis for the 1977 25 lbs/day molybdenum limit. The 1977 limit was not technology-based, so § 402(a)(1)(B) does not apply. In 1977 there was no applicable state water quality standard or EPA water quality criterion for molybdenum, so § 301(b)(1)(C) did not apply. Finally, the Red River did not exceed any applicable state water quality standard for molybdenum, so §§ 303(d) or (e) did not apply.

Even if the anti-backsliding rule does apply, Molycorp meets the backsliding requirements for allowing the 178.5 lbs/day molybdenum limitation. In order for a less stringent limitation to be lawful, Molycorp must either rely on one of the exceptions at § 402(o) of the Act, or comply with § 303(d)(4). 33 U.S.C. § 1342(o)(1-2). Raising Molycorp's mass-based molybdenum limit to 178.5 lbs/day would comply with the anti-backsliding provisions of § 303(d)(4). That provision has different compliance tests depending upon whether the applicable water quality standard has been attained. 33 U.S.C. § 1313(d)(4). In Molycorp's case, the applicable water quality standard for molybdenum of 1.0 mg/l in Segment 2-119 of the Red River has been attained. As a result, Molycorp's effluent limitation may be revised upward to 178.5 lbs/day so long as it is consistent with the New Mexico State antidegradation policy. 33 U.S.C. § 1313(d)(4)(B). To maintain the existing quality of waters such as the Red River in which stream standards are already being met, New Mexico's antidegradation policy requires "the highest and best degree of effluent treatment practicable." 20 NMAC 6.1, § 1101(A) (1995). Molycorp meets this criterion because Molycorp's ion exchange plant offers equivalent performance to EPA's BAT for molybdenum in the industrial categories for which such a limit has been established.

The only remaining criteria imposed by the anti-backsliding requirement, the limitations at § 402(o)(3) of the Clean Water Act, also do not apply. There are no effluent guidelines for molybdenum in effect, and the less stringent 178.5 lbs/day mass limit for molybdenum would not result in a violation of a water quality standard. Hence EPA may incorporate the 178.5 lbs/day mass limit into Molycorp's permit in compliance with the antibacksliding requirement.

BAT/BPJ for Molybdenum

The original molybdenum concentration limitation that was incorporated into the 1977 permit was based upon what EPA believed could be achieved in the reduction of molybdenum in process water through the application of BAT if and when BAT was developed for the Ore Mining and Dressing category. The estimated performance established in 1977 was that a monthly average of 1.0 mg/l and a daily maximum of 2.0 mg/l could be achieved on a regular basis. These limits would be considered BPJ. Since 1977, EPA has actually developed BAT for the Ore Mining and Dressing category, which utilizes lime, settle and filter, but which did not quantify effectiveness nor establish a BAT limitation for molybdenum. Therefore, a BAT limitation for molybdenum for the Questa operation is not directly applicable.

Best Available Technology for molybdenum, however, has been developed by EPA for both the Metallurgical Acid Plant subcategory (40 C.F.R. Part 421) and the Nonferrous Metals Forming and Metal Powders subcategory (40 C.F.R. Part 471). Different limitations exist for each subcategory. For Nonferrous Metals Forming and Metal Powders, the daily maximum is 5.03 mg/l and the daily average is 2.23 mg/l (ten samples per month). For the Metallurgical Acid Plants category, molybdenum limitations were established on a temporary basis at 30 mg/l average and 60 mg/l maximum.

The derivation of daily maximums and monthly averages for molybdenum under BAT follows the same methodology as described above for fluoride. For the Nonferrous Metals Forming and Metal

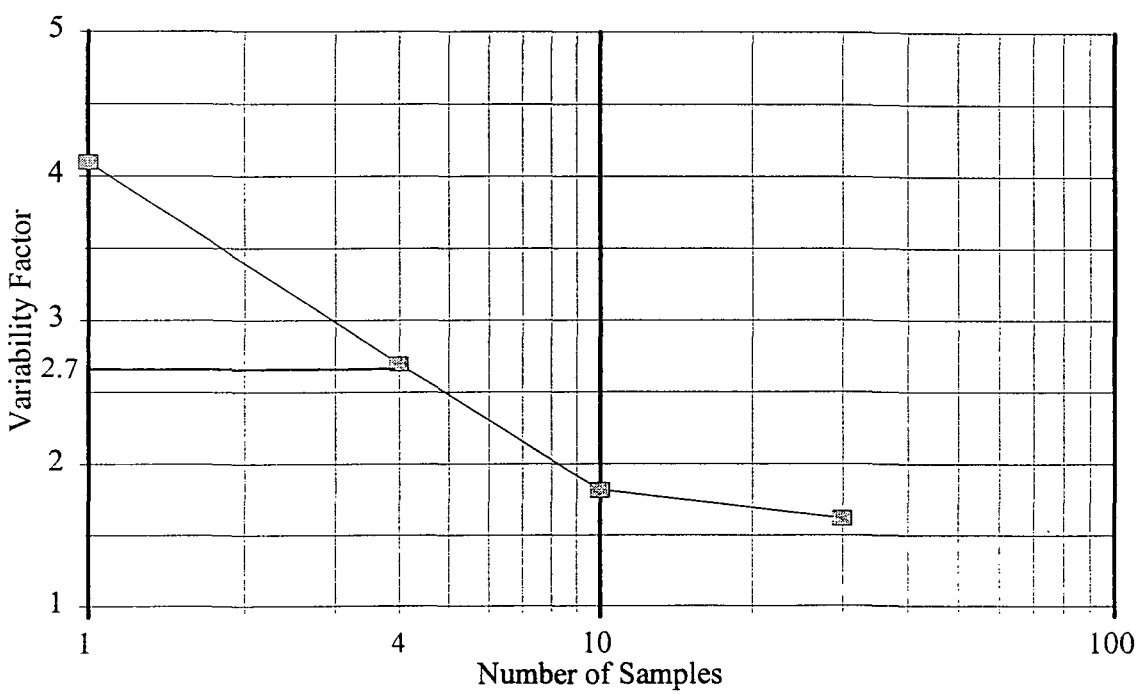
Powders category, EPA determined that the long-term BAT treatability concentration for molybdenum is 1.23 mg/l. Multiplying this concentration times the daily maximum variability factor of 4.1 yields the daily maximum BAT limitation of 5.03 mg/l. Likewise, multiplying the long term treatability concentration of 1.23 mg/l times the monthly average variability factor for ten samples per month of 1.821 yields a monthly average limitation of 2.23 mg/l.

As pointed out above, the monthly average calculation is based upon taking ten samples per month and averaging them. EPA spent a considerable effort in developing methodology for calculating a variability factor for the CMDB. Exhibit I-2 (EPA 440/1-79/003, August 1979) contains copies of EPA's rationale for support of variability factors and specific model development. The concept of variability factors supports EPA's observations that well-operated (BAT) treatment facilities experience inherent variability in system performance.

> "Allowance for the day-to-day variability in the concentration of a pollutant discharged from a well-designed and operated treatment system is incorporated into the standards by use of a 'variability factor'."

Figure 1.1 is a graphical representation taken from EPA data of variability factors versus the sampling frequency per month for a well-operated, BAT facility.

Figure 1-1
Variability Factors vs No. of Samples



As can be seen from Figure 1.1, the variability factor applicable if four samples per month are taken is 2.7. Applying this factor at 001, and assuming four samples per month as contained in the existing permit, yields a BAT monthly limitation of 3.3 mg/l. This limitation is more stringent than the limitation of 4.55 mg/l derived from the Segment 2-119, 1.0 mg/l agricultural standard for molybdenum.

The ion exchange plant offers equivalent performance to EPA's BAT for the Nonferrous Metals Forming and Metal Powders category, which is 3.3 mg/l average and 5.03 mg/l maximum, and far exceeds the limitations established by EPA for the Metallurgical Acid Plant category.

Molycorp is requesting less stringent molybdenum limitations at 001 than those in the existing permit. This request, however, does not violate the Clean Water Act's anti-backsliding rule. An exception to the anti-backsliding rule applies where "[t]he Administrator determines that technical mistakes...were made in issuing the [existing] permit" (33 U.S.C. §1342(o)(2)(B)(ii); 40 C.F.R. §122.44(I)(2)(i)(B)(2)), and where new information justifies less stringent limits (33 U.S.C. §1342(o)(2)(B)(i); 40 C.F.R. §122.44(I)(2)(i)(B)(1)).

The current molybdenum limitations at 001 of 1.0 mg/l average and 2.0 mg/l maximum originated in Molycorp's 1977 NPDES permit. (The first NPDES permit ever issued to Molycorp, on December 28, 1974, did not include any molybdenum concentration limitations.) These 1977 molybdenum limits apparently were based on EPA's best judgment as to the *results* obtainable by an application of best available technology economically achievable "as presently defined." Stipulated Agreement on NPDES Permit NM0022306 (June 16, 1977), at 7. Neither the permit nor the stipulated agreement which instituted it contain any explanation of the basis for EPA's judgment. The permit itself indicated only that Molycorp "shall develop a program to assure attainment of the [molybdenum] limitations by July 1, 1983." EPA, Authorization to Discharge, NPDES Permit NM0022306 (June 16, 1977), at 11.

In sum, EPA made a prediction about what the appropriate molybdenum concentration limits at 001 would be, based on no information we can identify. It then incorporated these limits in the 1977 permit, leaving Molycorp to figure out how to meet these limits.

Since 1977, however, two things have happened. First, EPA developed BAT limits for molybdenum that are much higher than the limits it gave Molycorp in 1977. Second, Molycorp completed its ion exchange plant in 1984. Since then, although the flows through 001 have been rare[1], molybdenum results from the ion exchange plant have corroborated the BAT limits. These results have generally exceeded the 1977 effluent limit. The average discharge concentration over the period 2/1/84 to 4/1/85 (23 data points) was 1.58 mg/l, with a standard deviation of 0.54 mg/l. The average performance plus two standard deviation equals 2.66 mg/l, which would support current EPA estimates as to what can be consistently achieved with BAT.

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[1] Indeed, past flows through 001 have been so infrequent that Molycorp has not previously sought recalculation of the 1977 molybdenum limitations. EPA should reconsider these limits now, however, because the mine anticipates an extended period of full production.

Molycorp's current molybdenum limits are thus based on "a technical mistake" EPA made in 1977 in predicting EPA's subsequent BAT limitations for molybdenum. New information justifies less stringent limits. Furthermore, since there are no applicable effluent limitations guidelines in effect for Molycorp's discharges of molybdenum, the restrictions on relaxation of limits found at §402(o)(3) of the Clean Water Act do not apply. A less stringent effluent limit in the 1998 permit is therefore permissible under the law.

Molybdenum Mass Limitation - *Molycorp requests that the mass discharge limitations for molybdenum at 001 be calculated based upon the allowed permitted flow of 4.290 MGD and the BAT concentration limitations.*

In the permit, particularly for those parameters based upon BPJ or BAT, there appears to be an inconsistency between the total allowed volumetric discharge rate and the mass discharge limitations based upon the maximum allowed discharge rate and concentration limit. For example, the current permit limit for molybdenum on a mass basis allows for the discharge of 25 lbs per day through the combined flow of 001 and 002. The recent flows at 002 correspond to a mass discharge of about 6 lbs/day, which leaves the balance of 19 lbs/day for 001. If the IX plant is operating at a molybdenum discharge concentration of 1.0 mg/l, 19 lbs/day would be discharged if the plant flowed at 1,582 g.p.m. This flow rate is considerably below the IX plant nominal capacity of 4,000 g.p.m.

The recommended approach is to utilize the permitted maximum flow for 001 and 002 of 4.726 MGD (3,283 gpm) and to calculate the desired mass allowance. For example, at a flow rate of 3,283 gpm and a BAT monthly average limitation of 3.3 mg/l, the mass limitation for combined 001 and 002 is calculated at 130 lb/day. This level is also protective of the Segment 2-119 agricultural standard for molybdenum that would permit a daily mass discharge of 178.5 lb./day.

Reduction of the Number of Parameters Monitored - *Molycorp requests that EPA delete from the permit those parameters that are consistently found at or below the minimum quantification level (MQL) and those parameters that are consistently less than 50 percent of the permit limitation and have never exceeded a permit limitation.*

The specific parameters and the reasons for deleting them are discussed below:

- For discharge location 001, arsenic was consistently below the MQL and Molycorp has no reason to believe that the concentration of this parameter will increase. (See Exhibit I-3.)

- For discharge location 001, COD, lead, manganese, and mercury were consistently detected at less than 50 percent of the concentration limits contained within the permit. Molycorp has no reason to believe that these parameter will increase in concentration, nor have those parameters ever exceeded permit limits. (See Exhibit

I-3.) We also refer to historical Outfall 001 water quality data which is presented in Exhibit I-4.

- For discharge locations 001 and 002, Molycorp requests that cyanide be dropped from the permit, as cyanide has not been used in the operation since 1985.

- For discharge location 002, COD, aluminum, arsenic, beryllium, cadmium, chlorine, chlordane, cobalt, copper, cyanide, mercury, selenium, silver, and zinc were consistently below the MQLs or the laboratory detection limit, and Molycorp has no reason to believe that the concentration of these parameters will increase. (See Exhibit I-5.)

- For discharge location 002, lead and iron were consistently detected at less than 50 percent of the concentration limits contained within the permit, and it is requested that these parameters be dropped. Molycorp has no reason to believe that these parameters will increase in concentration nor have those parameters ever exceeded permit limits. (See Exhibit I-5.)

EPA has acknowledged the need for and the technical justification for developing effluent limitations for an operation that focuses on several "key" parameters:

> "In general, EPA is not regulating non-conventional metal pollutants, even when they are the metal being formed. The Agency has concluded that regulation of just the priority metal pollutants will in most cases ensure the non-conventional metal pollutants are removed." (EPA 440/1-86/019, September 1986) (See Exhibit I-6.)

Indeed, EPA's regulations do not provide for control of every substance which has a water quality standard, but only those whose discharge might cause a standard to be exceeded in the receiving water.[2] The regulations require that permit limitations "control all pollutants or pollutant parameters...which...are or may be discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any State water quality standard, including State narrative criteria for water quality." 40 C.F.R. §122.44(d)(1)(i). Only if, after using the procedures listed at §122.44(d)(1)(ii), it is determined that an in-stream excursion above a State water quality standard for a pollutant may occur, must the permit contain effluent limits for that pollutant. *Id.* At §§ 122.44(d)(1)(iii).

Whole Effluent Toxicity Testing Frequency - *Molycorp requests that frequency of biomonitoring via the WET test at discharge locations 001 and 002 be reduced to once per year.*

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[2] EPA has proposed lifting limits even for guideline-listed pollutants on facilities that can certify that they are not discharging such pollutants. 61 Fed. Reg. 65273 (December 11, 1996).

One biomonitoring test per year is sufficient because there has never been a failure/noncompliance on testing carried out during the term of the existing permit. Although we have not had a discharge at location 001, compliance with the WET test at this discharge point will be similar to that achieved at 002. We are willing to confirm this similarity by sampling and testing once a quarter for the first twelve months of discharge from 001. If after this period the results confirm that the WET test is routinely passed, then we request approval in the permit to change frequency of testing to once per year. In this regard, the new permit should include a provision for this automatic reduction (upon passage of the test) in biomonitoring frequency. See Exhibit I-7 for a summary of test data for Outfall 002 for the first three quarters of 1996.

Total vs. Dissolved Analysis - *Molycorp requests that the permit be modified to allow for the use of **dissolved** analysis instead of **total** analysis for discharge samples taken at 002.*

We believe this request is reasonable for two reasons. First, and most important, discharge through 002 consists entirely of seepage water that is collected from a series of shallow wells and interceptor drains. This water, typical of developed wells and seepage water collection systems, should contain very low levels of suspended solids. For samples with zero or non-detect suspended solids, the results of a **total** analysis will be the same as the results from a **dissolved** analysis. Discharge monitoring data from 002 demonstrates that suspended solids are generally less than detection. Second, and just as important, a number of permit limitations, such as zinc, are based upon state water quality standards, which themselves are based upon concentration of **dissolved** metals. EPA under 40 CFR 122.45(c), which refers to technology-based limits, allows for the use of dissolved analysis if necessary to carry out the provisions of the Clean Water Act, which includes implementation of stream standards.

*Molycorp also requests that those parameters controlled and limited at 001, and that are also based on stream standards, be analyzed for **dissolved** rather than **total** metals; this is for the same reasons as stated above.*

EPA requires that metals limits in permits be stated as total recoverable in most cases. 40 C.F.R. §122.45(c). This is so despite the fact that EPA does not require that State water quality standards for metals be expressed as total recoverable metal. EPA, "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria," p. 5 (Oct.1, 1993) (See Exhibit I-8.) New Mexico expresses its water quality standards in terms of dissolved metals, so monitoring should be conducted on the same basis. Should EPA reject Molycorp's request to use dissolved metals analysis instead of total recoverable analysis, however, Molycorp requests a credit for translation from the dissolved to the total recoverable form.

Frequency of Analysis - *Molycorp requests that the frequency of sampling at 002 be reduced to twice a month and that the samples represent weekly composites.*

The current permit requires that discharge 002 be sampled on a composite basis once per week. We believe that this request to reduce monitoring frequency is justified on the basis that the flow discharged through 002 is collected seepage water and that the rate of change in quality is low as a result. Typical process waters can change frequently within certain ranges due to changes in operating conditions or the like. Seepage water, on the other hand, is not subject to these types of changes and therefore, water quality is more consistent. Seasonal changes to seepage water quality are more likely to be noted. Exhibit I-9 presents a summary of recent (last two years) water quality data for Outfall 002 which demonstrates the low variability of the data. We believe that twice a month sampling will adequately characterize and control water quality at 002.

Equivalent Molybdenum Analytical Procedure - *As approved by EPA in our current permit, Molycorp requests approval for continued use of an alternative molybdenum test procedure.*

Previous correspondence granting approval, together with supporting test results, can be found in Exhibit I-10.

EXHIBIT I-1

BEST AVAILABLE TECHNOLOGY FOR FLUORIDE REMOVAL - (EPA DEVELOPMENT DOCUMENT, EPA 44011-89-019.2, VOL. II)

not float "naturally" but require additional treatments. Therefore, skimming alone may not remove all the pollutants capable of being removed by air flotation or other more sophisticated technologies.

Operational Factors. Reliability: Because of its simplicity, skimming is a very reliable technique.

Maintainability: The skimming mechanism requires periodic lubrication, adjustment, and replacement of worn parts.

Solid Waste Aspects: The collected layer of debris must be disposed of by contractor removal, landfill, or incineration. Because relatively large quantities of water are present in the collected wastes, incineration is not always a viable disposal method.

Demonstration Status. Skimming is a common operation utilized extensively by industrial waste treatment systems. Oil skimming is used in four nonferrous metals manufacturing plants.

MAJOR TECHNOLOGY EFFECTIVENESS

The performance of individual treatment technologies was presented above. Performance of operating systems is discussed here. Two different systems are considered: L&S (hydroxide precipitation and sedimentation or lime and settle) and LS&F (hydroxide precipitation, sedimentation, and filtration or lime, settle, and filter). Subsequently, an analysis of effectiveness of such systems is made to develop one-day maximum, ten-day and thirty-day average concentration levels to be used in regulating pollutants. Evaluation of the L&S and the LS&F systems is carried out on the assumption that chemical reduction of chromium, cyanide precipitation and oil removal are installed and operating properly where appropriate.

L&S Performance -- Combined Metals Data Base

A data base known as the "combined metals data base" (CMDB) was used to determine treatment effectiveness of lime and settle treatment for certain pollutants. The CMDB was developed over several years and has been used in a number of regulations. During the development of coil coating and other categorical effluent limitations and standards, chemical analysis data were collected of raw wastewater (treatment influent) and treated wastewater (treatment effluent) from 55 plants (126 data days) sampled by EPA (or its contractor) using EPA sampling and chemical analysis protocols. These data are the initial data base for determining the effectiveness of L&S technology in treating nine pollutants. Each of the plants in the initial data base belongs to at least one of the following industry categories: aluminum forming, battery manufacturing, coil coating (including canmaking), copper forming, electroplating and porcelain enameling. All of the plants employ pH adjustment and hydroxide precipitation using lime or caustic, followed by

Stokes' law settling (tank, lagoon or clarifier) for solids removal. An analysis of this data was presented in the development documents for the proposed regulations for coil coating and porcelain enameling (January 1981). Prior to analyzing the data, some values were deleted from the data base. These deletions were made to ensure that the data reflect properly operated treatment systems. The following criteria were used in making these deletions:

- Plants where malfunctioning processes or treatment systems at the time of sampling were identified.

- Data days where pH was less than 7.0 for extended periods of time or TSS was greater than 50 mg/l (these are prima facie indications of poor operation).

In response to the coil coating and porcelain enameling proposals, some commenters claimed that it was inappropriate to use data from some categories for regulation of other categories. In response to these comments, the Agency reanalyzed the data. An analysis of variance was applied to the data for the 126 days of sampling to test the hypothesis of homogeneous plant mean raw and treated effluent levels across categories by pollutant. This analysis is described in the report "A Statistical Analysis of the Combined Metals Industries Effluent Data" which is in the administrative record supporting this rulemaking. Homogeneity is the absence of statistically discernible differences among the categories, while heterogeneity is the opposite (i.e., the presence of statistically discernible differences). The main conclusion drawn from the analysis of variance is that, with the exception of electroplating, the categories included in the data base are generally homogeneous with regard to mean pollutant concentrations in both raw and treated effluent. That is, when data from electroplating facilities are included in the analysis, the hypothesis of homogeneity across categories is rejected. When the electroplating data are removed from the analysis the conclusion changes substantially and the hypothesis of homogeneity across categories is not rejected. On the basis of this analysis, the electroplating data were removed from the data base used to determine limitations for the final coil coating, porcelain enameling, copper forming, aluminum forming, battery manufacturing, nonferrous metals manufacturing, nonferrous metals forming, and canmaking regulations.

Analytical data from nonferrous metals manufacturing treatment systems which include paired raw waste influent treatment and treated effluent are limited to nine plants with lime precipitation and sedimentation systems. Three of these systems were deemed to be inappropriate for consideration in establishing treatment effectiveness concentration for nonferrous metals manufacturing. Two of the plants had large non-scope flows entering the treatment system and the third had

high TSS (N 1000 mg/l) concentrations at the outfall of its lime and settle treatment system; concentrations indicative of poor system operation. The treated data from six of these nine nonferrous metals manufacturing plants with properly operated lime precipitation and sedimentation systems were compared to the achievable concentrations derived using the combined metals data base. These data generally supported the combined metals data base concentrations. These data and the analysis performed using the data are in the administrative record supporting this rulemaking.

EPA examined the homogeneity among nonferrous metals manufacturing subcategories, as well as across the combined metals data base. Homogeneity is the absence of statistically discernible differences among mean untreated pollutant concentrations observed in a set of data. The purpose of these analyses was to corroborate the Agency's engineering judgment that the untreated wastewater characteristics observed in the nonferrous category were similar to those observed in the combined metals data. Establishment of similarity of raw wastes through a statistical assessment provides further support to EPA's assumption that lime and settle treatment reduces the toxic metal pollutant concentrations in untreated nonferrous metals manufacturing wastewater to concentrations achieved by the same technology applied to the wastewater from the categories in the combined metals data base. In general, the results of the analysis showed that the nonferrous subcategories are homogeneous with respect to mean pollutant concentrations across subcategories. Comparison of the untreated nonferrous metals manufacturing data combined across subcategories and the combined metals data also showed good agreement.

The homogeneity observed among the nonferrous untreated data and the combined metals data supports the hypothesis of similar untreated wastewater characteristics and suggests that lime and settle treatment would reduce the concentrations of toxic metal pollutants in the nonferrous metals manufacturing to concentrations comparable to those achievable by lime and settle treatment of wastewater from the categories included in the combined metals data base.

There were several exceptions to the general finding of homogeneity among the industrial categories discussed above. The exceptional cases include:

1. Primary aluminum - cathode reprocessing wastewater and potline wet air pollution control wastewater commingled with cathode reprocessing wastewater.

2. Primary lead, zinc, and metallurgical acid plants - all process wastewater.

3. The primary beryllium subcategory has higher beryllium concentrations in the untreated wastewater than other plants in

in Table VII-14 (page 242) and are included in Table VII-21.

Additional Pollutants

Thirty-three additional pollutant parameters were evaluated to determine the performance of lime and settle treatment systems in removing them from industrial wastewater. Performance data for these parameters are not a part of the CMDB so other available data have been used to determine the long term average performance of lime and settle technology for each pollutant. These data are displayed in Table VII-15 (page 243). Treatment effectiveness values for these additional pollutants were calculated by multiplying the mean performance from Table VII-15 by the appropriate variability factor. (The variability factor is the ratio of the value of concern to the mean). The pooled variability factors are: one-day maximum - 4.100; ten-day average 1.821; and 30-day average - 1.618. These one-, ten-, and thirty-day values are tabulated in Table VII-21 (page 248).

In establishing which data were suitable for use in Table VII-15 two factors were heavily weighed: (1) the nature of the wastewater; and (2) the range of pollutants or pollutant matrix in the raw wastewater. These data have been selected from processes that generate dissolved metals in the wastewater and which are generally free from complexing agents. The pollutant matrix was evaluated by comparing the concentrations of pollutants found in the raw wastewaters with the range of pollutants in the raw wastewaters of the combined metals data set. The raw wastewater pollutant matrix for the CMDB is shown in Table VII-16 (page 243). Table VII-17 (page 244), displays the raw waste pollutant matrix of wastewaters from which long term average treatment effectiveness data were derived for 18 of the added pollutant(s). Data for the remaining added pollutants were developed from CMDB related manufacturing facilities. The available data on these added pollutants do not allow a homogeneity analysis as was performed on the combined metals data base. Because the concentrations of the componets in the raw wastewaters is similar to or less than that of the CMDB it is appropriate to logically assume transferability of the treated pollutant concentrations to the combined metals data base.

Antimony (Sb) - The achievable performance for antimony is based on data from a battery and secondary lead plant. Both EPA sampling data and recent permit data (1978-1982) confirm the achievability of 0.7 mg/l in the battery manufacturing wastewater matrix included in the combined data set. The 0.7 mg/l concentration is achieved at a nonferrous metals manufacturing and secondary lead plant with the comparable untreated wastewater matrix shown in Table VII-17 (page 244).

Arsenic (As) - The achievable performance of 0.51 mg/l for arsenic is based on permit data from two nonferrous metals

manufacturing plants. The untreated wastewater matrix shown in Table VII-17 (page 244) is comparable with the combined data set matrix.

Beryllium (Be) - The achievable performance of beryllium is from the nonferrous metals manufacturing industry. The 0.3 mg/l performance is achieved at a beryllium plant with the comparable untreated wastewater matrix shown in Table VII-17.

Mercury (Hg) - The achievable concentration of 0.06 mg/l for mercury is based on data from four battery plants. The untreated wastewater matrix at these plants was considered in the combined metals data set.

Selenium (Se) - The achievable concentration of 0.30 mg/l for selenium is based on recent permit data from one of the nonferrous metals manufacturing plants also used for arsenic performance. The untreated wastewater matrix for this plant is shown in Table VII-17.

Silver (S) - The achievable concentration of 0.1 mg/l for silver is based on an estimate from the inorganic chemicals industry. Additional data supporting a treatability as stringent or more stringent than 0.1 mg/l is also available from seven nonferrous metals manufacturing plants. The untreated wastewater matrix for these plants is comparable and summarized in Table VII-17.

Thallium (Tl) The 0.50 mg/l treatability for thallium is transferred from the inorganic chemicals industry. Although no untreated wastewater data are available to verify comparability with the combined metals data set plants, no other sources of data for thallium treatability could be identified.

Aluminum (Al) - The 2.24 mg/l achievable concentration of aluminum is based on the mean performance of three aluminum forming plants and one coil coating plant. These plants are from categories included in the combined metals data set, assuring untreated wastewater matrix comparability.

Barium (Ba) - The achievable performance for barium (0.42 mg/l) is based on data from one nonferrous metals forming plant. The untreated wastewater matrix shown in Table VII-17 is comparable with the combined metals data base.

Boron (B) - The achievable performance of 0.36 mg/l for boron is based on data from a nonferrous metals plant. The untreated wastewater matrix shown in Table VII-17 is comparable with the combined metals data base.

Cesium (Cs) - The achievable performance for cesium (0.124 mg/l) is based on the performance achievable for sodium using ion exchange technology. This transfer of performance is technically justifiable because of the similarity of the chemical and physical behavior of these monovalent atoms.

Cobalt (Co) - The 0.05 mg/l achievable concentration is based on nearly complete removal of cobalt at a porcelain enameling plant with a mean untreated wastewater cobalt concentration of 4.31 mg/l. In this case, the analytical detection limit using aspiration techniques for this pollutant is used as the basis of the treatability. Porcelain enameling was considered in the combined metals data base, assuring untreated wastewater matrix comparability.

Columbium (Nb) - Data collected at two refractory metals forming plants indicate that lime and settle reduces columbium to below the level of detection (using x-ray fluorescence analytical methods) when an operating pH of eight is maintained. Another sampled lime and settle treatment system is operated at a higher pH, from 10.5 to 11.5. Effluent concentrations of columbium from this system are significantly higher. Therefore, the data indicate that if the treatment system is operated at a pH near 8, columbium should be removed to below the level of detection. The level of detection (0.12 mg/l) is used as the one-day maximum concentration for lime and settle treatment effectiveness values are established since it is impossible to determine precisely what concentrations are achievable. The untreated wastewater matrix shown in Table VII-17 (page 244) is comparable with the combined metals data base.

Fluoride (F) - The 14.5 mg/l treatability of fluoride generally applicable to metals processing is based on the mean performance (47 samples) from two electronics manufacturing phase II plants. The untreated wastewater matrix for this plant shown in Table VII-17 is comparable to the combined metals data set.

Gallium (Ga) - The achievable concentration of gallium is assumed to be the same as the level for chromium (0.084 mg/l) for the reasons discussed below for indium.

Germanium (Ge) - The achievable concentration of germanium is assumed to be the same as the level for chromium (0.084 mg/l) for the reasons discussed for indium (see below).

Gold (Au). The treatment effectiveness value for gold (0.1 mg/l) is based on the performance achieved at a secondary precious metals manufacturing facility whose treatment scheme includes lime, settle, filter and ion exchange. This value is supported by data obtained from an ion exchange equipment manufacturer (Rohm & Haas) for treatment of electroplating rinse water.

Hafnium (Hf) - The achievable performance for hafnium (7.28 mg/l) is based on the performance achieved for zirconium at two nonferrous metals forming plants. The Agency believes that since the water chemistry for zirconium and hafnium is similar, hafnium can be removed to the same levels as zirconium.

Indium (In) - The achievable concentration for indium is assumed to be the same as the level for chromium (0.084 mg/l).

EXHIBIT I-2

EPA RATIONALE FOR SUPPORT OF VARIABILITY FACTORS
(EPA 440/1-79/003, August 1979)

United States
Environmental Protection
Agency
Water and Waste Management

Effluent Guidelines Division
WH-552
Washington, DC 20460

EPA 440/1-79/003
August 1979

EPA

Development Document for Existing Source Pretreatment Standards for the Electroplating Point Source Category

Final

Environmental Protection Agency
Library
1860 Lincoln
Denver, CO 80295 Suite 203

DEVELOPMENT DOCUMENT

for

EXISTING SOURCE PRETREATMENT STANDARDS

for the

ELECTROPLATING

POINT SOURCE CATEGORY

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This section provides an overview of statistical methodologies employed to determine pretreatment standards for the electroplating industry. The methodology consisted essentially of determining long term average pollutant discharges, expected from a well designed and operated pretreatment system, and multiplying these long term averages by variability factors designed to allow for random fluctuations in treatment system performance. The resulting products yielded daily and 30-day-average maximum limitations for each pollutant. A simple, approximate equation was employed to obtain N-day-average maximum limitations for N = 2, 3,...29. Modifications of this procedure were made to accommodate mass-based and TSS options. The general statistical derivation of long term averages, variability factors, and the resulting limitations follows.

Determination of Long Term Average

The long term average (LTA) is the expected discharge concentration of a pollutant in mg/l from an electroplating plant having a well designed, maintained, and operated pretreatment system. The long term average was determined for each pollutant to be regulated, and used to obtain corresponding limitations for that pollutant. It is not intended as a limitation itself, but rather as a specification which the pretreatment system should be designed to attain over the long term.

For the analyses on hexavalent chromium and cyanide and the metals plated in the Electroless and Printed Circuit Board subcategories, the long term average was calculated as the median of the plant averages for each of these pollutants.

Determination of Variability Factors

Even plants that are achieving good pollutant removal experience fluctuations in the discharge pollutant concentrations from their pretreatment system. These fluctuations may reflect temporary imbalances in the treatment system caused by fluctuations in flow, raw waste load of a particular pollutant, chemical feed, mixing flows within tasks, or a variety of other factors.

Allowance for the day-to-day variability in the concentration of a pollutant discharged from a well designed and operated treatment system is incorporated into the standards by the use of a "variability factor." The theoretical derivation of the variability factor is presented in Appendix XII-A.1. Under certain assumptions, discussed below, the application of a variability factor allows the calculation of an upper bound for the concentration of a particular pollutant such that in expectation 99 percent of the randomly observed daily values

from a pretreatment system discharging this pollutant at a known mean concentration will fall below this bound.

The theoretical derivation of the variability factor is based on the assumption that the daily pollutant concentrations follow a lognormal distribution. This assumption is supported by test statistics (Kuiper and Kolmogorov-Smirnov, not reported here), plots of the cumulative distribution of observed concentrations for various pollutants (as shown later), and comparisons of variability factors estimated from plant data by two theoretically equivalent formulas (Appendix XII-A.3).

The variability factor is estimated by the equation derived in Appendix XII-A.1, which is:

$$\log (VF) = Z(Sigma) - 1.15(Sigma)^2 \qquad [1]$$

where

VF is the variability factor

Z is 2.326, which is the 99 percentile of the standard normal distribution, and

Sigma is the standard deviation of the logarithms (base 10) of the concentrations.

The accuracy of the variability factor is a function of the accuracy of Sigma, the standard deviation of the logarithm of the observations of a well designed and well operated plant. Important considerations for assessing the accuracy of Sigma include:

1. the randomness of the concentrations sampled for each plant,

2. the number and accuracy of the daily samples per plant,

3. the number and appropriateness of the plants included in the sample, and

4. the assumption that the daily pollutant concentrations follow a lognormal distribution.

The last consideration has been discussed above. The methodology for obtaining Sigma, and thus VF, takes into consideration the first three factors.

The estimated single-day variability factor of a pollutant from a well designed and operated plant was calculated in the following manner:

1. For each plant[1] with 10 or more but less than 100 observations and a small number of 0 values[2] for the pollutant, Sigma was calculated according to the standard statistical formula[3] and was then substituted into Equation [1] to find the VF.

2. For those plants with over 100 observations, the VF was estimated directly by dividing the 99th percentile of observed sample values by the average of the observations.

3. The VF for each pollutant was then calculated to be the median of the plant variability factors for that pollutant.

Allowance for the variability of the average of a random sample of N daily observations about the mean value of a pollutant discharged from a well designed and operated pretreatment system was obtained by use of a theoretically derived term (Appendix XII-A.2) called the "N-day-

---

[1]Plants with both high and low average concentrations fulfilling the stated conditions were included in the data base to calculate the variability factors. This was done since Appendix XII-A.4 showed that the sample means and standard deviations of the logarithms of the concentrations of a specific pollutant for each plant were not significantly correlated across plants, i.e., standard deviations from plants with high average concentration were not significantly larger than standard deviations from plants with low average concentrations for each pollutant. This is consistent with the assumption of lognormality.

[2]Only 7 of 68 cases observed effluent concentrations of 0 and these never represented more than 25% of the observations. Since log(0) is undefined, the 0 values were set equal to one-half the next lowest pollutant concentration. This was found to have little effect on the results and in six of the above seven cases, the individual variability factors were greater than the median variability factor.

[3]
$$\frac{(x \quad - x)^2}{n-1}$$

where

x is the log of observation i
x is the average of the observations
n is the number of observations

average variability factor." This term allows the calculation of an upper bound for the concentration of a particular pollutant (under the same assumptions stated above) such that in expectation 99 per cent of the randomly observed N-day average values from a pretreatment system discharging the pollutant at a known mean concentration will fall below this bound. Thirty-day average variability factors are reported in all analyses.

The N-day-average variability factor was estimated by a theoretically based equation (Appendix XII-A.2).

$$\log(VF\ ) = Z(Sigma\ ) - 1.15(Sigma\ )^2 \qquad [2]$$

where

VF is the N-day-average variability factor

Z is 2.326, which is the 99th percentile of the standard normal distribution, and

Sigma is a function of Sigma and N.

Sigma can be obtained from the estimate of the (daily) variability factor, VF, as outlined in Appendix XII-A.2. This is a departure from the Monte Carlo simulation used to calculate this term in the previous Development Document for proposed electroplating pretreatment regulations.

Determination of Limitations

Daily maximum and 30-day-average maximum limitations (L and L_{30}, respectively) were calculated for each pollutant from the long term average (LTA), the daily variability factor (VF), and the 30-day-average variability factor (VF_{30}) for that pollutant by the following equations:

$$L = VF \times LTA \qquad [3]$$

$$L_{30} = VF_{30} \times LTA \qquad [4]$$

The daily maximum limitation calculated for each pollutant is a value which is not to be exceeded on any one day by a plant discharging that pollutant. The 30-day-average maximum limitation is a value which is not to be exceeded by the average of any 30 single-day observations for the regulated pollutant.

APPENDIX XII-A.1

DERIVATION OF DAILY VARIABILITY FACTOR EQUATION

The daily concentration of a plant's metal or pollutant discharge is assumed to be random and was found to closely follow the lognormal distribution (Chapter XII and Appendix XII-A.3). The variability factor is a measure of the daily fluctuation of the effluent pollutant concentration and is measured by the ratio of concentration to its long-term average. Given the lognormality of the discharge concentration, the equation to calculate the variability factor (Equation (1) of Chapter XII) is

$$\log(VF) = Z(\text{Sigma}) - 1.15(\text{Sigma})^2 \qquad (1)$$

where VF = the variability factor

Z = 2.326 (99th percentile of the standard normal distribution)

Sigma = the standard deviation of the log of the observations

The derivation of this equation is set out below.

C = concentration of metal or pollutant in discharge

A = average of concentration

= μ (C)

σ = standard deviation of the logarithm of C

= σ (log C)

μ = average of the logarithm of C

= μ (log C)

Z = standard normal variable.

In the following calculations, the use of "log" or the subscript "10" refers to common logarithms (base 10). When μ and σ do not appear with a subscript, they refer to the mean and standard deviation of ln(C) (i.e., the natural logarithm of C).

It is assumed that C follows a lognormal distribution. Therefore, log C is normally distributed. Thus:

$$Z = \frac{\log C - \mu_{10}}{\sigma_{10}} \tag{2}$$

or

$$\log C = \mu_{10} + Z\sigma_{10} \tag{3}$$

According to Aitchison and Brown*:

$$A = e^{(\mu + 0.5\sigma^2)} \tag{4}$$

This equation follows directly from lognormal properties. Equation (4) is now conveniently converted to the common logarithm (base 10).

$$\log A = \mu_{10} + 1.15\sigma^2_{10} \quad (\text{since } \ln(y) = \log(y) \times 2.3026) \tag{5}$$

Substituting (3) and (5) into

$$\log (C/A) = \log C - \log A \tag{6}$$

gives

$$\log (C/A) = Z\sigma_{10} - 1.15\sigma^2_{10} \tag{7}$$

---

* Aitchison, J. and Brown, J.A.C., The Lognormal Distribution, Cambridge University Press, London, Page 8, 1969.

Finally, replacing C/A and σ_{10} with their sample estimates, VF and Sigma, respectively, and Z by 2.326 (99th percentile of standard normal distribution), in Equation (7) results in the variability factor equation, Equation (1).

APPENDIX XII-A.2

DERIVATION OF THE N-DAY-AVERAGE VARIRABILITY FACTOR

The variability factor for the N-day-average for N greater than or equal to two was estimated from the following equation:

$$\log (C_N/A) = Z\sigma^*_N - 1.15\sigma^{*2}_N \quad (1)$$

where

C_N = average concentration of N daily observations

A = average of concentration

σ^*_N = adjusted standard deviation for the logarithm of the concentrations used for the N-day-average (derived below)

Z = 2.326 (99th percentile of the standard normal distribution).

Assume X, concentration of a pollutant in the discharge, to be lognormal with μ and σ as the mean and standard deviation of ln(X). Then, based on lognormal properties:

$$E(X) = e^{\mu + \frac{1}{2}\sigma^2} \quad (2)$$

$$Var(X) = e^{2\mu + \sigma^2}(e^{\sigma^2} - 1) \quad (3)$$

For the N-day-average, $\overline{X}_N$, where each X is independent:

$$E(\overline{X}_N) = E(X) \quad (4)$$

$$Var(\overline{X}_N) = \frac{Var(X)}{N} \quad (5)$$

It was then assumed that $\overline{X}_N$ follows a lognormal distribution with parameters μ'_N and σ'_N. The assumption, though theoretically invalid (since distribution of $\overline{X}_N$ is unknown), was made in order to approximate the true distribution of $\overline{X}_N$ in the upper tail of the distribution and, based on this approximation, to obtain estimates of the standard deviation, variability factor and limitation of the N-day-average. The validity of this assumption was examined later by comparing the 99th percentile of the empirical distribution of $\overline{X}_N$ with the 99th percentile based on the lognormality assumption and Equation (1).

Since $\overline{X}_N$ is assumed to be lognormal, E $(\overline{X}_N)$ and Var $(\overline{X}_N)$ are given by:

$$E\ (\overline{X}_N) = e^{(\mu'_N + \frac{1}{2}\sigma'^2_N)} \tag{6}$$

$$Var\ (\overline{X}_N) = e^{(2\mu'_N + \sigma'^2_N)}\ (e^{\sigma'^2_N} - 1) \tag{7}$$

Using equations (2), (3), (4), (5), (6), and (7),

μ'_N and σ'^2_N are derived in terms of μ and σ as:

$$\mu'_N = \mu + \frac{\sigma^2}{2} - \frac{1}{2} \ln\ (1 + \frac{e^{\sigma^2} - 1}{N}) \tag{8}$$

$$\sigma'^2_N = \ln\ (1 + \frac{e^{\sigma^2} - 1}{N}) \tag{9}$$

where σ is the standard deviation of the natural logarithm of the observations. Finally, σ'_N is transformed back to the log (base 10) by the following expression.

$$\sigma^*_N = \sigma'_N \times \frac{1}{2.3026} \quad (\text{since } \ln(y) = \log(y) \times 2.3026) \tag{10}$$

This parameter σ^*_N, the assumption of lognormality stated above, and the theory in Appendix XII-A.1 result in Equation (1).

Calculation of the N-Day-Average Variability Factor

The N-day-average variability factor, VF_N, is an estimate of C_N/A and is obtained from:

$$\log (VF_N) = Z\ Sigma_N - 1.15\ (Sigma_N)^2 \tag{11}$$

where $Sigma_N$ is an estimate of σ^*_N. Sigma can be obtained indirectly from the variability factor, VF, calculated in Equation (1) of Appendix XII-A.1. Sigma can be found by substituting VF into this equation. This, in turn, can be transformed into the estimate of σ, the standard deviation of the natural logarithm of the observations, using the relation:

$$\ln(y) = \log(y) \times 2.3026 \tag{12}$$

This estimate is substituted in Equation (9) to obtain an estimate of σ'_N. Applying Equation (12) to the last estimate gives the desired value, $Sigma_N$.

EXHIBIT I-3

DISCHARGE LOCATION 001

(Those parameters that are consistently less than their MQL, and those parameters that are consistently less than 50 percent of the permit limitation)

Exhibit I-3

Comparison of Selected Outfall 001 Constituents to Permit MQLs (all values in mg/l)		
Constituent	**Arithmetic Mean of DMR 30-day Averages**	**Constituent MQL**
Arsenic (tot)	0.0067	0.01
Cyanide (tot) (amenable to chlorination)	0.0010	0.01

Comparison of Selected Outfall 001 Constituents to Permit Effluent Limitations (all values in mg/l)		
Constituent	**Arithmetic Mean of DMR 30-day Average**	**Permit Effluent Limitation Daily Average**
Chemical Oxygen Demand	7.67	60
Lead (tot)	0.06	0.3
Manganese (tot)	0.40	1.0
Mercury (tot)	0.0001	0.001

EXHIBIT I-4

OUTFALL 001 HISTORIC WATER QUALITY

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	FLOW		TEMPERATURE				HARDNESS	CHEMICAL OXYGEN DEMAND			
	(MGD)		(DEG. F)		(DEG. C)		(mg/l)	(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.		Avg.	Max.	Avg.	Max.
2/1/85	3.10	4.10			8.0	9.0				11.00	12.00
3/1/85	1.69	3.31	48.0	50.0						7.00	10.00
4/1/85	0.14	0.14	50.0	50.0						5.00	5.00
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	pH			TOTAL SUSPENDED SOLIDS				CYANIDE (tot.)			
	(S.U.)			(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Min.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85	6.70		6.90			4.0	6.0			0.002	0.002
3/1/85	8.20		8.80			4.0	7.0			<0.001	<0.001
4/1/85	8.00		8.00			3.0	3.0			0.001	0.001
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	FLUORIDE (tot.)				ARSENIC (tot.)				BERYLLIUM (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85				1.9			0.01	0.01				
3/1/85				2.0			<0.01	<0.01				
4/1/85				2.0			0.01	0.01				
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	CADMIUM (tot.)				COBALT (tot.)				COPPER (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85				0.02							0.01	0.01
3/1/85				0.02							0.02	0.03
4/1/85				0.01							0.02	0.02
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	IRON (tot.)				LEAD (tot.)				MANGANESE (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85				0.31			0.06	0.08			0.32	0.56
3/1/85				0.33			0.07	0.07			0.43	0.49
4/1/85				0.48			0.05	0.05			0.46	0.46
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	MOLYBDENUM (tot.)				SILVER (tot.)				VANADIUM (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85	13.00	28.00	0.50	0.62								
3/1/85	9.60	21.00	0.68	0.76								
4/1/85	0.60	0.60	0.46	0.46								
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	ZINC (tot.)				ALUMINUM (tot.)				SELENIUM (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85				0.03								
3/1/85				0.06								
4/1/85				0.01								
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

TABLE 1
OUTFALL 001 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	CHLORDANE (tot.)				CHLORINE (tot.)				MERCURY (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85											<.0002	<.0002
3/1/85											0.0001	0.0002
4/1/85											0.0002	0.0002
1/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
2/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
3/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
4/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
5/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
6/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
7/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
8/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
9/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
10/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
11/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge
12/1/96	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge	No Discharge

EXHIBIT I-5

DISCHARGE LOCATION 002

(Those parameters that are consistently less than their MQL, and those parameters that are consistently less than 50 percent of the permit limitation)

Exhibit I-5

Comparison of Selected Outfall 002 Constituents to Permit MQLs (all values in mg/l)		
Constituent	**Arithmetic Mean of DMR 30-day Averages**	**Constituent MQL**
Chemical Oxygen Demand	5.48	(NA)
Aluminum (tot)	0.0045	(NA)
Arsenic (tot)	0.0008	0.01
Beryllium (tot)	0.000	0.005
Cadmium (tot)	0.0004	0.001
Chlorine (tot resid.)	0.000	0.011
Chlordane (tot)	0.000	0.0002
Cobalt (tot)	0.000	(NA)
Copper (tot)	0.0042	0.01
Cyanide (tot) (amenable to chlorination)	0.0006	0.01
Mercury (tot)	0.000008	0.0002
Selenium (tot)	0.0000	0.005
Silver (tot)	0.0000	0.002
Zinc (tot)	0.0015	0.02

Comparison of Selected Outfall 002 Constituents to Permit Effluent Limitations (all values in mg/l)		
Constituent	**Arithmetic Mean of DMR 30-day Average**	**Permit Effluent Limitation Daily Average**
Iron (tot)	0.02	0.6
Lead (tot)	0.009	0.3

EXHIBIT I-6

EPA LANGUAGE ON KEY PARAMETERS FROM DEVELOPMENT DOCUMENT ON NONFERROUS METAL FORMING, (EPA 440/1-86/019)

DEVELOPMENT DOCUMENT

for

EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS

for the

NONFERROUS METALS FORMING AND METAL POWDERS

POINT SOURCE CATEGORY

VOLUME III

Lee M. Thomas
Administrator

Lawrence J. Jensen
Assistant Administrator for Water

William A. Whittington
Director
Office of Water Regulations and Standards

Devereaux Barnes, Acting Director
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Ernst P. Hall, P.E., Chief
Metals Industries Branch

Janet K. Goodwin
Technical Project Officer

September 1986

U.S. Environmental Protection Agency
Office of Water
Office of Water Regulations and Standards
Industrial Technology Division
Washington, D.C. 20460

model technology were added at Option 2. Since the Agency cannot show any incremental pollutant removal with the application of additional flow reduction technologies to direct dischargers, the BAT limitations are based on Option 1. Thus, BPT and BAT limitations for the metal powders subcategory are equal.

REGULATED POLLUTANT PARAMETERS

In each nonferrous metals forming subcategory, the raw wastewater concentrations from individual operations and the subcategory as a whole were examined to select those pollutant parameters found at frequencies and concentrations warranting regulation. In general, in each subcategory EPA has selected for regulation the two or three priority metals present at the highest concentrations in the raw waste, because in removing these two or three priority metals, the lime and settle treatment system also provides adequate removal of the priority and nonconventional metal pollutants present at lower concentrations. By establishing limitations for only two or three priority metal pollutants instead of all priority metals present at treatable concentrations, dischargers should attain the same degree of control as they would have been required to achieve had all priority metal pollutants been directly limited, with fewer monitoring and recordkeeping requirements.

In each subcategory, the metal pollutant present in the highest concentration is the metal being subjected to the forming operations. In several subcategories the metal pollutant present in the greatest amount is a priority pollutant (nickel in the nickel-cobalt forming subcategory, for example). In other subcategories, the metal pollutant present in greatest amount is a nonconventional pollutant (titanium in the titanium forming subcategory, for example). In general, EPA is not regulating nonconventional metal pollutants, even when they are the metal being formed. The Agency has concluded that regulation of just the priority metal pollutants will in most cases ensure the nonconventional metal pollutants are removed. Further, establishing regulations for only the priority metal pollutants allows plants greater flexibility in combining wastewater streams for treatment which are covered by more than one category or subcategory, because the pollutants controlled are more likely to be the same. However, EPA is regulating one nonconventional metal pollutant, molybdenum, in the refractory metals forming and uranium forming subcategories. A lime and settle system alone will not remove molybdenum adequately; it is necessary to add iron to coprecipitate molybdenum. Molybdenum is present in significant concentrations at refractory metals plants because it is one of the refractory metals being formed. It is also present in significant concentrations at uranium forming plants because it is used as a major alloying agent in depleted uranium alloys.

As discussed in Section VII, maintaining the correct pH in the treatment system is important to assure adequate removal of priority metal pollutants. The Agency believes that by maintaining the correct pH range for removal of the regulated

United States
Environmental Protection
Agency

Industrial Technology Division
WH-552
Washington, DC 20460

EPA 440/1-86/019
September 1986

Water

EPA

Development Document for Effluent Limitations Guidelines and Standards for the Nonferrous Metals Forming and Metal Powders

Final

Point Source Category

Volume III

DEVELOPMENT DOCUMENT

for

EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS

for the

NONFERROUS METALS FORMING AND METAL POWDERS

POINT SOURCE CATEGORY

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Washington, D.C. 20460

Table VII-21

SUMMARY OF TREATMENT EFFECTIVENESS (mg/l)

Pollutant Parameter	L&S Technology System Mean	One-Day Maximum	10-Day Average	30-Day Average	LS&F Technology System Mean	One-Day Maximum	10-Day Average	30-Day Average	Sulfide Precipitation Filtration Mean	One-Day Maximum	10-Day Average	30-Day Average
114 Sb	0.70	2.87	1.28	1.14	0.47	1.93	0.86	0.76				
115 As	0.51	2.09	0.93	0.83	0.34	1.39	0.62	0.55				
117 Be	0.30	1.23	0.55	0.49	0.20	0.82	0.37	0.32				
118 Cd	0.079	0.34	0.15	0.13	0.049	0.20	0.08	0.08	0.01	0.04	0.018	0.016
119 Cr	0.084	0.44	0.18	0.12	0.07	0.37	0.15	0.10	0.08	0.21	0.091	0.081
120 Cu	0.58	1.90	1.00	0.73	0.39	1.28	0.61	0.49	0.05	0.21	0.091	0.081
121 CN	0.07	0.29	0.12	0.11	0.047	0.20	0.08	0.08				
122 Pb	0.12	0.42	0.20	0.16	0.08	0.28	0.13	0.11	0.01	0.04	0.018	0.016
123 Hg	0.06	0.25	0.10	0.10	0.036	0.15	0.06	0.06	0.03	0.13	0.0555	0.049
124 Ni	0.74	1.92	1.27	1.00	0.22	0.55	0.37	0.29	0.05	0.21	0.091	0.081
125 Se	0.30	1.23	0.55	0.49	0.20	0.82	0.37	0.33				
126 Ag	0.10	0.41	0.17	0.16	0.07	0.29	0.12	0.10	0.05	0.21	0.091	0.081
127 Tl	0.50	2.05	0.91	0.81	0.34	1.40	0.61	0.55				
128 Zn	0.33	1.46	0.61	0.45	0.23	1.02	0.42	0.31	0.01	0.04	0.018	0.016
Al	2.24	6.43	3.20	2.52	1.49	6.11	2.71	2.41				
Co	0.05	0.21	0.09	0.08	0.034	0.14	0.07	0.06				
F	14.5	59.5	26.4	23.5		59.5	26.4	23.5				
						35	19.9					
Fe	0.41	1.20	0.61	0.50	0.28	1.20	0.61	0.50				
Mn	0.16	0.68	0.29	0.21	0.14	0.30	0.23	0.19				
P	4.08	16.7	6.83	6.60	2.72	11.2	4.6	4.4				
O&G		20.0	12.0	10.0		10.0	10.0	10.0				
TSS	12.0	41.0	19.5	15.5	2.6	15.0	12.0	10.0				

Table VII-22

SUMMARY OF TREATMENT EFFECTIVENESS FOR SELECTED NONCONVENTIONAL METAL POLLUTANTS (mg/l)

Pollutant Parameter	L&S Technology System Mean	One-Day Maximum	10-Day Average	30-Day Average	LS&F Technology System Mean	One-Day Maximum	10-Day Average	30-Day Average
NH3	32.2	133.3	58.6	52.1	32.2	133.3	58.6	52.1
Cb	**	0.12*	**	**	**	0.12*	**	**
Au	**	0.1	**	**	**	0.1	**	**
Hf	7.28	28.8	13.9	NC	4.81	19.7	9.01	NC
Mg	**	0.1*	**	**	**	0.1*	**	**
Mo	1.83	6.61	3.42	NC	1.23	5.03	2.23	NC
Pt	**	0.1	**	**	**	0.1	**	**
Ta	**	0.45*	**	**	**	0.45*	**	**
Ti	0.19	0.94	0.41	NC	0.13	0.53	0.23	NC
W	1.29	6.96	2.78	NC	0.85	3.48	1.55	NC
U	4.00	6.50	4.73	NC	2.67	4.29	3.12	NC
V	**	0.1*	**	**	**	0.1*	**	**
Zr	7.28	28.8	13.9	NC	4.81	19.7	9.01	NC

**None established.

*Limits of detection.

NC - Not calculated.

EXHIBIT I-7

HISTORIC BIOMONITORING TEST RESULTS FOR OUTFALL 002

NAME [redacted] COLORADO INC. QUESTA DIV. [redacted]

ADDRESS P. O. BOX 469

QUESTA NM 87556

FACILITY

LOCATION

ATTN: DAVID R SHOEMAKER, GEN. SUPT.

[redacted] (16) [redacted] (19) [redacted]

NM0022306 — PERMIT NUMBER

TX2 0 — DISCHARGE NUMBER

F - FINAL

MAJOR

Form Approved. 12375
OMB No. 2040-0004
Approval expires 10-31-94

MONITORING PERIOD	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	01	01	TO	96	03	31
	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)

*** NO DISCHARGE [ ] ***

NOTE: Read Instructions before completing this form.

PARAMETER (32-37)		QUANTITY OR LOADING (3 Card Only) (46-53) AVERAGE	QUANTITY OR LOADING (54-61) MAXIMUM	UNITS	QUALITY OR CONCENTRATION (4 Card Only) (38-45) MINIMUM	QUALITY OR CONCENTRATION (46-53) AVERAGE	QUALITY OR CONCENTRATION (54-61) MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
TX P/F LETH STATRE 7 DAY CHR CERIODAPHNIA 1P3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	0	******	(19A)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PASS=0 FAIL=1		TRLY	COMP24
TX P/F LETH STATRE 7 DAY CHR PIMEPHALES 1P6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	0	******	(19A)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PASS=0 FAIL=1		TRLY	COMP24
TX2 LETHAL STATRE 7 DAY CHR CERIODAPHNIA 1P3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		TRLY	COMP24
TX2 LETHAL STATRE 7 DAY CHR PIMEPHALES 1P6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		TRLY	COMP24
TX2 SUB-LTH STATRE 7 DAY CHR CERIODAPHNI 1P3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		TRLY	COMP24
TX2 SUB-LTH STATRE 7 DAY CHR PIMEPHALES 1P6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		TRLY	COMP24
TX2 DOSE OF VAR STATRE 7 DAY CHR CERIODAPHNIA 1P3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	23.5	******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		TRLY	COMP24

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER		TELEPHONE		DATE		
David R. Shoemaker Mine Manager	I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED HEREIN; AND BASED ON MY INQUIRY OF THOSE INDIVIDUALS IMMEDIATELY RESPONSIBLE FOR OBTAINING THE INFORMATION, I BELIEVE THE SUBMITTED INFORMATION IS TRUE, ACCURATE AND COMPLETE. I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT. SEE 18 U.S.C. § 1001 AND 33 U.S.C. § 1319. *(Penalties under these statutes may include fines up to $10,000 and or maximum imprisonment of between 6 months and 5 years.)*	SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT	505 AREA CODE	586 0212 NUMBER	96 YEAR	04 MO	09 DAY
TYPED OR PRINTED						

COMMENT AND EXPLANATION OF ANY VIOLATIONS *(Reference all attachments here)*

(PASS = 0 FAIL = 1) REPORT PASS AS '0' REPORT FAIL AS '1' IN CONCENTRATION AVG ABOVE. REPORT INVALID TEST AS '*' IN THE REPORTING FIELD AND FOOTNOTE IN THE COMMENT FIELD.

[redacted]

DDRESS P. O. BOX 469
QUESTA NM 87556
ACILITY
OCATION
EN: DAVID R SHOEMAKER, GEN. SUPT.

NM0022306 — PERMIT NUMBER
TX2 0 — DISCHARGE NUMBER

F - FINAL
MAJOR

Form Approved [redacted]
OMB No. 2040-0004
Approval expires 10-31-94

MONITORING PERIOD	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	01	01	TO	96	01	31
	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)

*** NO DISCHARGE | | ***

NOTE: Read instructions before completing this form.

PARAMETER (32-37)		QUANTITY OR LOADING (3 Card Only) (46-53) AVERAGE	(54-61) MAXIMUM	UNITS	QUALITY OR CONCENTRATION (4 Card Only) (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
OF VAR STATRE 7	SAMPLE MEASUREMENT	******	******		******	8.9	******	(23)	0	1/90	COMP 24
Y CHR PINEPHALES	PERMIT REQUIREMENT	******	******	***	******	REPORT	******	PER-		TRLY	COMP24
P6C J 0 0				****		7 DA AVG		CENT			
EFLUENT GROSS VALUE											
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
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	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER

David R. Shoemaker
Mine Manager

TYPED OR PRINTED

I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED HEREIN; AND BASED ON MY INQUIRY OF THOSE INDIVIDUALS IMMEDIATELY RESPONSIBLE FOR OBTAINING THE INFORMATION, I BELIEVE THE SUBMITTED INFORMATION IS TRUE, ACCURATE AND COMPLETE. I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT. SEE 18 U.S.C. § 1001 AND 33 U.S.C. § 1319. *(Penalties under these statutes may include fines up to $10,000 and or maximum imprisonment of between 6 months and 5 years.)*

David R. Shoemaker
SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT

TELEPHONE		DATE		
505	586 0212	96	04	09
AREA CODE	NUMBER	YEAR	MO	DAY

COMMENT AND EXPLANATION OF ANY VIOLATIONS *(Reference all attachments here)*

(PASS = 0 FAIL = 1) REPORT PASS AS '0' REPORT FAIL AS '1' IN CONCENTRATION AVG ABOVE. REPORT INVALID TEST AS '*' IN THE REPORTING FIELD AND FOOTNOTE IN THE COMMENT FIELD.

PERMITTEE NAME, ADDRESS (Include Facility Name/Location if different)

NAME HOLYOKE INC. QUESTA DIV.

ADDRESS P. O. BOX 159

QUESTA NM 87556

FACILITY

LOCATION

ATTN: DAVID R SHOEMAKER, SR. SUPT.

DISCHARGE MONITORING REPORT (DMR)

(2-16) PERMIT NUMBER: NM0022306

(17-19) DISCHARGE NUMBER: 002

MONITORING PERIOD

	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	04	01	TO	96	06	30
	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)

PULP, PAPER AND PAPERBOARD MILLS

Form Approved. 12/29/87

OMB No. 2040-0004

Approval expires 10-31-94

MAJOR

*** NO DISCHARGE [ ] ***

NOTE: Read instructions before completing this form.

PARAMETER (32-37)		QUANTITY OR LOADING (3 Card Only) (46-53) AVERAGE	(54-61) MAXIMUM	UNITS	QUALITY OR CONCENTRATION (4 Card Only) (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
LE C/F LETH STATRE 7 DAY CHR CERIODAPHNIA TLP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	0	*******	(PA)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PASS=0 FAIL=		QTRLY	COMP24
LE C/F LETH STATRE 7 DAY CHR PIMEPHALES TPPGC 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	0	*******	(PA)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PASS=0 FAIL=		QTRLY	COMP24
MOEL LETHAL STATRE 7 DAY CHR CERIODAPHNIA TDP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	29	*******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PA- CONT		QTRLY	COMP24
MOEL LETHAL STATRE 7 DAY CHR PIMEPHALES TPPGC 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	29	*******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PA- CONT		QTRLY	COMP24
MOEL SUB-LTH STATRE 7DAY CHR CERIODAPHNIA TPP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	29	*******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PA- CONT		QTRLY	COMP24
MOEL SUB-LTH STATRE 7DAY CHR PIMEPHALES TPPGC 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	29	*******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PA- CONT		QTRLY	COMP24
COEF OF VAR STATRE 7 DAY CHR CERIODAPHNIA TDP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	*******	*******		*******	33.3	*******	(23)	0	1/90	COMP 24
	PERMIT REQUIREMENT	*******	*******	*** ****	*******	REPORT 7 DA AVG	*******	PA- CONT		QTRLY	COMP24

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER

David R. Shoemaker
Mine Manager

TYPED OR PRINTED

I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED HEREIN; AND BASED ON MY INQUIRY OF THOSE INDIVIDUALS IMMEDIATELY RESPONSIBLE FOR OBTAINING THE INFORMATION, I BELIEVE THE SUBMITTED INFORMATION IS TRUE, ACCURATE AND COMPLETE. I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT. SEE 18 U.S.C. § 1001 AND 33 U.S.C. § 1319. *(Penalties under these statutes may include fines up to $10,000 and or maximum imprisonment of between 6 months and 5 years.)*

SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT

TELEPHONE: AREA CODE 505 NUMBER 586 0212

DATE: YEAR 96 MO 07 DAY 11

COMMENT AND EXPLANATION OF ANY VIOLATIONS *(Reference all attachments here)*

(PASS = 0 FAIL = 1) REPORT PASS AS '0' REPORT FAIL AS '1' IN CONCENTRATION AND ABOVE. REPORT INVALID TEST AS '*' IN THE REPORTING FIELD AND FOOTNOTE IN THE COMMENT FIELD.

EPA Form 3320-1 (Rev. 9-88) Previous editions may be used. (REPLACES EPA FORM T-40 WHICH MAY NOT BE USED)

[redacted]

TTEE NAME/ADDRESS (Include
y Name/Location if different)
E POLYCORP INC. OHESTA DIV.
RESS P. O. BOX 169
OHESTA NE 37555
LITY
ATION
N: DAVID R SHOEMAKER, GEN. SUPT.

NAT[redacted]POLL[redacted] DISC[redacted]E ELIM[redacted]ON SY[redacted]NT'D[redacted]

DISCHARGE MONITORING REPORT (DMR)

(2-16) PERMIT NUMBER: NE0 223[illegible]

(17-19) DISCHARGE NUMBER: "E2 [illegible]

WHOLE EFFLUENT TOXICITY
Form Approved. 1[illegible]
OMB No. 2040-0004
Approval expires 10-31-94

P - FINAL
MAJOR

*** NO DISCHARGE [ ] ***

NOTE: Read Instructions before completing this form.

MONITORING PERIOD	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	07	11	TO	[illegible]	[illegible]	[illegible]
	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)

PARAMETER (32-37)		(3 Card Only) QUANTITY OR LOADING (46-53) AVERAGE	(54-61) MAXIMUM	UNITS	(4 Card Only) QUALITY OR CONCENTRATION (46-53) MINIMUM	(54-61) AVERAGE	MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
F OF VAR STATIC 7	SAMPLE MEASUREMENT	******	******		******		******	(23)			
CHR PIMEPHALES						8.4			0	1/90	COMP 24
50 1 0 0	PERMIT REQUIREMENT	******	******	****	******	REPORT 7 DA AVG	******	EFF-CONC		QTRLY	COMP24
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER			TELEPHONE		DATE		
David R. Shoemaker Mine Manager	I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED HEREIN; AND BASED ON MY INQUIRY OF THOSE INDIVIDUALS IMMEDIATELY RESPONSIBLE FOR OBTAINING THE INFORMATION, I BELIEVE THE SUBMITTED INFORMATION IS TRUE, ACCURATE AND COMPLETE. I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT. SEE 18 U.S.C. § 1001 AND 33 U.S.C. § 1319. *(Penalties under these statutes may include fines up to $10,000 and or maximum imprisonment of between 6 months and 5 years.)*		505	586 0212	96	07	11
TYPED OR PRINTED		SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT	AREA CODE	NUMBER	YEAR	MO	DAY

MENT AND EXPLANATION OF ANY VIOLATIONS *(Reference all attachments here)*

ASS = 0 FAIL = 1) REPORT PASS AS '0' REPORT FAIL AS '1' IN CONCENTRATION AND ABOVE. REPORT INVALID
T AS '*' IN THE REPORTING FIELD AND FOOTNOTE IN THE COMMENT FIELD.

NAME MOLYCORP INC. QUESTA DIV.

ADDRESS P. O. BOX 469
QUESTA NM 87556

NM0022306 — PERMIT NUMBER

TX2 Q — DISCHARGE NUMBER

12345

F - FINAL
MAJOR

FACILITY LOCATION MOLYCORP INC. QUESTA DIV.
ATTN DAVID R SHOEMAKER, GEN. SUPT.

MONITORING PERIOD	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	07	01	TO	96	09	30
	(20-21)	(22-23)	(24-26)		(26-27)	(28-29)	(30-31)

*** NO DISCHARGE ***

NOTE: Read instructions before completing this form.

PARAMETER (32-37)		(3 Card Only) QUANTITY OR LOADING (46-53) AVERAGE	(54-61) MAXIMUM	UNITS	(4 Card Only) QUANTITY OR CONCENTRATION (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
LF P/F LETH STATRE 7 DAY CHR CERIODAPHNIA TLP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	0	******	9A	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PASS 0 FAIL 1		QTRLY	COMP24
LF P/F LETH STATRE 7 DAY CHR PIMEPHALES TLP6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	0	******	9A	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PASS 0 FAIL 1		QTRLY	[illegible]P2
NOEL LETHAL STATRE 7 DAY CHR CERIODAPHNIA TDP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	23	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	COMP24
NOEL LETHAL STATRE 7 DAY CHR PIMEPHALES TDP6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	23	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	COMP24
NOEL SUB-LTH STATRE 7DAY CHR CERIODAPHNI TPP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	23	0	1/90	COMP 2
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	COMP2
NOEL SUB-LTH STATRE 7DAY CHR PIMEPHALES TPP6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	29	******	23	0	1/90	COMP 2
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	[illegible]MP2
COEF OF VAR STATRE 7 DAY CHR CERIODAPHNIA TGP3B 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	20.8	******	23	0	1/90	COMP 2
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	COMP2

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER

David R. Shoemaker
Mine Manager

TYPED OR PRINTED

I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED HEREIN; AND BASED ON MY INQUIRY OF THOSE INDIVIDUALS IMMEDIATELY RESPONSIBLE FOR OBTAINING THE INFORMATION, I BELIEVE THE SUBMITTED INFORMATION IS TRUE, ACCURATE AND COMPLETE. I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT. SEE 18 U.S.C. § 1001 AND 33 U.S.C. § 1319. *(Penalties under these statutes may include fines up to $10,000 and or maximum imprisonment of between 6 months and 5 years.)*

SIGNATURE OF PRINCIPAL EXECUTIVE OFFICER OR AUTHORIZED AGENT

TELEPHONE		DATE		
505	586 7601	96	10	14
AREA CODE	NUMBER	YEAR	MO	DAY

COMMENTS AND EXPLANATION OF ANY VIOLATIONS *(Reference all attachments here)*

PASS 0 FAIL 1 REPORT PASS AS '0' REPORT FAIL AS '1' IN CONCENTRATION AVG ABOVE. REPORT INVALID TEST AS '*' IN THE REPORTING FIELD AND FOOTNOTE IN THE COMMENT FIELD.

PERM[redacted] NAM[redacted]DRESS[redacted] Facili[redacted] Locati[redacted]rent) [redacted] [redacted] [redacted] DISCHARG[redacted]NITO[redacted]REPO[redacted]MR) [redacted] [redacted] [redacted] [redacted] WHOLE EFFLUENT TO[redacted] Approval expires 05-31-98

NAME MULYCORP INC. QUESTA DIV.

ADDRESS P. O. BOX 469
QUESTA NM 87556

(2-16) NM0022306 PERMIT NUMBER

(17-19) TX2 0 DISCHARGE NUMBER

12345

F - FINAL
MAJOR

FACILITY LOCATION MULYCORP INC. QUESTA DIV.

MONITORING PERIOD

	YEAR	MO	DAY		YEAR	MO	DAY
FROM	96	07	01	TO	96	09	30
	(20-21)	(22-23)	(24-25)		(26-27)	(28-29)	(30-31)

*** NO DISCHARGE ***

ATTN DAVID R SHOEMAKER, GEN. SUPT.

NOTE: Read instructions before completing this form.

PARAMETER (32-37)		(3 Card Only) QUANTITY OR LOADING (46-53) AVERAGE	(54-61) MAXIMUM	UNITS	(4 Card Only) QUANTITY OR CONCENTRATION (38-45) MINIMUM	(46-53) AVERAGE	(54-61) MAXIMUM	UNITS	NO. EX (62-63)	FREQUENCY OF ANALYSIS (64-68)	SAMPLE TYPE (69-70)
COEF OF VAR STATRE 7 DAY CHR PIMEPHALES TQP6C 1 0 0 EFFLUENT GROSS VALUE	SAMPLE MEASUREMENT	******	******		******	14.7	******	23	0	1/90	COMP 24
	PERMIT REQUIREMENT	******	******	**** ****	******	REPORT 7 DA AVG	******	PER-CENT		QTRLY	COMP24
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										
	SAMPLE MEASUREMENT										
	PERMIT REQUIREMENT										

NAME/TITLE PRINCIPAL EXECUTIVE OFFICER

David R. Shoemaker
Mine Manager

TYPED OR PRINTED

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EXHIBIT I-8

EPA TECHNICAL GUIDANCE ON INTERPRETATION AND IMPLEMENTATION OF AQUATIC LIFE METALS CRITERIA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OCT 1 1993

OFFICE OF WATER

MEMORANDUM

SUBJECT: Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria

FROM: Martha G. Prothro
Acting Assistant Administrator for Water

TO: Water Management Division Directors
Environmental Services Division Directors
Regions I-X

Introduction

The implementation of metals criteria is complex due to the site-specific nature of metals toxicity. We have undertaken a number of activities to develop guidance in this area, notably the Interim Metals Guidance, published May 1992, and a public meeting of experts held in Annapolis, MD, in January 1993. This memorandum transmits Office of Water (OW) policy and guidance on the interpretation and implementation of aquatic life criteria for the management of metals and supplements my April 1, 1993, memorandum on the same subject. The issue covers a number of areas including the expression of aquatic life criteria; total maximum daily loads (TMDLs), permits, effluent monitoring, and compliance; and ambient monitoring. The memorandum covers each in turn. Attached to this policy memorandum are three guidance documents with additional technical details. They are: Guidance Document on Expression of Aquatic Life Criteria as Dissolved Criteria (Attachment #2), Guidance Document on Dynamic Modeling and Translators (Attachment #3), and Guidance Document on Monitoring (Attachment #4). These will be supplemented as additional data become available. (See the schedule in Attachment #1.)

Since metals toxicity is significantly affected by site-specific factors, it presents a number of programmatic challenges. Factors that must be considered in the management of metals in the aquatic environment include: toxicity specific to effluent chemistry; toxicity specific to ambient water chemistry; different patterns of toxicity for different metals; evolution of the state of the science of metals toxicity, fate, and transport; resource limitations for monitoring, analysis, implementation, and research functions; concerns regarding some of the analytical data currently on record due to possible sampling and analytical contamination; and lack of standardized protocols for clean and ultraclean metals analysis. The States have the key role in the risk management process of balancing these factors in the management of water programs. The site-specific nature of this issue could be perceived as requiring a permit-by-permit approach to implementation. However, we believe

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that this guidance can be effectively implemented on a broader level, across any waters with roughly the same physical and chemical characteristics, and recommend that we work with the States with that perspective in mind.

Expression of Aquatic Life Criteria

o Dissolved vs. Total Recoverable Metal

A major issue is whether, and how, to use dissolved metal concentrations ("dissolved metal") or total recoverable metal concentrations ("total recoverable metal") in setting State water quality standards. In the past, States have used both approaches when applying the same Environmental Protection Agency (EPA) criteria numbers. Some older criteria documents may have facilitated these different approaches to interpretation of the criteria because the documents were somewhat equivocal with regards to analytical methods. The May 1992 interim guidance continued the policy that either approach was acceptable.

It is now the policy of the Office of Water that the use of dissolved metal to set and measure compliance with water quality standards is the recommended approach, because dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal. This conclusion regarding metals bioavailability is supported by a majority of the scientific community within and outside the Agency. One reason is that a primary mechanism for water column toxicity is adsorption at the gill surface which requires metals to be in the dissolved form.

The position that the dissolved metals approach is more accurate has been questioned because it neglects the possible toxicity of particulate metal. It is true that some studies have indicated that particulate metals appear to contribute to the toxicity of metals, perhaps because of factors such as desorption of metals at the gill surface, but these same studies indicate the toxicity of particulate metal is substantially less than that of dissolved metal.

Furthermore, any error incurred from excluding the contribution of particulate metal will generally be compensated by other factors which make criteria conservative. For example, metals in toxicity tests are added as simple salts to relatively clean water. Due to the likely presence of a significant concentration of metals binding agents in many discharges and ambient waters, metals in toxicity tests would generally be expected to be more bioavailabile than metals in discharges or in ambient waters.

If total recoverable metal is used for the purpose of water quality standards, compounding of factors due to the lower bioavailability of particulate metal and lower bioavailability of metals as they are discharged may result in a conservative water quality standard. The use of dissolved metal in water quality standards gives a more accurate result. However, the majority of the participants at the Annapolis meeting felt that total recoverable measurements in ambient water had some value, and that exceedences of criteria on a total recoverable basis were an indication that metal loadings could be a stress to the ecosystem, particularly in locations other than the water column.

The reasons for the potential consideration of total recoverable measurements include risk management considerations not covered by evaluation of water column toxicity. The ambient water quality criteria are neither designed nor intended to protect sediments, or to prevent effects due to food webs containing sediment dwelling organisms. A risk manager, however, may consider sediments and food chain effects and may decide to take a conservative approach for metals, considering that metals are very persistent chemicals. This conservative approach could include the use of total recoverable metal in water quality standards. However, since consideration of sediment impacts is not incorporated into the criteria methodology, the degree of conservatism inherent in the total recoverable approach is unknown. The uncertainty of metal impacts in sediments stem from the lack of sediment criteria and an imprecise understanding of the fate and transport of metals. EPA will continue to pursue research and other activities to close these knowledge gaps.

Until the scientific uncertainties are better resolved, a range of different risk management decisions can be justified. EPA recommends that State water quality standards be based on dissolved metal. (See the paragraph below and the attached guidance for technical details on developing dissolved criteria.) EPA will also approve a State risk management decision to adopt standards based on total recoverable metal, if those standards are otherwise approvable as a matter of law.

o Dissolved Criteria

In the toxicity tests used to develop EPA metals criteria for aquatic life, some fraction of the metal is dissolved while some fraction is bound to particulate matter. The present criteria were developed using total recoverable metal measurements or measures expected to give equivalent results in toxicity tests, and are articulated as total recoverable. Therefore, in order to express the EPA criteria as dissolved, a total recoverable to dissolved correction factor must be used. Attachment #2 provides guidance for calculating EPA dissolved criteria from the published total recoverable criteria. The data expressed as percentage metal dissolved are presented as recommended values and ranges. However, the choice within ranges is a State risk management decision. We have recently supplemented the data for copper and are proceeding to further supplement the data for copper and other metals. As testing is completed, we will make this information available and this is expected to reduce the magnitude of the ranges for some of the conversion factors provided. We also strongly encourage the application of dissolved criteria across a watershed or waterbody, as technically sound and the best use of resources.

o Site-Specific Criteria Modifications

While the above methods will correct some site-specific factors affecting metals toxicity, further refinements are possible. EPA has issued guidance (Water Quality Standards Handbook, 1983; Guidelines for Deriving Numerical Aquatic Site-Specific Water Quality Criteria by Modifying National Criteria, EPA-600/3-H4-099, October 1984) for three site-specific criteria development methodologies: recalculation procedure, indicator species procedure (also known as the water-effect ratio (WER)) and resident species procedure. Only the first two of these have been widely used.

In the National Toxics Rule (57 FR 60848, December 22, 1992), EPA identified the WER as an optional method for site-specific criteria development for certain metals. EPA committed in the NTR preamble to provide guidance on determining the WER. A draft of this guidance has been circulated to the States and Regions for review and comment. As justified by water characteristics and as recommended by the WER guidance, we strongly encourage the application of the WER across a watershed or waterbody as opposed to application on a discharger by discharger basis, as technically sound and an efficient use of resources.

In order to meet current needs, but allow for changes suggested by protocol users, EPA will issue the guidance as "interim." EPA will accept WERs developed using this guidance, as well as by using other scientifically defensible protocols. OW expects the interim WER guidance will be issued in the next two months.

Total Maximum Daily Loads (TMDLs) and National Pollutant Discharge Elimination System (NPDES) Permits

o Dynamic Water Quality Modeling

Although not specifically part of the reassessment of water quality criteria for metals, dynamic or probabilistic models are another useful tool for implementing water quality criteria, especially for those criteria protecting aquatic life. These models provide another way to incorporate site-specific data. The 1991 Technical Support Document for Water Quality-based Toxics Control (TSD) (EPA/505/2-90-001) describes dynamic, as well as static (steady-state) models. Dynamic models make the best use of the specified magnitude, duration, and frequency of water quality criteria and, therefore, provide a more accurate representation of the probability that a water quality standard exceedence will occur. In contrast, steady-state models make a number of simplifying, worst case assumptions which makes them less complex and less accurate than dynamic models.

Dynamic models have received increased attention over the last few years as a result of the widespread belief that steady-state modeling is over-conservative due to environmentally conservative dilution assumptions. This belief has led to the misconception that dynamic models will always lead to less stringent regulatory controls (e.g., NPDES effluent limits) than steady-state models, which is not true in every application of dynamic models. EPA considers dynamic models to be a more accurate approach to implementing water quality criteria and continues to recommend their use. Dynamic modeling does require commitment of resources to develop appropriate data. (See Attachment #3 and the TSD for details on the use of dynamic models.)

o Dissolved-Total Metal Translators

Expressing water quality criteria as the dissolved form of a metal poses a need to be able to translate from dissolved metal to total recoverable metal for TMDLs and NPDES permits. TMDLs for metals must be able to calculate: (1) dissolved metal in order to ascertain attainment of water quality standards, and (2) total recoverable metal in order to achieve mass balance necessary for permitting purposes.

EPA's NPDES regulations require that limits of metals in permits be stated as total recoverable in most cases (see 40 CFR §122.45(c)) except when an effluent guideline specifies the limitation in another form of the metal, the approved analytical methods measure only dissolved metal, or the permit writer expresses a metals limit in another form (e.g., dissolved, valent, or total) when required to carry out provisions of the Clean Water Act. This is because the chemical conditions in ambient waters frequently differ substantially from those in the effluent, and there is no assurance that effluent particulate metal would not dissolve after discharge. The NPDES rule does not require that State water quality standards be expressed as total recoverable; rather, the rule requires permit writers to translate between different metal forms in the calculation of the permit limit so that a total recoverable limit can be established. Both the TMDL and NPDES uses of water quality criteria require the ability to translate between dissolved metal and total recoverable metal. Attachment #3 provides methods for this translation.

Guidance on Monitoring

o Use of Clean Sampling and Analytical Techniques

In assessing waterbodies to determine the potential for toxicity problems due to metals, the quality of the data used is an important issue. Metals data are used to determine attainment status for water quality standards, discern trends in water quality, estimate background loads for TMDLs, calibrate fate and transport models, estimate effluent concentrations (including effluent variability), assess permit compliance, and conduct research. The quality of trace level metal data, especially below 1 ppb, may be compromised due to contamination of samples during collection, preparation, storage, and analysis. Depending on the level of metal present, the use of "clean" and "ultraclean" techniques for sampling and analysis may be critical to accurate data for implementation of aquatic life criteria for metals.

The magnitude of the contamination problem increases as the ambient and effluent metal concentration decreases and, therefore, problems are more likely in ambient measurements. "Clean" techniques refer to those requirements (or practices for sample collection and handling) necessary to produce reliable analytical data in the part per billion (ppb) range. "Ultraclean" techniques refer to those requirements or practices necessary to produce reliable analytical data in the part per trillion (ppt) range. Because typical concentrations of metals in surface waters and effluents vary from one metal to another, the effect of contamination on the quality of metals monitoring data varies appreciably.

We plan to develop protocols on the use of clean and ultra-clean techniques and are coordinating with the United States Geological Survey (USGS) on this project, because USGS has been doing work on these techniques for some time, especially the sampling procedures. We anticipate that our draft protocols for clean techniques will be available in late calendar year 1993. The development of comparable protocols for ultra-clean techniques is underway and will be available in 1995. In developing these protocols, we will consider the costs of these techniques and will give guidance as to the situations where their use is necessary. Appendix B to the WER guidance document provides some general guidance on the use of

clean analytical techniques. (See Attachment #4.) We recommend that this guidance be used by States and Regions as an interim step, while the clean and ultra-clean protocols are being developed.

o Use of Historical Data

The concerns about metals sampling and analysis discussed above raise corresponding concerns about the validity of historical data. Data on effluent and ambient metal concentrations are collected by a variety of organizations including Federal agencies (e.g., EPA, USGS), State pollution control agencies and health departments, local government agencies, municipalities, industrial dischargers, researchers, and others. The data are collected for a variety of purposes as discussed above.

Concern about the reliability of the sample collection and analysis procedures is greatest where they have been used to monitor very low level metal concentrations. Specifically, studies have shown data sets with contamination problems during sample collection and laboratory analysis, that have resulted in inaccurate measurements. For example, in developing a TMDL for New York Harbor, some historical ambient data showed extensive metals problems in the harbor, while other historical ambient data showed only limited metals problems. Careful resampling and analysis in 1992/1993 showed the latter view was correct. The key to producing accurate data is appropriate quality assurance (QA) and quality control (QC) procedures. We believe that most historical data for metals, collected and analyzed with appropriate QA and QC at levels of 1 ppb or higher, are reliable. The data used in development of EPA criteria are also considered reliable, both because they meet the above test and because the toxicity test solutions are created by adding known amounts of metals.

With respect to effluent monitoring reported by an NPDES permittee, the permittee is responsible for collecting and reporting quality data on a Discharge Monitoring Report (DMR). Permitting authorities should continue to consider the information reported to be true, accurate, and complete as certified by the permittee. Where the permittee becomes aware of new information specific to the effluent discharge that questions the quality of previously submitted DMR data, the permittee must promptly submit that information to the permitting authority. The permitting authority will consider all information submitted by the permittee in determining appropriate enforcement responses to monitoring/reporting and effluent violations. (See Attachment #4 for additional details.)

Summary

The management of metals in the aquatic environment is complex. The science supporting our technical and regulatory programs is continuing to evolve, here as in all areas. The policy and guidance outlined above represent the position of OW and should be incorporated into ongoing program operations. We do not expect that ongoing operations would be delayed or deferred because of this guidance.

If you have questions concerning this guidance, please contact Jim Hanlon, Acting Director, Office of Science and Technology, at 202-260-5400. If you have questions on specific details of the guidance, please contact the appropriate OW Branch Chief. The Branch Chiefs responsible for the various areas of the water quality program are: Bob April (202-260-6322, water quality criteria), Elizabeth Fellows (202-260-7046, monitoring and data issues), Russ Kinerson (202-260-1330, modeling and translators), Don Brady (202-260-7074, Total Maximum Daily Loads), Sheila Frace (202-260-9537, permits), Dave Sabock (202-260-1315, water quality standards), Bill Telliard (202-260-7134, analytical methods) and Dave Lyons (202-260-8310, enforcement).

Attachments

ATTACHMENT #1

TECHNICAL GUIDANCE FOR METALS

Schedule of Upcoming Guidance

Water-effect Ratio Guidance - September 1993

Draft "Clean" Analytical Methods - Spring 1994

Dissolved Criteria - currently being done; as testing is completed, we will release the updated percent dissolved data

Draft Sediment Criteria for Metals - 1994

Final Sediment Criteria for Metals - 1995

ATTACHMENT #2

GUIDANCE DOCUMENT ON DISSOLVED CRITERIA

Expression of Aquatic Life Criteria

October 1993

Percent Dissolved in Aquatic Toxicity Tests on Metals

The attached table contains all the data that were found concerning the percent of the total recoverable metal that was dissolved in aquatic toxicity tests. This table is intended to contain the available data that are relevant to the conversion of EPA's aquatic life criteria for metals from a total recoverable basis to a dissolved basis. (A factor of 1.0 is used to convert aquatic life criteria for metals that are expressed on the basis of the acid-soluble measurement to criteria expressed on the basis of the total recoverable measurement.) Reports by Grunwald (1992) and Brungs et al. (1992) provided references to many of the documents in which pertinent data were found. Each document was obtained and examined to determine whether it contained useful data.

"Dissolved" is defined as metal that passes through a 0.45-μm membrane filter. If otherwise acceptable, data that were obtained using 0.3-μm glass fiber filters and 0.1-μm membrane filters were used, and are identified in the table; these data did not seem to be outliers.

Data were used only if the metal was in a dissolved inorganic form when it was added to the dilution water. In addition, data were used only if they were generated in water that would have been acceptable for use as a dilution water in tests used in the derivation of water quality criteria for aquatic life; in particular, the pH had to be between 6.5 and 9.0, and the concentrations of total organic carbon (TOC) and total suspended solids (TSS) had to be below 5 mg/L. Thus most data generated using river water would not be used.

Some data were not used for other reasons. Data presented by Carroll et al. (1979) for cadmium were not used because 9 of the 36 values were above 150%. Data presented by Davies et al. (1976) for lead and Holcombe and Andrew (1978) for zinc were not used because "dissolved" was defined on the basis of polarography, rather than filtration.

Beyond this, the data were not reviewed for quality. Horowitz et al. (1992) reported that a number of aspects of the filtration procedure might affect the results. In addition, there might be concern about use of "clean techniques" and adequate QA/QC.

Each line in the table is intended to represent a separate piece of information. All of the data in the table were determined in fresh water, because no saltwater data were found. Data are becoming available for copper in salt water from the New York

Harbor study; based on the first set of tests, Hansen (1993) suggested that the average percent of the copper that is dissolved in sensitive saltwater tests is in the range of 76 to 82 percent.

A thorough investigation of the percent of total recoverable metal that is dissolved in toxicity tests might attempt to determine if the percentage is affected by test technique (static, renewal, flow-through), feeding (were the test animals fed and, if so, what food and how much), water quality characteristics (hardness, alkalinity, pH, salinity), test organisms (species, loading), etc.

The attached table also gives the freshwater criteria concentrations (CMC and CCC) because percentages for total recoverable concentrations much (e.g., more than a factor of 3) above or below the CMC and CCC are likely to be less relevant. When a criterion is expressed as a hardness equation, the range given extends from a hardness of 50 mg/L to a hardness of 200 mg/L.

The following is a summary of the available information for each metal:

Arsenic(III)

The data available indicate that the percent dissolved is about 100, but all the available data are for concentrations that are much higher than the CMC and CCC.

Cadmium

Schuytema et al. (1984) reported that "there were no real differences" between measurements of total and dissolved cadmium at concentrations of 10 to 80 ug/L (pH = 6.7 to 7.8, hardness = 25 mg/L, and alkalinity = 33 mg/L); total and dissolved concentrations were said to be "virtually equivalent".

The CMC and CCC are close together and only range from 0.66 to 8.6 ug/L. The only available data that are known to be in the range of the CMC and CCC were determined with a glass fiber filter. The percentages that are probably most relevant are 75, 92, 89, 78, and 80.

Chromium(III)

The percent dissolved decreased as the total recoverable concentration increased, even though the highest concentrations reduced the pH substantially. The percentages that are probably

most relevant to the CMC are 50-75, whereas the percentages that are probably most relevant to the CCC are 86 and 61.

Chromium(VI)

The data available indicate that the percent dissolved is about 100, but all the available data are for concentrations that are much higher than the CMC and CCC.

Copper

Howarth and Sprague (1978) reported that the total and dissolved concentrations of copper were "little different" except when the total copper concentration was above 500 ug/L at hardness = 360 mg/L and pH = 8 or 9. Chakoumakos et al. (1979) found that the percent dissolved depended more on alkalinity than on hardness, pH, or the total recoverable concentration of copper.

Chapman (1993) and Lazorchak (1987) both found that the addition of daphnid food affected the percent dissolved very little, even though Chapman used yeast-trout chow-alfalfa whereas Lazorchak used algae in most tests, but yeast-trout chow-alfalfa in some tests. Chapman (1993) found a low percent dissolved with and without food, whereas Lazorchak (1987) found a high percent dissolved with and without food. All of Lazorchak's values were in high hardness water; Chapman's one value in high hardness water was much higher than his other values.

Chapman (1993) and Lazorchak (1987) both compared the effect of food on the total recoverable LC50 with the effect of food on the dissolved LC50. Both authors found that food raised both the dissolved LC50 and the total recoverable LC50 in about the same proportion, indicating that food did not raise the total recoverable LC50 by sorbing metal onto food particles; possibly the food raised both LC50s by (a) decreasing the toxicity of dissolved metal, (b) forming nontoxic dissolved complexes with the metal, or (c) reducing uptake.

The CMC and CCC are close together and only range from 6.5 to 34 ug/L. The percentages that are probably most relevant are 74, 95, 95, 73, 57, 53, 52, 64, and 91.

Lead

The data presented in Spehar et al. (1978) were from Holcombe et al. (1976). Both Chapman (1993) and Holcombe et al. (1976) found that the percent dissolved increased as the total recoverable concentration increased. It would seem reasonable to expect more precipitate at higher total recoverable concentrations and

therefore a lower percent dissolved at higher concentrations. The increase in percent dissolved with increasing concentration might be due to a lowering of the pH as more metal is added if the stock solution was acidic.

The percentages that are probably most relevant to the CMC are 9, 18, 25, 10, 62, 68, 71, 75, 81, and 95, whereas the percentages that are probably most relevant to the CCC are 9 and 10.

Mercury

The only percentage that is available is 73, but it is for a concentration that is much higher than the CMC.

Nickel

The percentages that are probably most relevant to the CMC are 88, 93, 92, and 100, whereas the only percentage that is probably relevant to the CCC is 76.

Selenium

No data are available.

Silver

There is a CMC, but not a CCC. The percentage dissolved seems to be greatly reduced by the food used to feed daphnids, but not by the food used to feed fathead minnows. The percentages that are probably most relevant to the CMC are 41, 79, 79, 73, 91, 90, and 93.

Zinc

The CMC and CCC are close together and only range from 59 to 210 ug/L. The percentages that are probably most relevant are 31, 77, 77, 99, 94, 100, 103, and 96.

Recommended Values (%)[A] and Ranges of Measured Percent Dissolved Considered Most Relevant in Fresh Water

Metal	CMC		CCC	
	Recommended Value (%)	(Range %)	Recommended Value (%)	(Range %)
Arsenic(III)	95	100-104[B]	95	100-104[B]
Cadmium	85	75-92	85	75-92
Chromium(III)	85	50-75	85	61-86
Chromium(VI)	95	100[B]	95	100[B]
Copper	85	52-95	85	52-95
Lead	50	9-95	25	9-10
Mercury	85	73[B]	NA[E]	NA[E]
Nickel	85	88-100	85	76
Selenium	NA[E]	NA[C]	NA[E]	NA[C]
Silver	85	41-93	YY[D]	YY[D]
Zinc	85	31-103	85	31-103

[A] The recommended values are based on current knowledge and are subject to change as more data becomes available.

[B] All available data are for concentrations that are much higher than the CMC.

[C] NA = No data are available.

[D] YY = A CCC is not available, and therefore cannot be adjusted.

[E] NA = Bioaccumulative chemical and not appropriate to adjust to percent dissolved.

Concn.[A] (ug/L)	Percent Diss.[B]	n[C]	Species[D]	SRF[E]	Food	Hard.	Alk.	pH	Ref.
ARSENIC(III) (Freshwater: CCC = 190 ug/L; CMC = 360 ug/L)									
600-15000	104	5	?	?	?	48	41	7.6	Lima et al. 1984
12600	100	3	FM	F	No	44	43	7.4	Spehar and Fiandt 1986
CADMIUM (Freshwater: CCC = 0.66 to 2.0 ug/L; CMC = 1.8 to 8.6 ug/L)[F]									
0.16	41	?	DM	R	Yes	53	46	7.6	Chapman 1993
0.28	75	?	DM	R	Yes	103	83	7.9	Chapman 1993
0.4-4.0	92[G]	?	CS	F	No	21	19	7.1	Finlayson and Verrue 1982
13	89	3	FM	F	No	44	43	7.4	Spehar and Fiandt 1986
15-21	96	8	FM	S	No	42	31	7.5	Spehar and Carlson 1984
42	84	4	FM	S	No	45	41	7.4	Spehar and Carlson 1984
10	78	?	DM	S	No	51	38	7.5	Chapman 1993
35	77	?	DM	S	No	105	88	8.0	Chapman 1993
51	59	?	DM	S	No	209	167	8.4	Chapman 1993
6-80	80	8	?	S	No	47	44	7.5	Call et al. 1982
3-232	90[H]	5	?	F	?	46	42	7.4	Spehar et al. 1978
450-6400	70	5	FM	F	No	202	157	7.7	Pickering and Gast 1972

CHROMIUM(III) (Freshwater: CCC = 120 to 370 ug/L; CMC = 980 to 3100 ug/L)[F]

5-13	94	?	SG	F	?	25	24	7.3	Stevens and Chapman 1984
19-495	86	?	SG	F	?	25	24	7.2	Stevens and Chapman 1984
>1100	50-75	?	SG	F	No	25	24	7.0	Stevens and Chapman 1984
42	54	?	DM	R	Yes	206	166	8.2	Chapman 1993
114	61	?	DM	R	Yes	52	45	7.4	Chapman 1993
16840	26	?	DM	S	No	<51	9	6.3[1]	Chapman 1993
26267	32	?	DM	S	No	110	9	6.7	Chapman 1993
27416	27	?	DM	S	No	96	10	6.0[1]	Chapman 1993
58665	23	?	DM	S	No	190	25	6.2[1]	Chapman 1993

CHROMIUM(VI) (Freshwater: CCC = 11 ug/L; CMC = 16 ug/L)

>25,000	100	1	FM,GF	F	Yes	220	214	7.6	Adelman and Smith 1976
43,300	99.5	4	FM	F	No	44	43	7.4	Spehar and Fiandt 1986

COPPER (Freshwater: CCC = 6.5 to 21 ug/L; CMC = 9.2 to 34 ug/L)[F]

10-30	74	?	CT	F	No	27	20	7.0	Chakoumakos et al. 1979
40-200	78	?	CT	F	No	154	20	6.8	Chakoumakos et al. 1979
30-100	79	?	CT	F	No	74	23	7.6	Chakoumakos et al. 1979
100-200	82	?	CT	F	No	192	72	7.0	Chakoumakos et al. 1979
20-200	86	?	CT	F	No	31	78	8.3	Chakoumakos et al. 1979
40-300	87	?	CT	F	No	83	70	7.4	Chakoumakos et al. 1979
10-80	89	?	CT	F	No	25	169	8.5	Chakoumakos et al. 1979

300-1300	92	?	CT	F	No	195	160	7.0	Chakoumakos et al. 1979
100-400	94	?	CT	F	No	70	174	8.5	Chakoumakos et al. 1979
3-4[J]	125-167	2	CD	R	Yes	31	38	7.2	Carlson et al. 1986a,b
12-91[J]	79-84	3	CD	R	Yes	31	38	7.2	Carlson et al. 1986a,b
18-19	95	2	DA	S	No	52	55	7.7	Carlson et al. 1986b
20[J]	95	1	DA	R	No	31	38	7.2	Carlson et al. 1986b
50	96	2	FM	S	No	52	55	7.7	Carlson et al. 1986b
175[J]	91	2	FM	R	No	31	38	7.2	Carlson et al. 1986b
5-52	>82[K]	?	FM	F	Yes[L]	47	43	8.0	Lind et al. 1978
6-80	83[G]	?	CS	F	No	21	19	7.1	Finlayson and Verrue 1982
6.7	57	?	DM	S	No	49	37	7.7	Chapman 1993
35	43	?	DM	S	Yes	48	39	7.4	Chapman 1993
13	73	?	DM	R	Yes	211	169	8.1	Chapman 1993
16	57	?	DM	R	Yes	51	44	7.6	Chapman 1993
51	39	?	DM	R	Yes	104	83	7.8	Chapman 1993
32	53	?	DM	S	No	52	45	7.8	Chapman 1993
33	52	?	DM	S	No	105	79	7.9	Chapman 1993
39	64	?	DM	S	No	106	82	8.1	Chapman 1993
25-84	96	14	FM,GM	S	No	50	40	7.0	Hammermeister et al. 1983
17	91	6	DM	S	No	52	43	7.3	Hammermeister et al. 1983
120	88	14	SG	S	No	48	47	7.3	Hammermeister et al. 1983
15-90	74	19	?	S	No	48	47	7.7	Call et al. 1982
12-162	80[H]	?	BG	F	Yes[L]	45	43	7-8	Benoit 1975
28-58	85	6	DM	R	No	168	117	8.0	Lazorchak 1987
26-59	79	7	DM	R	Yes[M]	168	117	8.0	Lazorchak 1987
56,101	86	2	DM	R	Yes[N]	168	117	8.0	Lazorchak 1987

96	86	4	FM	F	No	44	43	7.4	Spehar and Fiandt 1986
160	94	1	FM	S	No	203	171	8.2	Geckler et al. 1976
230-3000	>69->79	?	CR	F	No	17	13	7.6	Rice and Harrison 1983

LEAD (Freshwater: CCC = 1.3 to 7.7 ug/L; CMC = 34 to 200 ug/L)[F]

17	9	?	DM	R	Yes	52	47	7.6	Chapman 1993
181	18	?	DM	R	Yes	102	86	7.8	Chapman 1993
193	25	?	DM	R	Yes	151	126	8.1	Chapman 1993
612	29	?	DM	S	No	50	--	---	Chapman 1993
952	33	?	DM	S	No	100	--	---	Chapman 1993
1907	~38	?	DM	S	No	150	--	---	Chapman 1993
7-29	10	?	EZ	R	No	22	--	---	JRB Associates 1983
34	62[H]	?	BT	F	Yes	44	43	7.2	Holcombe et al. 1976
58	68[H]	?	BT	F	Yes	44	43	7.2	Holcombe et al. 1976
119	71[H]	?	BT	F	Yes	44	43	7.2	Holcombe et al. 1976
235	75[H]	?	BT	F	Yes	44	43	7.2	Holcombe et al. 1976
474	81[H]	?	BT	F	Yes	44	43	7.2	Holcombe et al. 1976
4100	82[H]	?	BT	F	No	44	43	7.2	Holcombe et al. 1976
2100	79	7	FM	F	No	44	43	7.4	Spehar and Fiandt 1986
220-2700	96	14	FM,GM,DM	S	No	49	44	7.2	Hammermeister et al. 1983
580	95	14	SG	S	No	51	48	7.2	Hammermeister et al. 1983

MERCURY(II) (Freshwater: CMC = 2.4 ug/L)

172	73	1	FM	F	No	44	43	7.4	Spehar and Fiandt 1986

NICKEL (Freshwater: CCC = 88 to 280 ug/L; CMC = 790 to 2500 ug/L)[F]

21	81	?	DM	R	Yes	51	49	7.4	Chapman 1993
150	76	?	DM	R	Yes	107	87	7.8	Chapman 1993
578	87	?	DM	R	Yes	205	161	8.1	Chapman 1993
645	88	?	DM	S	No	54	43	7.7	Chapman 1993
1809	93	?	DM	S	No	51	44	7.7	Chapman 1993
1940	92	?	DM	S	No	104	84	8.2	Chapman 1993
2344	100	?	DM	S	No	100	84	7.9	Chapman 1993
4000	90	?	PK	R	No	21	--	---	JRB Associates 1983

SELENIUM (FRESHWATER: CCC = 5 ug/L; CMC = 20 ug/L)

No data are available.

SILVER (Freshwater: CMC = 1.2 to 13 ug/L; a CCC is not available)

0.19	74	?	DM	S	No	47	37	7.6	Chapman 1993
9.98	13	?	DM	S	Yes	47	37	7.5	Chapman 1993
4.0	41	?	DM	S	No	36	25	7.0	Nebeker et al. 1983
4.0	11	?	DM	S	Yes	36	25	7.0	Nebeker et al. 1983
3	79	?	FM	S	No	51	49	8.1	UWS 1993
2-54	79	?	FM	S	Yes[O]	49	49	7.9	UWS 1993
2-32	73	?	FM	S	No	50	49	8.1	UWS 1993
4-32	91	?	FM	S	No	48	49	8.1	UWS 1993
5-89	90	?	FM	S	No	120	49	8.2	UWS 1993
6-401	93	?	FM	S	No	249	49	8.1	UWS 1993

ZINC (Freshwater: CCC = 59 to 190 ug/L; CMC 65 to 210 ug/L)[F]

52	31	?	DM	R	Yes	211	169	8.2	Chapman 1993
62	77	?	DM	R	Yes	104	83	7.8	Chapman 1993
191	77	?	DM	R	Yes	52	47	7.5	Chapman 1993
356	74	?	DM	S	No	54	47	7.6	Chapman 1993
551	78	?	DM	S	No	105	85	8.1	Chapman 1993
741	76	?	DM	S	No	196	153	8.2	Chapman 1993
7[I]	71-129	2	CD	R	Yes	31	38	7.2	Carlson et al. 1986b
18-273[I]	81-107	2	CD	R	Yes	31	38	7.2	Carlson et al. 1986b
167[I]	99	2	CD	R	No	31	38	7.2	Carlson et al. 1986b
180	94	1	CD	S	No	52	55	7.7	Carlson et al. 1986b
188-393[I]	100	2	FM	R	No	31	38	7.2	Carlson et al. 1986b
551	100	1	FM	S	No	52	55	7.7	Carlson et al. 1986b
40-500	95[G]	?	CS	F	No	21	19	7.1	Finlayson and Verrue 1982
1940	100	?	AS	F	No	20	12	7.1	Sprague 1964
5520	83	?	AS	F	No	20	12	7.9	Sprague 1964
<4000	90	?	FM	F	No	204	162	7.7	Mount 1966
>4000	70	?	FM	F	No	204	162	7.7	Mount 1966
160-400	103	13	FM,GM,DM	S	No	52	43	7.5	Hammermeister et al. 1983
240	96	13	SG	S	No	49	46	7.2	Hammermeister et al. 1983

[A] Total recoverable concentration.

[B] Except as noted, a 0.45-μm membrane filter was used.

[C] Number of paired comparisons.

[D] The abbreviations used are:

AS = Atlantic salmon
BT = Brook trout
CD = *Ceriodaphnia dubia*
CR = Crayfish
CS = Chinook salmon
CT = Cutthroat trout
DA = Daphnids
DM = *Daphnia magna*
EZ = *Elassoma zonatum*
FM = Fathead minnow
GF = Goldfish
GM = Gammarid
PK = *Palaemonetes kadiakensis*
SG = *Salmo gairdneri*

[E] The abbreviations used are:

S = static
R = renewal
F = flow-through

[F] The two numbers are for hardnesses of 50 and 200 mg/L, respectively.

[G] A 0.3-μm *glass fiber* filter was used.

[H] A 0.10-μm membrane filter was used.

[I] The pH was below 6.5.

[J] The dilution water was a clean river water with TSS and TOC below 5 mg/L.

[K] Only limited information is available concerning this value.

[L] It is assumed that the solution that was filtered was from the test chambers that contained fish and food.

[M] The food was algae.

[N] The food was yeast-trout chow-alfalfa.

[O] The food was frozen adult brine shrimp.

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ATTACHMENT #3

GUIDANCE DOCUMENT
ON DYNAMIC MODELING AND TRANSLATORS
August 1993

Total Maximum Daily Loads (TMDLs) and Permits

o Dynamic Water Quality Modeling

Although not specifically part of the reassessment of water quality criteria for metals, dynamic or probabilistic models are another useful tool for implementing water quality criteria, especially those for protecting aquatic life. Dynamic models make best use of the specified magnitude, duration, and frequency of water quality criteria and thereby provide a more accurate calculation of discharge impacts on ambient water quality. In contrast, steady-state modeling is based on various simplifying assumptions which makes it less complex and less accurate than dynamic modeling. Building on accepted practices in water resource engineering, ten years ago OW devised methods allowing the use of probability distributions in place of worst-case conditions. The description of these models and their advantages and disadvantages is found in the 1991 Technical Support Document for Water Quality-based Toxic Control (TSD).

Dynamic models have received increased attention in the last few years as a result of the perception that static modeling is over-conservative due to environmentally conservative dilution assumptions. This has led to the misconception that dynamic models will always justify less stringent regulatory controls (e.g. NPDES effluent limits) than static models. In effluent dominated waters where the upstream concentrations are relatively constant, however, a dynamic model will calculate a more stringent wasteload allocation than will a steady state model. The reason is that the critical low flow required by many State water quality standards in effluent dominated streams occurs more frequently than once every three years. When other environmental factors (e.g. upstream pollutant concentrations) do not vary appreciably, then the overall return frequency of the steady state model may be greater than once in three years. A dynamic modeling approach, on the other hand, would be more stringent, allowing only a once in three year return frequency. As a result, EPA considers dynamic models to be a <u>more accurate</u> rather than a less stringent approach to implementing water quality criteria.

The 1991 TSD provides recommendations on the use of steady state and dynamic water quality models. The reliability of any modeling technique greatly depends on the accuracy of the data used in the analysis. Therefore, the selection of a model also depends upon the data. EPA recommends that steady state wasteload allocation analyses generally be used where few or no whole effluent toxicity or specific chemical measurements are available, or where daily receiving water flow records are not available. Also, if staff resources are insufficient to use and defend the use of dynamic models, then steady state

models may be necessary. If adequate receiving water flow and effluent concentration data are available to estimate frequency distributions, EPA recommends that one of the dynamic wasteload allocation modeling techniques be used to derive wasteload allocations which will more exactly maintain water quality standards. The minimum data required for input into dynamic models include at least 30 years of river flow data and one year of effluent and ambient pollutant concentrations.

o Dissolved-Total Metal Translators

When water quality criteria are expressed as the dissolved form of a metal, there is a need to translate TMDLs and NPDES permits to and from the dissolved form of a metal to the total recoverable form. TMDLs for toxic metals must be able to calculate 1) the dissolved metal concentration in order to ascertain attainment of water quality standards and 2) the total recoverable metal concentration in order to achieve mass balance. In meeting these requirements, TMDLs consider metals to be conservative pollutants and quantified as total recoverable to preserve conservation of mass. The TMDL calculates the dissolved or ionic species of the metals based on factors such as total suspended solids (TSS) and ambient pH. (These assumptions ignore the complicating factors of metals interactions with other metals.) In addition, this approach assumes that ambient factors influencing metal partitioning remain constant with distance down the river. This assumption probably is valid under the low flow conditions typically used as design flows for permitting of metals (e.g., 7Q10, 4B3, etc) because erosion, resuspension, and wet weather loadings are unlikely to be significant and river chemistry is generally stable. In steady-state dilution modeling, metals releases may be assumed to remain fairly constant (concentrations exhibit low variability) with time.

EPA's NPDES regulations require that metals limits in permits be stated as total recoverable in most cases (see 40 CFR §122.45(c)). Exceptions occur when an effluent guideline specifies the limitation in another form of the metal or the approved analytical methods measure only the dissolved form. Also, the permit writer may express a metals limit in another form (e.g., dissolved, valent, or total) when required, in highly unusual cases, to carry out the provisions of the CWA.

The preamble to the September 1984 National Pollutant Discharge Elimination System Permit Regulations states that the total recoverable method measures dissolved metals plus that portion of solid metals that can easily dissolve under ambient conditions (see 49 Federal Register 38028, September 26, 1984). This method is intended to measure metals in the effluent that are or may easily become environmentally active, while not measuring metals that are expected to settle out and remain inert.

The preamble cites, as an example, effluent from an electroplating facility that adds lime and uses clarifiers. This effluent will be a combination of solids not removed by the clarifiers and residual dissolved metals. When the effluent from the clarifiers, usually with a

high pH level, mixes with receiving water having significantly lower pH level, these solids instantly dissolve. Measuring dissolved metals in the effluent, in this case, would underestimate the impact on the receiving water. Measuring with the total metals method, on the other hand, would measure metals that would be expected to disperse or settle out and remain inert or be covered over. Thus, measuring total recoverable metals in the effluent best approximates the amount of metal likely to produce water quality impacts.

However, the NPDES rule does not require in any way that State water quality standards be in the total recoverable form; rather, the rule requires permit writers to consider the translation between differing metal forms in the calculation of the permit limit so that a total recoverable limit can be established. Therefore, both the TMDL and NPDES uses of water quality criteria require the ability to translate from the dissolved form and the total recoverable form.

Many toxic substances, including metals, have a tendency to leave the dissolved phase and attach to suspended solids. The partitioning of toxics between solid and dissolved phases can be determined as a function of a pollutant-specific partition coefficient and the concentration of solids. This function is expressed by a linear partitioning equation:

$$C = \frac{C_{Tf}}{1 + K_d \cdot TSS \cdot 10^{-6}}$$

where,

C = dissolved phase metal concentration,
C_{Tf} = total metal concentration,
TSS = total suspended solids concentration, and
K_d = partition coefficient.

A key assumption of the linear partitioning equation is that the sorption reaction reaches dynamic equilibrium at the point of application of the criteria; that is, after allowing for initial mixing the partitioning of the pollutant between the adsorbed and dissolved forms can be used at any location to predict the fraction of pollutant in each respective phase.

Successful application of the linear partitioning equation relies on the selection of the partition coefficient. The use of a partition coefficient to represent the degree to which toxics adsorb to solids is most readily applied to organic pollutants; partition coefficients for metals are more difficult to define. Metals typically exhibit more complex speciation and complexation reactions than organics and the degree of partitioning can vary greatly depending upon site-specific water chemistry. Estimated partition coefficients can be determined for a number of metals, but waterbody or site-specific observations of dissolved and adsorbed concentrations are preferred.

EPA suggests three approaches for instances where a water quality criterion for a metal is expressed in the dissolved form in a State's water quality standards:

1. Using clean analytical techniques and field sampling procedures with appropriate QA/QC, collect receiving water samples and determine site specific values of K_d for each metal. Use these K_d values to "translate" between total recoverable and dissolved metals in receiving water. This approach is more difficult to apply because it relies upon the availability of good quality measurements of ambient metal concentrations. This approach provides an accurate assessment of the dissolved metal fraction providing sufficient samples are collected. EPA's initial recommendation is that at least four pairs of total recoverable and dissolved ambient metal measurements be made during low flow conditions or 20 pairs over all flow conditions. EPA suggests that the average of data collected during low flow or the 95th percentile highest dissolved fraction for all flows be used. The low flow average provides a representative picture of conditions during the rare low flow events. The 95th percentile highest dissolved fraction for all flows provides a critical condition approach analogous to the approach used to identify low flows and other critical environmental conditions.

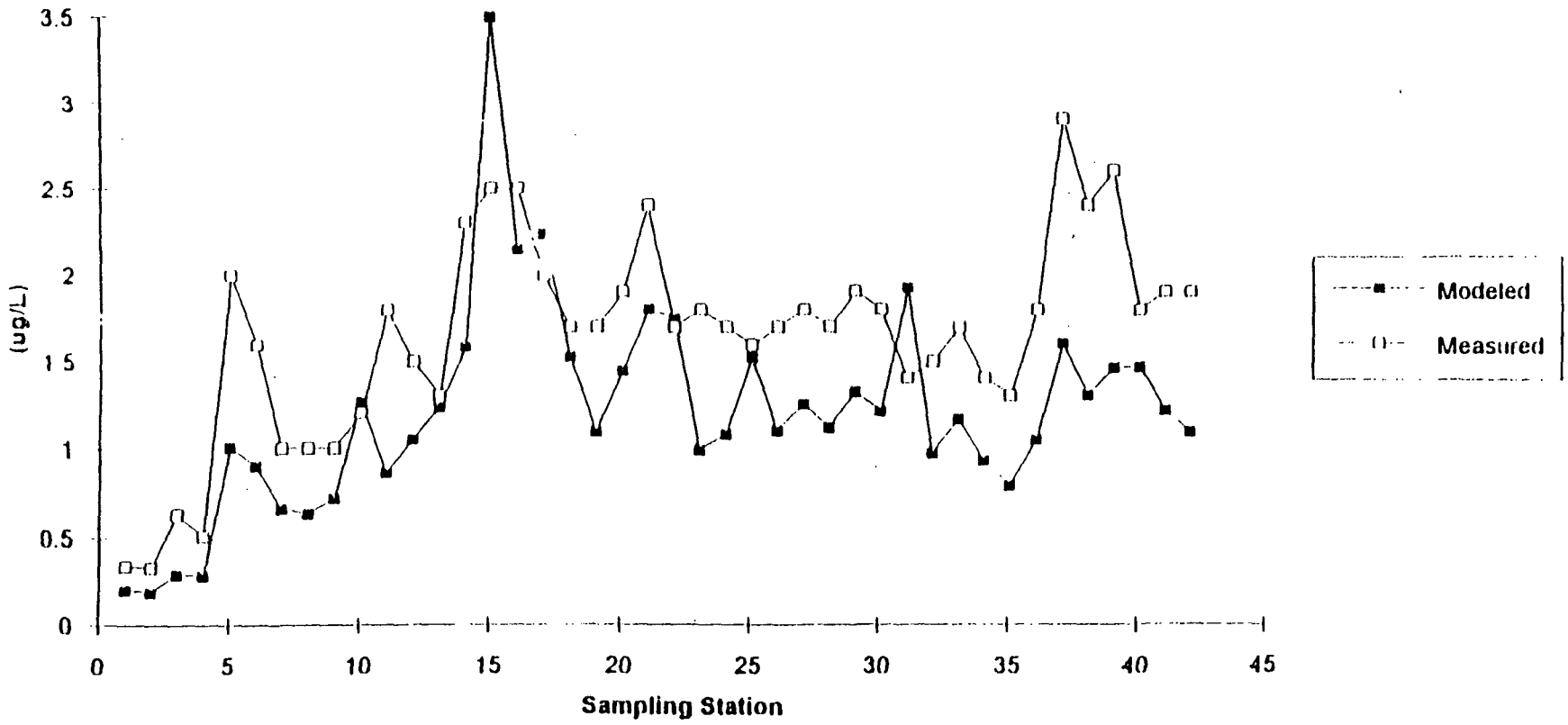
2. Calculate the total recoverable concentration for the purpose of setting the permit limit. Use a value of 1 unless the permittee has collected data (see #1 above) to show that a different ratio should be used. The value of 1 is conservative and will not err on the side of violating standards. This approach is very simple to apply because it places the entire burden of data collection and analysis solely upon permitted facilities. In terms of technical merit, it has the same characteristics of the previous approach. However, permitting authorities may be faced with difficulties in negotiating with facilities on the amount of data necessary to determine the ratio and the necessary quality control methods to assure that the ambient data are reliable.

3. Use the historical data on total suspended solids (TSS) in receiving waterbodies at appropriate design flows and K_d values presented in the Technical Guidance Manual for Performing Waste Load Allocations. Book II. Streams and Rivers. EPA-440/4-84-020 (1984) to "translate" between (total recoverable) permits limits and dissolved metals in receiving water. This approach is fairly simple to apply. However, these K_d values are suspect due to possible quality assurance problems with the data used to develop the values. EPA's initial analysis of this approach and these values in one site indicates that these K_d values generally over-estimate the dissolved fraction of metals in ambient waters (see Figures following). Therefore, although this approach may not provide an accurate estimate of the dissolved fraction, the bias in the estimate is likely to be a conservative one.

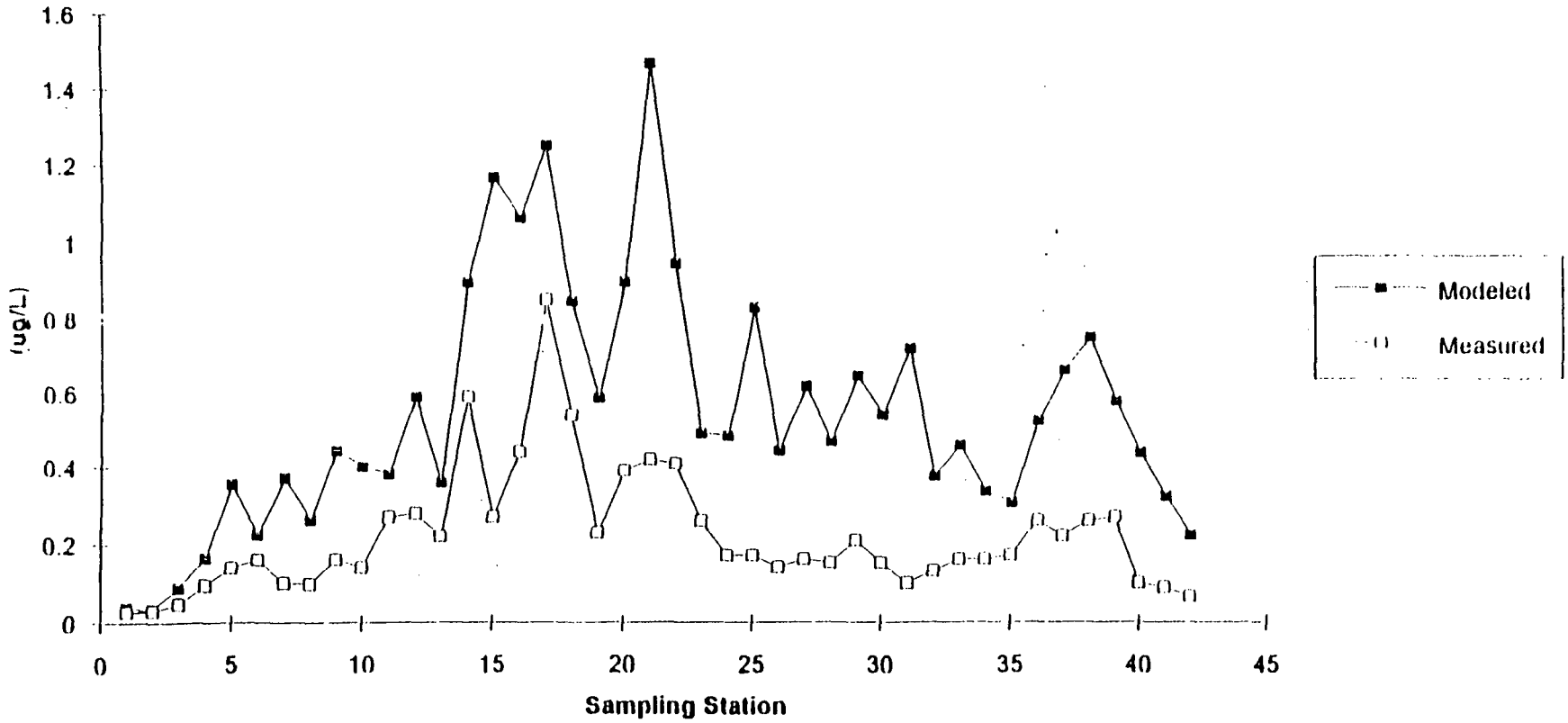
EPA suggests that regulatory authorities use approaches #1 and #2 where States express their water quality standards in the dissolved form. In those States where the standards are in the total recoverable or acid soluble form, EPA recommends that no

translation be used until the time that the State changes the standards to the dissolved form. Approach #3 may be used as an interim measure until the data are collected to implement approach #1.

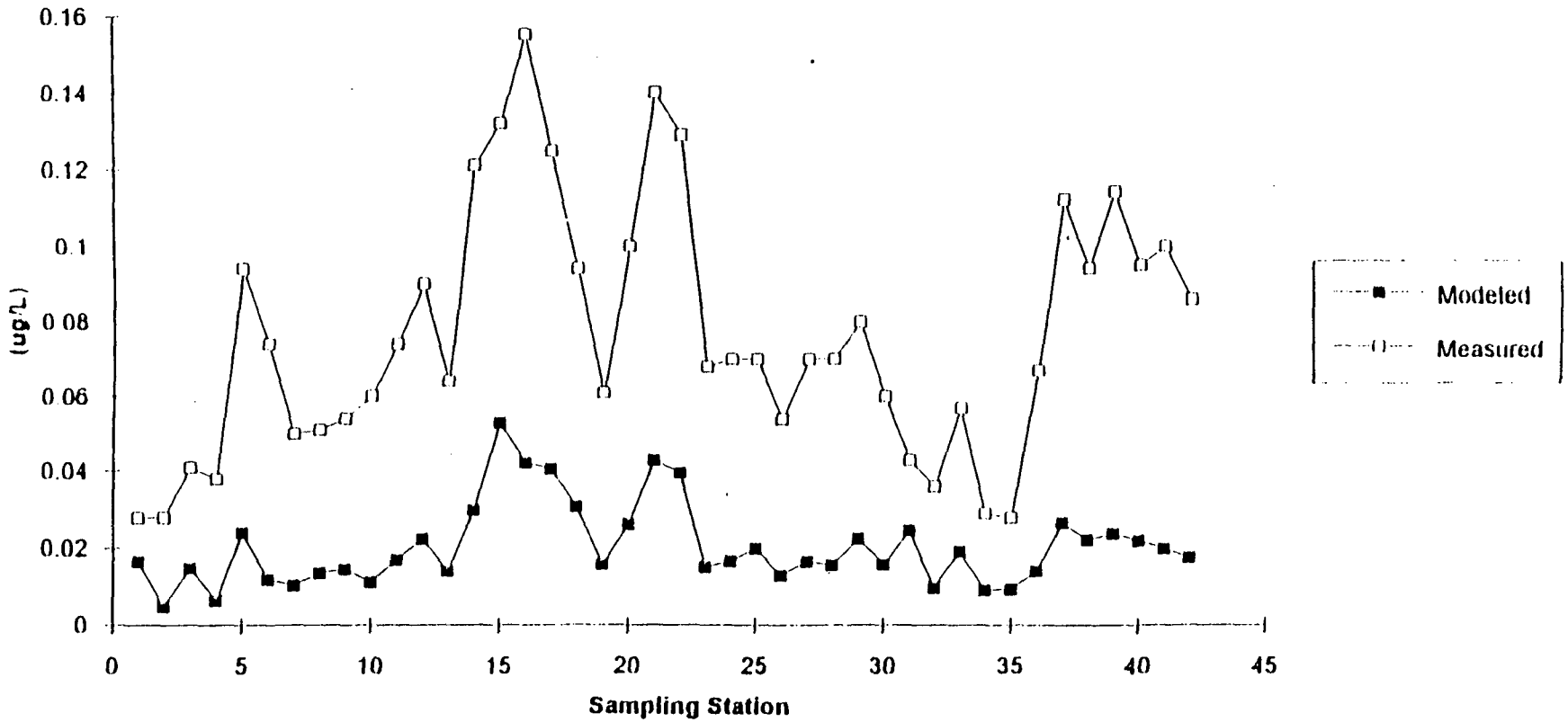
Measured vs. Modeled Dissolved Copper Concentrations



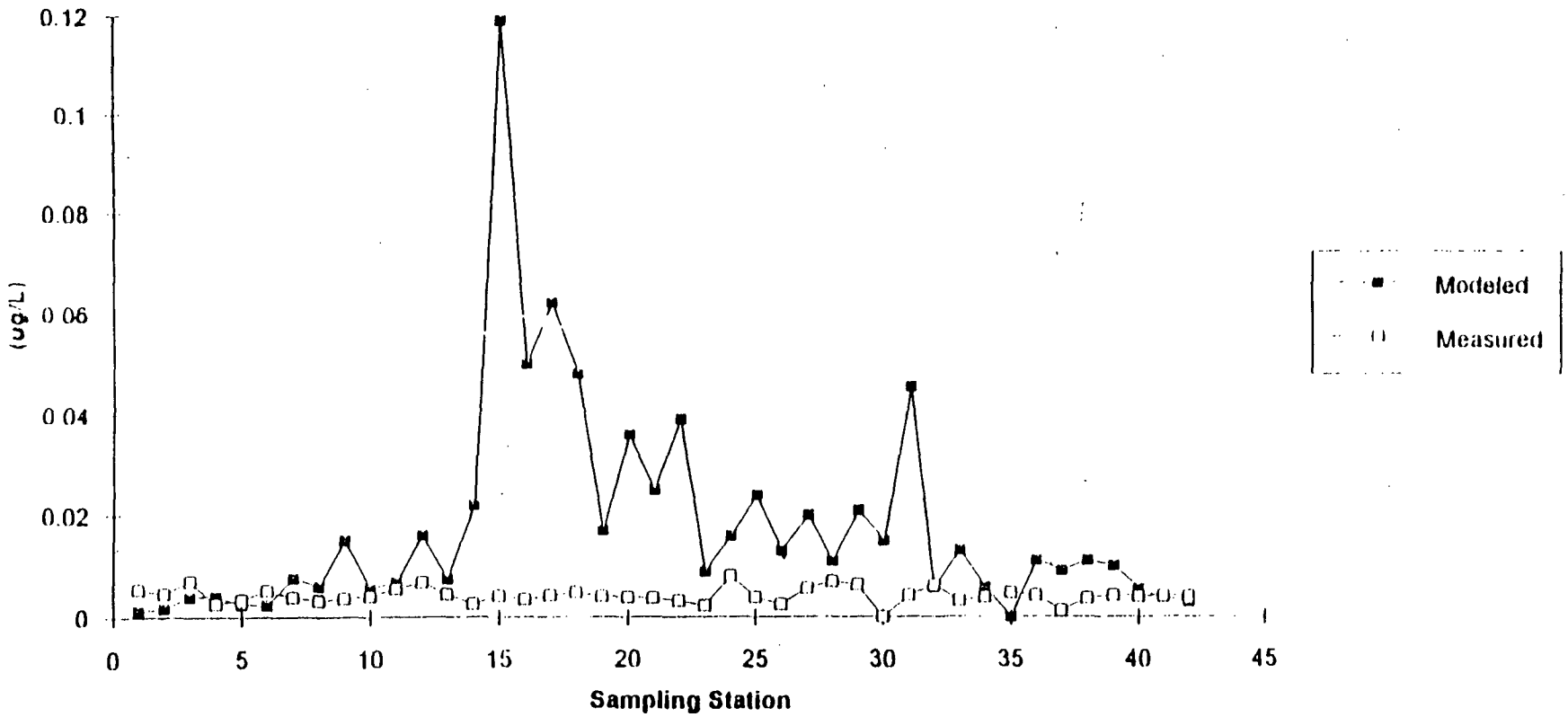
Measured vs. Modeled Dissolved Lead Concentrations



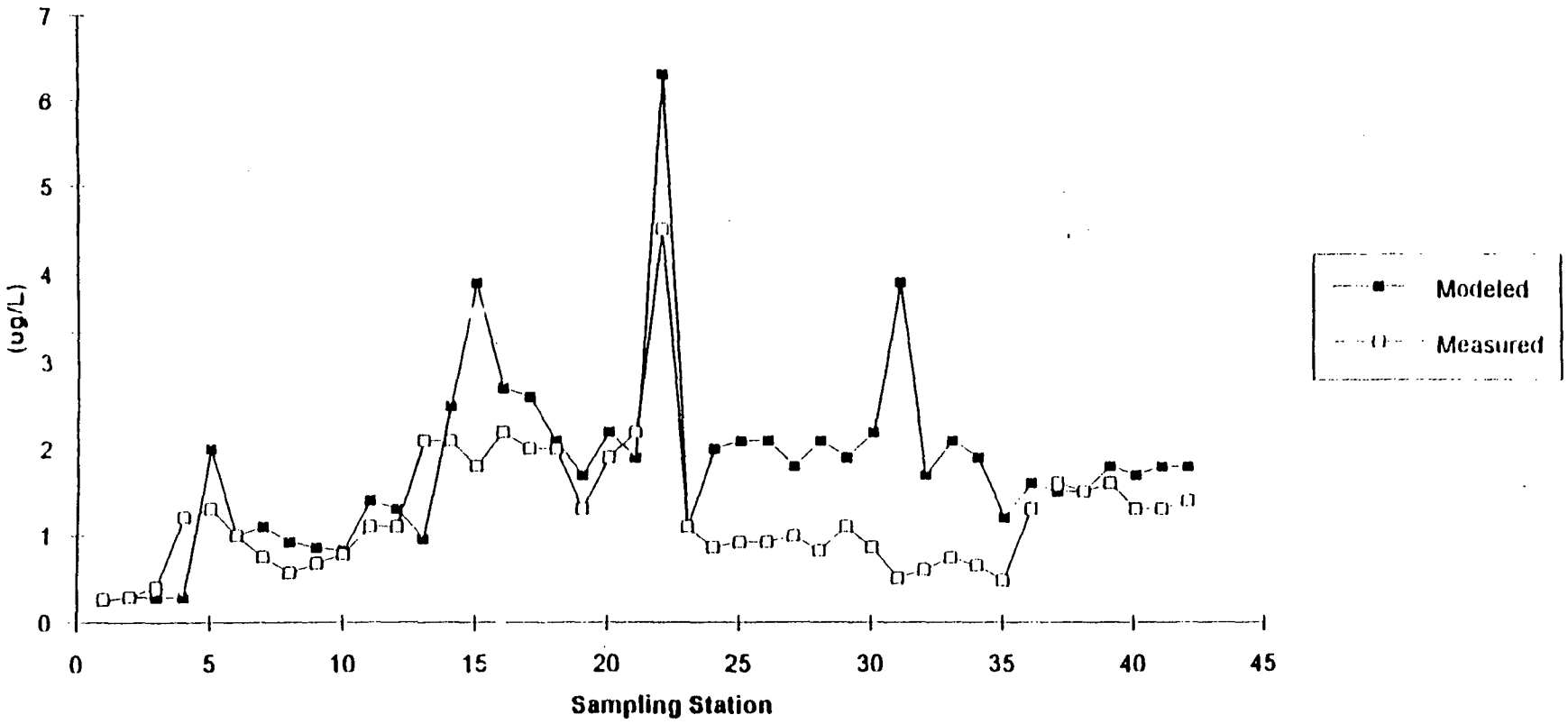
Measured vs. Modeled Dissolved Cadmium Concentrations



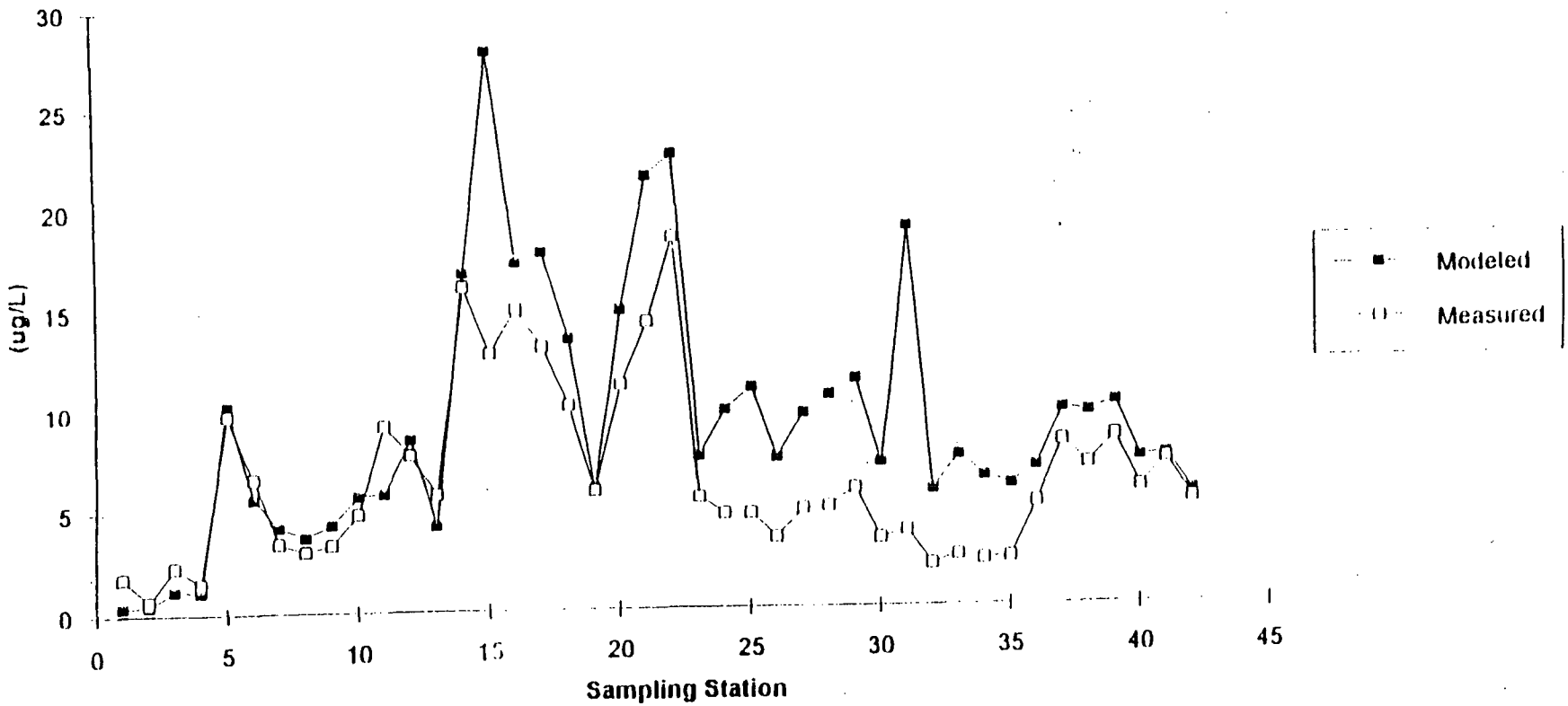
Measured vs. Modeled Dissolved Mercury Concentrations



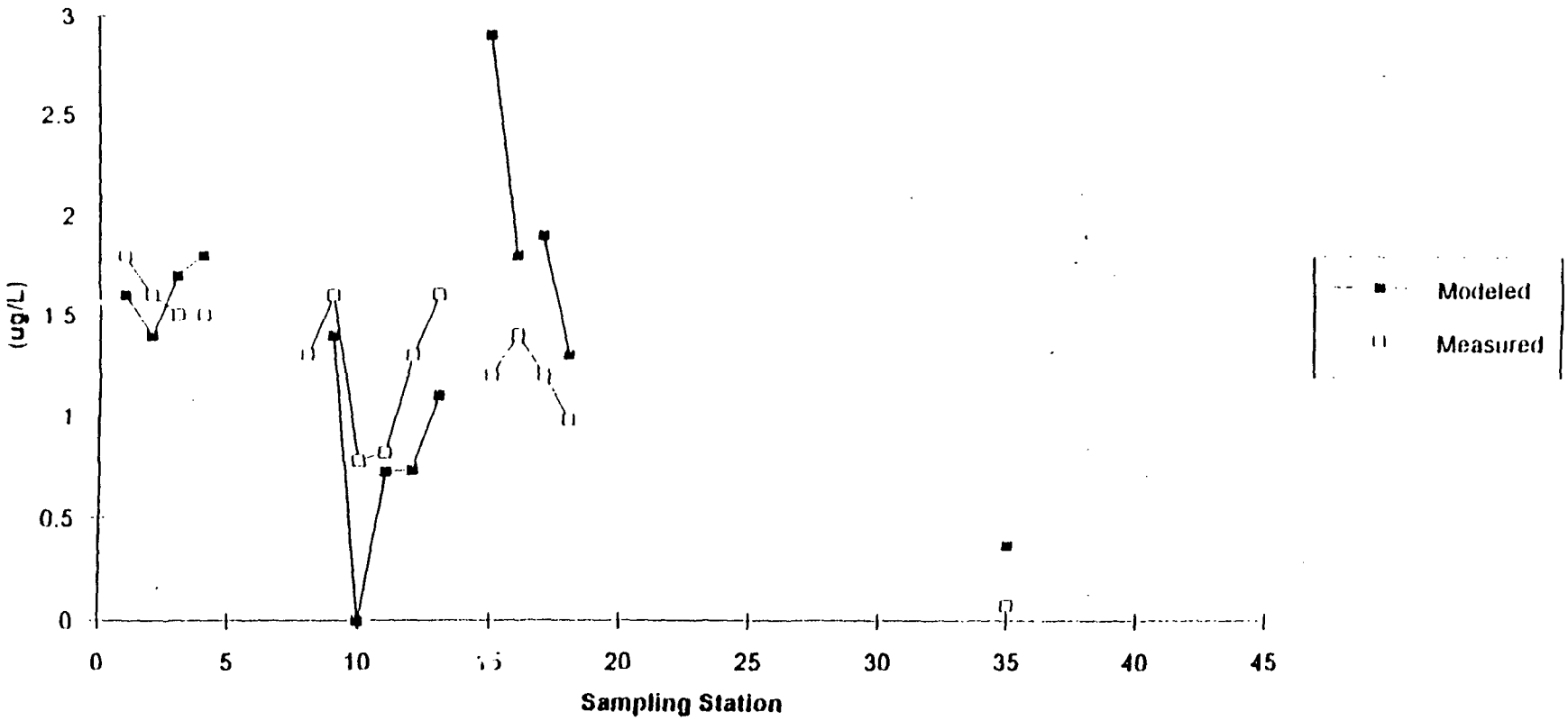
Measured vs. Modeled Dissolved Nickel Concentrations



Measured vs. Modeled Dissolved Zinc Concentrations



Measured vs. Modeled Dissolved Arsenic Concentrations



ATTACHMENT #4

GUIDANCE DOCUMENT
ON CLEAN ANALYTICAL TECHNIQUES AND MONITORING
October 1993

Guidance on Monitoring

o Use of Clean Sampling and Analytical Techniques

Appendix B to the WER guidance document (attached) provides some general guidance on the use of clean techniques. The Office of Water recommends that this guidance be used by States and Regions as an interim step while the Office of Water prepares more detailed guidance.

o Use of Historical DMR Data

With respect to effluent or ambient monitoring data reported by an NPDES permittee on a Discharge Monitoring Report (DMR), the certification requirements place the burden on the permittee for collecting and reporting quality data. The certification regulation at 40 CFR 122.22(d) requires permittees, when submitting information, to state: "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 assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, 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."

Permitting authorities should continue to consider the information reported in DMRs to be true, accurate, and complete as certified by the permittee. Under 40 CFR 122.41(l)(8), however, as soon as the permittee becomes aware of new information specific to the effluent discharge that calls into question the accuracy of the DMR data, the permittee must submit such information to the permitting authority. Examples of such information include a new finding that the reagents used in the laboratory analysis are contaminated with trace levels of metals, or a new study that the sampling equipment imparts trace metal contamination. This information must be specific to the discharge and based on actual measurements rather than extrapolations from reports from other facilities. Where a permittee submits information

In addition to submitting the information described above, the permittee also must develop procedures to assure the collection and analysis of quality data that are true, accurate, and complete. For example, the permittee may submit a revised quality assurance plan that describes the specific procedures to be undertaken to reduce or eliminate trace metal contamination.

Appendix B. Guidance Concerning the Use of "Clean Techniques" and QA/QC in the Measurement of Trace Metals

Recent information (Shiller and Boyle 1987; Windom et al. 1991) has raised questions concerning the quality of reported concentrations of trace metals in both fresh and salt (estuarine and marine) surface waters. A lack of awareness of true ambient concentrations of metals in saltwater and freshwater systems can be both a cause and a result of the problem. The ranges of dissolved metals that are typical in surface waters of the United States away from the immediate influence of discharges (Bruland 1983; Shiller and Boyle 1985,1987; Trefry et al. 1986; Windom et al. 1991) are:

Metal	Salt water (ug/L)	Fresh water (ug/L)
Cadmium	0.01 to 0.2	0.002 to 0.08
Copper	0.1 to 3.	0.4 to 4.
Lead	0.01 to 1.	0.01 to 0.19
Nickel	0.3 to 5.	1. to 2.
Silver	0.005 to 0.2	----------
Zinc	0.1 to 15.	0.03 to 5.

The U.S. EPA (1983,1991) has published analytical methods for monitoring metals in waters and wastewaters, but these methods are inadequate for determination of ambient concentrations of some metals in some surface waters. Accurate and precise measurement of these low concentrations requires appropriate attention to seven areas:

1. Use of "clean techniques" during collecting, handling, storing, preparing, and analyzing samples to avoid contamination.
2. Use of analytical methods that have sufficiently low detection limits.
3. Avoidance of interference in the quantification (instrumental analysis) step.
4. Use of blanks to assess contamination.
5. Use of matrix spikes (sample spikes) and certified reference materials (CRMs) to assess interference and contamination.
6. Use of replicates to assess precision.
7. Use of certified standards.

In a strict sense, the term "clean techniques" refers to techniques that reduce contamination and enable the accurate and precise measurement of trace metals in fresh and salt surface waters. In a broader sense, the term also refers to related issues concerning detection limits, quality control, and quality assurance. Documenting data quality demonstrates the amount of confidence that can be placed in the data, whereas increasing the sensitivity of methods reduce the problem of deciding how to

interpret results that are reported to be below detection limits.

This appendix is written for those analytical laboratories that want guidance concerning ways to lower detection limits, increase precision, and/or increase accuracy. The ways to achieve these goals are to increase the sensitivity of the analytical methods, decrease contamination, and decrease interference. Ideally, validation of a procedure for measuring concentrations of metals in surface water requires demonstration that agreement can be obtained using completely different procedures beginning with the sampling step and continuing through the quantification step (Bruland et al. 1979), but few laboratories have the resources to compare two different procedures. Laboratories can, however, (a) use techniques that others have found useful for improving detection limits, accuracy, and precision, and (b) document data quality through use of blanks, spikes, CRMs, replicates, and standards.

In general, in order to achieve accurate and precise measurement of a particular concentration, both the detection limit and the blanks should be less than one-tenth of that concentration. Therefore, the term "metal-free" can be interpreted to mean that the total amount of contamination that occurs during sample collection and processing (e.g., from gloves, sample containers, labware, sampling apparatus, cleaning solutions, air, reagents, etc.) is sufficiently low that blanks are less than one-tenth of the lowest concentration that needs to be measured.

Atmospheric particulates can be a major source of contamination (Moody 1982; Adeloju and Bond 1985). The term "class-100" refers to a specification concerning the amount of particulates in air (Moody 1982); although the specification says nothing about the composition of the particulates, generic control of particulates can greatly reduce trace-metal blanks. Except during collection of samples and initial cleaning of equipment, all handling of samples, sample containers, labware, and sampling apparatus should be performed in a class-100 bench, room, or glove box.

Nothing contained or not contained in this appendix adds to or subtracts from any regulatory requirements set forth in other EPA documents concerning metal analyses. The word "**must**" is used in this appendix merely to indicate items that are considered very important by analytical chemists who have worked to increase accuracy and precision and lower detection limits in trace-metal analysis. Some items are considered important because they have been found to have received inadequate attention in some laboratories performing trace-metal analyses.

Two topics that are not addressed in this appendix are:

1. The "ultraclean techniques" that are likely to be necessary when trace analyses of mercury are performed.
2. Safety in analytical laboratories.

Other documents should be consulted if these topics are of concern.

Avoiding contamination by use of "clean techniques"

Measurement of trace metals in receiving waters **must** take into account the potential for contamination during each step in the process. Regardless of the specific procedures used for collection, handling, storage, preparation (digestion, filtration, and/or extraction), and quantification (instrumental analysis), the general principles of contamination control **must** be applied. Some specific recommendations are:

a. Non-talc latex or class-100 polyethylene gloves **must** be worn during all steps from sample collection to analysis. (Talc seems to be a particular problem with zinc; gloves made with talc cannot be decontaminated sufficiently.) Gloves should only contact surfaces that are metal-free; gloves should be changed if even suspected of contamination.
b. The acid used to acidify samples for preservation and digestion and to acidify water for final cleaning of labware, sampling apparatus, and sample containers **must** be metal-free. The quality of the acid used should be better than reagent-grade. Each lot of acid **must** be analyzed for the metal(s) of interest before use.
c. The water used to prepare acidic cleaning solutions and to rinse labware, sample containers, and sampling apparatus may be prepared by distillation, deionization, or reverse osmosis, and **must** be demonstrated to be metal-free.
d. The work area, including bench tops and hoods, should be cleaned (e.g., washed and wiped dry with lint-free, class-100 wipes) frequently to remove contamination.
e. All handling of samples in the laboratory, including filtering and analysis, **must** be performed in a class-100 clean bench or a glove box fed by particle-free air or nitrogen; ideally the clean bench or glove box should be located within a class-100 clean room.
f. Labware, reagents, sampling apparatus, and sample containers **must** never be left open to the atmosphere; they should be stored in a class-100 bench, covered with plastic wrap, stored in a plastic box, or turned upside down on a clean surface. Minimizing the time between cleaning and using will help minimize contamination.
g. Separate sets of sample containers, labware, and sampling apparatus should be dedicated for different kinds of samples, e.g., receiving water samples, effluent samples, etc.
h. To avoid contamination of clean rooms, samples that contain very high concentrations of metals and do not require use of "clean techniques" should not be brought into clean rooms.
i. Acid-cleaned plastic, such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), or a fluoroplastic, **must** be the only material that ever contacts a sample, except possibly during digestion for the total recoverable

measurement. (Total recoverable samples can be digested in some plastic containers.) Even HDPE and LDPE might not be acceptable for mercury, however.

j. All labware, sample containers, and sampling apparatus **must** be acid-cleaned before use or reuse.
   1. Sample containers, sampling apparatus, tubing, membrane filters, filter assemblies, and other labware **must** be soaked in acid until metal-free. The amount of cleaning necessary might depend on the amount of contamination and the length of time the item will be in contact with samples. For example, if an acidified sample will be stored in a sample container for three weeks, ideally the container should have been soaked in an acidified metal-free solution for at least three weeks.
   2. It might be desirable to perform initial cleaning, for which reagent-grade acid may be used, before the items are allowed into a clean room. For most metals, items should be either (a) soaked in 10 percent concentrated nitric acid at 50°C for at least one hour, or (b) soaked in 50 percent concentrated nitric acid at room temperature for at least two days; for arsenic and mercury, soaking for up to two weeks at 50°C in 10 percent concentrated nitric acid might be required. For plastics that might be damaged by strong nitric acid, such as polycarbonate and possibly HDPE and LDPE, soaking in 10 percent concentrated hydrochloric acid, either in place of or before soaking in a nitric acid solution, might be desirable.
   3. Chromic acid **must not** be used to clean items that will be used in analysis of metals.
   4. Final soaking and cleaning of sample containers, labware, and sampling apparatus **must** be performed in a class-100 clean room using metal-free acid and water. The solution in an acid bath **must** be analyzed periodically to demonstrate that it is metal-free.
   5. After labware and sampling apparatus are cleaned, they may be stored in a clean room in a weak acid bath prepared using metal-free acid and water. Before use, the items should be rinsed at least three times with metal-free water. After the final rinse, the items should be moved immediately, with the open end pointed down, to a class-100 clean bench. Items may be dried on a class-100 clean bench; items **must not** be dried in an oven or with laboratory towels. The sampling apparatus should be assembled in a class-100 clean room or bench and double-bagged in metal-free polyethylene zip-type bags for transport to the field; new bags are usually metal-free.
   6. After sample containers are cleaned, they should be filled with metal-free water that has been acidified to a pH of 2 with metal-free nitric acid (about 0.5 mL per liter) for storage until use. At the time of sample collection, the sample containers should be emptied and rinsed at least twice with the solution being sampled before the actual

sample is placed in the sample container.

k. Field samples **must** be collected in a manner that eliminates the potential for contamination from the sampling platform, probes, etc. Exhaust from boats and the direction of wind and water currents should be taken into account. The people who collect the samples **must** be specifically trained on how to collect field samples. After collection, all handling of samples in the field that will expose the sample to air **must** be performed in a portable class-100 clean bench or glove box.

l. Samples **must** be acidified (after filtration if dissolved metal is to be measured) to a pH of less than 2, except that the pH **must** be less than 1 for mercury. Acidification should be done in a clean room or bench, and so it might be desirable to wait and acidify samples in a laboratory rather than in the field. If samples are acidified in the field, metal-free acid can be transported in plastic bottles and poured into a plastic container from which acid can be removed and added to samples using plastic pipettes. Alternatively, plastic automatic dispensers can be used.

m. Such things as probes and thermometers **must not** be put in samples that are to be analyzed for metals. In particular, pH electrodes and mercury-in-glass thermometers **must not** be used if mercury is to be measured. If pH is measured, it **must** be done on a separate aliquot.

n. Sample handling should be minimized. For example, instead of pouring a sample into a graduated cylinder to measure the volume, the sample can be weighed after being poured into a tared container; alternatively, the container from which the sample is poured can be weighed. (For saltwater samples, the salinity or density should be taken into account when weight is converted to volume.)

o. Each reagent used **must** be verified to be metal-free. If metal-free reagents are not commercially available, removal of metals will probably be necessary.

p. For the total recoverable measurement, samples should be digested in a class-100 bench, not in a metallic hood. If feasible, digestion should be done in the sample container by acidification and heating.

q. The longer the time between collection and analysis of samples, the greater the chance of contamination, loss, etc.

r. Samples **must** be stored in the dark, preferably between 0 and 4°C with no air space in the sample container.

<u>Achieving low detection limits</u>

a. Extraction of the metal from the sample can be extremely useful if it simultaneously concentrates the metal and eliminates potential matrix interferences. For example, ammonium 1-pyrrolidinedithiocarbamate and/or diethylammonium diethyldithiocarbamate can extract cadmium, copper, lead,

nickel, and zinc (Bruland et al. 1979; Nriagu et al. 1993).

b. The detection limit should be less than ten percent of the lowest concentration that is to be measured.

Avoiding interferences

a. Potential interferences **must** be assessed for the specific instrumental analysis technique used and each metal to be measured.
b. If direct analysis is used, the salt present in high-salinity saltwater samples is likely to cause interference in most instrumental techniques.
c. As stated above, extraction of the metal from the sample is particularly useful because it simultaneously concentrates the metal and eliminates potential matrix interferences.

Using blanks to assess contamination

a. A laboratory (procedural, method) blank consists of filling a sample container with analyzed metal-free water and processing (filtering, acidifying, etc.) the water through the laboratory procedure in exactly the same way as a sample. A laboratory blank **must** be included in each set of ten or fewer samples to check for contamination in the laboratory, and **must** contain less than ten percent of the lowest concentration that is to be measured. Separate laboratory blanks **must** be processed for the total recoverable and dissolved measurements, if both measurements are performed.
b. A field (trip) blank consists of filling a sample container with analyzed metal-free water in the laboratory, taking the container to the site, processing the water through tubing, filter, etc., collecting the water in a sample container, and acidifying the water the same as a field sample. A field blank **must** be processed for each sampling trip. Separate field blanks **must** be processed for the total recoverable measurement and for the dissolved measurement, if filtrations are performed at the site. Field blanks **must** be processed in the laboratory the same as laboratory blanks.

Assessing accuracy

a. A calibration curve **must** be determined for each analytical run and the calibration should be checked about every tenth sample. Calibration solutions **must** be traceable back to a certified standard from the U.S. EPA or the National Institute of Science and Technology (NIST).
b. A blind standard or a blind calibration solution **must** be included in each group of about twenty samples.

c. At least one of the following **must** be included in each group of about twenty samples:
   1. A matrix spike (spiked sample; the method of known additions).
   2. A CRM, if one is available in a matrix that closely approximates that of the samples. Values obtained for the CRM **must** be within the published values.

The concentrations in blind standards and solutions, spikes, and CRMs **must not** be more than 5 times the median concentration expected to be present in the samples.

Assessing precision

a. A sampling replicate **must** be included with each set of samples collected at each sampling location.
b. If the volume of the sample is large enough, replicate analysis of at least one sample **must** be performed along with each group of about ten samples.

Special considerations concerning the dissolved measurement

Whereas the total recoverable measurement is especially subject to contamination during the digestion step, the dissolved measurement is subject to both loss and contamination during the filtration step.

a. Filtrations **must** be performed using acid-cleaned plastic filter holders and acid-cleaned membrane filters. Samples **must not** be filtered through glass fiber filters, even if the filters have been cleaned with acid. If positive-pressure filtration is used, the air or gas **must** be passed through a 0.2-um in-line filter; if vacuum filtration is used, it **must** be performed on a class-100 bench.
b. Plastic filter holders **must** be rinsed and/or dipped between filtrations, but they do not have to be soaked between filtrations if all the samples contain about the same concentrations of metal. It is best to filter samples from low to high concentrations. A membrane filter **must not** be used for more than one filtration. After each filtration, the membrane filter **must** be removed and discarded, and the filter holder **must** be either rinsed with metal-free water or dilute acid and dipped in a metal-free acid bath or rinsed at least twice with metal-free dilute acid; finally, the filter holder **must** be rinsed at least twice with metal-free water.
c. For each sample to be filtered, the filter holder and membrane filter **must** be conditioned with the sample, i.e., an initial portion of the sample **must** be filtered and discarded.

The accuracy and precision of the dissolved measurement should be

assessed periodically. A large volume of a buffered solution (such as aerated 0.05 N sodium bicarbonate) should be spiked so that the concentration of the metal of interest is in the range of the low concentrations that are to be measured. The total recoverable concentration and the dissolved concentration of the metal in the spiked buffered solution should be measured alternately until each measurement has been performed at least ten times. The means and standard deviations for the two measurements should be the same. All values deleted as outliers **must** be acknowledged.

Reporting results

To indicate the quality of the data, reports of results of measurements of the concentrations of metals **must** include a description of the blanks, spikes, CRMs, replicates, and standards that were run, the number run, and the results obtained. All values deleted as outliers **must** be acknowledged.

Additional information

The items presented above are some of the important aspects of "clean techniques"; some aspects of quality assurance and quality control are also presented. This is not a definitive treatment of these topics; additional information that might be useful is available in such publications as Patterson and Settle (1976), Zief and Mitchell (1976), Bruland et al. (1979), Moody and Beary (1982), Moody (1982), Bruland (1983), Adeloju and Bond (1985), Berman and Yeats (1985), Byrd and Andreae (1986), Taylor (1987), Sakamoto-Arnold (1987), Tramontano et al. (1987), Puls and Barcelona (1989), Windom et al. (1991), U.S. EPA (1992), Horowitz et al. (1992), and Nriagu et al. (1993).

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EXHIBIT I-9

OUTFALL 002 HISTORIC WATER QUALITY

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	FLOW		TEMPERATURE				HARDNESS	CHEMICAL OXYGEN DEMAND				pH		
	(MGD)		(DEG. F)		(DEG. C)		(mg/l)	(lb/day)		(mg/l)		(S.U.)		
	Avg.	Max.	Avg.	Max.	Avg.	Max.		Avg.	Max.	Avg.	Max.	Min.	Avg.	Max.
2/1/85	0.490	0.510			11.0	13.0				8.00	10.00	7.10		7.30
3/1/85	0.460	0.510	52.0	54.0						7.00	10.00	7.50		7.80
4/1/85	0.540	0.610	54.0	57.0						6.00	10.00	7.40		7.70
1/1/96	0.260	0.313	50.0	50.2				12.80	16.40	5.90	7.50	7.34		7.64
2/1/96	0.258	0.317	49.7	49.8				11.89	16.36	5.54	7.60	7.24		7.62
3/1/96	0.252	0.304	50.1	50.5				9.93	10.90	4.70	5.10	7.27		7.64
4/1/96	0.244	0.292	50.7	51.8				7.73	10.10	3.80	5.00	7.42		7.62
5/1/96	0.242	0.292	50.0	50.2				9.40	10.10	4.64	5.00	7.38		7.64
6/1/96	0.243	0.295	50.5	52.5				10.52	10.97	5.19	5.36	7.38		7.60
7/1/96	0.263	0.314	52.9	53.6				11.07	11.41	5.05	5.10	7.48		7.54
8/1/96	0.266	0.569	52.7	53.6				11.29	12.11	5.13	5.33	7.45		7.51
9/1/96	0.266	0.321	51.45	51.5				11.28	12.16	5.05	5.30	7.25		7.50
10/1/96	0.227	0.311	50.3	51.4				8.46	10.12	4.60	5.80	7.26	7.67	7.67
11/1/96	0.215	0.602	49.8	51.8				8.92	9.31	<5.00	<5.00	7.33		7.57
12/1/96	0.266	0.403	49.1	50.0				16.09	25.54	7.75	10.00	7.19		7.57
1/1/97	0.336	0.412	49.1	51.0				12.72	18.65	4.53	6.65	7.23		7.48
2/1/97	0.329	0.408	48.8	51.3				12.35	13.77	4.83	5.50	7.28		7.54
3/1/97	0.305	0.433	49.8	50.5				12.99	13.56	5.09	5.18	7.16		7.43
4/1/97	0.314	0.380	50.2	50.4				26.27	26.79	10.00	10.00	7.36		7.46
5/1/97	0.310	0.383	51.32	53.4				25.81	26.08	<10.0	<10.0	7.21		7.45
6/1/97	0.314	0.385	51.8	53.2				25.64	27.37	<10.0	<10.0	7.31		7.57
7/1/97	0.295	0.373	52.6	53.6				64.33	123.89	<26.2	<50.0	7.16		7.38
8/1/97	0.301	0.405	51.5	52.5				28.86	36.05	11.50	14.00	7.00		7.45
9/1/97	0.310	0.462	51.9	52.2				25.56	25.70	10.25	11.00	7.33		7.53
10/1/97	0.350	0.482	51.6	52.0				35.71	54.08	12.40	18.00	7.30		7.49

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	TOTAL SUSPENDED SOLIDS				CYANIDE (tot.)				FLUORIDE (tot.)				ARSENIC (tot.)				BERYLLIUM (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85			8.00	23.00			0.002	0.003				2.20			0.010	0.010				
3/1/85			1.00	3.00			0.002	0.002				2.20			<0.01	<0.01				
4/1/85			12.00	21.00			0.002	0.003				2.10			0.010	0.010				
1/1/96	5.30	8.50	2.40	3.90	0	0	<0.01	<0.01	4.50	4.70	2.07	2.19	0	0	<0.01	<0.01	0	0	<0.005	<0.005
2/1/96	3.34	6.15	1.56	2.90	0	0	<.005	<.005	4.49	4.77	2.10	2.25	0	0	<.010	<.010	0	0	<.005	<.005
3/1/96	3.28	4.49	1.60	2.10	0	0	<.010	<.010	4.31	4.62	2.04	2.16	0	0	<.010	<.010	0	0	<.005	<.005
4/1/96	2.14	2.43	1.10	1.20	0	0	<.010	<.010	4.35	4.54	2.14	2.22	0	0	<.010	<.010	0	0	<.005	<.005
5/1/96	2.15	2.42	1.10	1.20	0	0	<0.005	<0.005	4.17	4.72	2.06	2.22	0	0	<0.01	<0.01	0	0	<0.005	<0.005
6/1/96	2.03	2.07	1.00	1.00	0	0	<.005	<.005	4.31	4.52	2.12	2.21	0	0	<.01	<.01	0	0	<.005	<.005
7/1/96	2.40	2.93	2.10	1.40	0	0	<.010	<.010	4.67	4.87	2.13	2.21	0	0	<.010	<.010	0	0	<.005	<.005
8/1/96	2.20	2.33	<1.00	<1.00	0	0	<.010	<.010	4.57	4.87	2.07	2.13	0	0	<.010	<.010	0	0	<.005	<.005
9/1/96	2.46	3.18	1.10	1.40	0	0	<.010	<.010	4.72	4.97	2.11	2.19	0	0	<0.010	<0.010	0	0	<.005	<.005
10/1/96	10.20	18.53	5.60	10.00	0	0	<0.01	<0.01	2.95	4.05	1.98	2.10	0	0	<.010	<.010	0	0	<.005	<.005
11/1/96	18.51	20.20	10.40	12.00	0	0	<.010	<.010	3.46	3.69	1.94	2.01	0	0	<.005	<.005	0	0	<.004	<.004
12/1/96	19.97	28.37	10.00	10.00	0	0	<.010	<.010	3.45	4.94	1.73	1.74	0	0	<.005	<.005	0	0	<.005	<.005
1/1/97	8.30	28.37	2.94	10.00	0	0	<0.01	<0.01	5.21	5.59	1.86	1.97	0	0	<.005	<.005	0	0	<.005	<.005
2/1/97	2.69	3.00	1.05	1.20	0	0	<0.01	<0.01	4.88	5.07	1.91	1.95	0	0	<.005	<.005	0	0	<.004	<.004
3/1/97	2.83	3.14	1.10	1.30	0	0	<0.01	<0.01	4.85	5.01	1.90	2.00	0	0	<0.001	<0.001	0	0	<0.005	<0.005
4/1/97	10.60	13.10	4.05	5.00	0	0	<.010	<.010	5.04	5.21	1.90	2.00	0	0	<.001	<.001	0	0	<.002	<.002
5/1/97	12.91	13.04	<5.0	<5.0	0.021	0.103	0.008	0.040	4.65	4.96	1.80	1.90	0	0	<.001	<.001	0	0	<.002	<.002
6/1/97	13.50	16.42	5.25	6.00	0	0	<0.01	<0.01	4.80	4.98	1.88	1.90	0	0	<0.01	<0.01	0	0	<.002	<.002
7/1/97	26.50	49.60	10.80	20.00	0	0	<.010	<.010	4.63	5.22	1.90	2.10	0	0	<.0002	<.001	0	0	<.002	<.002
8/1/97	50.20	50.41	<20.0	<20.0	0	0	<0.01	<0.01	4.08	4.51	1.63	1.80	0	0	<.005	<.005	0	0	<.005	<.005
9/1/97	51.12	51.41	<20.0	<20.0	0	0	<0.01	<0.01	4.35	4.57	1.70	1.80	0	0	<0.005	<0.005	0	0	<0.004	<0.004
10/1/97	57.80	60.80	<20.0	<20.0	0	0	<.010	<.010	4.34	4.51	1.50	1.60	0	0	<.005	<.005	0	0	<.005	<.005

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	CADMIUM (tot.)				COBALT (tot.)				COPPER (tot.)				IRON (tot.)				LEAD (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85				0.02							0.06	0.19				0.18			0.06	0.06
3/1/85				0.01							0.02	0.03				0.24			0.08	0.09
4/1/85				0.01							0.02	0.02				0.47			0.05	0.06
1/1/96	0.012	0.012	<0.005	<0.005	0.022	0.022	<0.01	<0.01	0	0	<0.01	<0.01	0.218	0.219	<0.1	<.0.1	0	0	<0.003	<0.003
2/1/96	0.110	0.110	<.005	<.005	0.021	0.021	0.010	0.010	0	0	<.010	<.010	0.214	0.216	<0.1	<0.1	0	0	<.003	<.003
3/1/96	0.011	0.011	<.005	<.005	0.021	0.021	<.010	<.010	0	0	<.010	<.010	0.211	0.214	<0.1	<0.1	0.010	0.013	<.0045	<.0060
4/1/96	0.011	0.011	<.005	<.005	0.021	0.021	<.010	<.010	0	0	<.010	<.010	0.204	0.205	<0.1	<0.1	0	0	<.003	<.003
5/1/96	0.011	0.011	<0.005	<0.005	0.020	0.020	<0.010	<0.010	0	0	<0.010	<0.010	0.202	0.205	<0.10	<0.10	0	0	<0.005	<0.005
6/1/96	0	0	<.001	<.001	0.021	0.021	<.010	<.010	0	0	<.010	<.010	0.203	0.207	<0.1	<0.1	0	0	<.005	<.005
7/1/96	0	0	<.001	<.001	0.021	0.021	<.010	<.010	0	0	<.010	<.010	0.219	0.224	<0.1	<0.1	0	0	<.0045	<.0045
8/1/96	0	0	<.001	<.001	0.022	0.022	<.010	<.010	0	0	<.010	<.010	0.221	0.232	<0.1	<0.1	0	0	<.0045	<.0045
9/1/96	0	0	<.0001	<.0001	0.022	0.022	<.010	<.010	0	0	<.010	<.010	0.223	0.229	<0.1	<0.1	0	0	<.00045	<.00045
10/1/96	0.009	0.010	<.005	<.005	0.021	0.021	<.010	<.010	0	0	<.010	<.010	0.187	0.208	<0.1	<0.1	0	0	<.003	<.003
11/1/96	0.009	0.009	<.005	<.005	0.018	0.018	<.010	<.010	0	0	<.010	<.010	0.178	0.186	<0.10	<0.10	0	0	<.003	<.003
12/1/96	0.010	0.010	<.005	<.005	0.020	0.020	<.010	<.010	0	0	<.010	<.010	0.200	0.284	<0.10	<0.10	0	0	<.003	<.003
1/1/97	0	0	<.001	<.001	0.028	0.028	<.010	<.010	0	0	<.010	<.010	0.280	0.280	<0.1	<0.1	0	0	<.003	<.003
2/1/97	0.0065	0.0140	0.0028	0.0050	0.028	0.028	<.010	<.010	0	0	<.010	<.010	0.175	0.279	0.060	0.100	0	0	<.002	<.003
3/1/97	0	0	0.0008	0.0030	0.025	0.025	<.010	<.010	0	0	<.010	<.010	0.057	0.075	0.023	0.030	0.077	0.201	0.030	0.080
4/1/97	0	0	<.0005	<.0005	0.027	0.027	<.010	<.010	0	0	<.010	<.010	0.052	0.078	0.020	0.030	0	0	<.001	<.001
5/1/97	0	0	<.0005	<.0005	0.026	0.026	<0.01	<0.01	0.015	0.051	0.006	0.020	0.046	0.102	0.018	0.040	0	0	<.001	<.001
6/1/97	0	0	<.0005	<.0005	0.026	0.026	<.01	<.01	0	0	<.010	<.010	0.077	0.101	0.030	0.040	0	0	<.001	<.001
7/1/97	0.0024	0.0120	0.0037	0.0050	0.025	0.025	<.010	<.010	0	0	<.010	<.010	0.201	0.249	0.082	0.100	0.0028	0.014	0.0032	0.006
8/1/97	0	0	<.001	<.001	0.025	0.025	<.010	<.010	0	0	<.010	<.010	0.314	0.502	0.125	0.200	0.0037	0.015	0.0015	<.006
9/1/97	0	0	<0.001	<0.001	0.025	0.025	<.010	<.010	0	0	<.010	<.010	0.256	0.257	<0.10	<0.10	0.0037	0.015	0.0015	0.006
10/1/97	0.0021	0.0110	0.0008	0.0040	0.028	0.028	<.010	<.010	0	0	<.010	<.010	0.289	0.300	<.010	<.010	0	0	<.003	<.003

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	MANGANESE (tot.)				MOLYBDENUM (tot.)				SILVER (tot.)				VANADIUM (tot.)				ZINC (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85	-		1.20	1.30	9.00	12.00	2.30	2.60												0.02
3/1/85	-		1.40	1.50	8.40	12.00	2.17	2.83												0.03
4/1/85	-		1.38	1.48	10.80	12.10	2.42	2.63												0.03
1/1/96	4.00	4.20	1.85	1.90	5.00	5.30	2.30	2.40	0.022	0.022	<0.01	<0.01	0.022	0.022	<0.01	<0.01	0	0	<0.020	<0.020
2/1/96	3.95	4.11	1.84	1.90	4.80	4.97	2.24	2.30	0.021	0.021	<.010	<.010	0.021	0.021	<.010	<.010	0	0	<.020	<.020
3/1/96	4.01	4.19	1.90	2.00	4.97	5.05	2.35	2.40	0.021	0.021	<.010	<.010	0.021	0.021	<.010	<.010	0	0	<.020	<.020
4/1/96	3.92	4.06	1.93	2.00	5.04	5.25	2.48	2.60	0.021	0.021	<.010	<.010	0.021	0.021	<.010	<.010	0	0	<.020	<.020
5/1/96	3.56	3.70	1.76	1.80	5.14	5.25	2.54	2.61	0.020	0.020	<.010	<.010	0.020	0.020	<.010	<.010	0	0	<.020	<.020
6/1/96	3.89	3.95	1.91	1.93	4.88	5.03	2.40	2.46	0.021	0.021	<.010	<.010	0.021	0.021	<.010	<.010	0	0	<.020	<.020
7/1/96	4.32	4.48	1.97	2.03	5.44	5.60	2.48	2.54	0.021	0.021	<.010	<.010	0.021	0.021	<.010	<.010	0	0	<.020	<.020
8/1/96	4.21	4.47	1.91	1.95	5.63	5.90	2.55	2.63	0	0	<.002	<.002	0.022	0.022	<.010	<.010	0.045	0.047	0.021	0.022
9/1/96	4.15	4.29	1.86	1.87	5.52	5.61	2.47	2.50	0	0	<.002	<.002	0.022	0.022	<.010	<.010	0	0	<.020	<.020
10/1/96	2.84	3.95	1.90	1.90	4.58	4.97	2.45	2.50	0	0	<.002	<.002	0.021	0.021	<.010	<.010	0	0	<.020	<.020
11/1/96	3.24	3.35	1.82	1.90	4.50	4.65	2.52	2.60	0	0	<.002	<.002	0.018	0.018	<.010	<.010	0	0	<.020	<.020
12/1/96	3.19	4.54	1.60	1.60	4.84	7.38	2.38	2.50	0	0	<.002	<.002	0.020	0.020	<.010	<.010	0	0	<.020	<.020
1/1/97	4.43	4.54	1.58	1.61	6.28	6.98	2.24	2.29	0	0	<.002	<.002	0.028	0.028	<.010	<.010	0.076	0.109	0.027	0.039
2/1/97	4.55	4.66	1.78	1.86	5.89	6.08	2.31	2.43	0	0	<.002	<.002	0.028	0.028	<.010	<.010	0	0	<.015	<.020
3/1/97	4.62	4.80	1.82	1.91	6.09	6.23	2.39	2.48	0	0	<.002	<.002	0.025	0.025	<.010	<.010	0	0	<.020	<.020
4/1/97	4.56	4.71	1.74	1.76	6.32	6.51	2.41	2.43	0	0	<.0005	<.0005	0.027	0.027	<.010	<.010	0	0	<.010	<.010
5/1/97	4.26	4.49	1.65	1.73	6.02	6.26	2.33	2.41	0	0	<.0005	<.0005	0.013	0.013	<.005	<.005	0	0	0.002	0.010
6/1/97	4.35	4.41	1.70	1.75	6.30	6.84	2.46	2.50	0	0	<.0005	<.0005	0.013	0.013	<.005	<.005	0	0	0.005	0.010
7/1/97	4.23	4.46	1.72	1.80	5.96	6.44	2.40	2.60	0	0	<.0005	<.0005	0.025	0.025	<.010	<.010	0	0	<.020	<.020
8/1/97	4.15	4.28	1.65	1.70	5.77	6.01	2.30	2.40	0	0	<.002	<.002	0.025	0.025	<.010	<.010	0	0	<.020	<.020
9/1/97	4.09	4.11	1.60	1.60	6.06	6.36	2.38	2.50	0	0	<0.002	<0.002	0.025	0.025	<0.010	<0.010	0	0	<0.020	<0.020
10/1/97	4.57	5.47	1.58	1.80	6.07	6.68	2.10	2.20	0	0	<0.002	<0.002	0.028	0.028	<.010	<.010	0	0	<.020	<.020

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	ALUMINUM (tot.)				SELENIUM (tot.)				CHLORDANE (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85												
3/1/85												
4/1/85												
1/1/96	0.437	0.437	<0.2	<0.2	0	0	<0.005	<0.005	0.0017	0.0017	<0.0005	<0.0005
2/1/96	0.427	0.427	<0.2	<0.2	0	0	<.005	<.005	0.0017	0.0017	<.0005	<.0005
3/1/96	0.427	0.427	<0.2	<0.2	0	0	<.005	<.005	0.0017	0.0017	<.0005	<.0005
4/1/96	0.411	0.411	<0.2	<0.2	0	0	<.005	<.005	0.0017	0.0017	<.011	<.011
5/1/96	0.404	0.404	<0.2	<0.2	0	0	<.005	<.005	0.0017	0.0017	<.0005	<.0005
6/1/96	0.414	0.414	<0.2	<0.2	0	0	<.005	<.005	0.0017	0.0017	<.0005	<.0005
7/1/96	0.418	0.419	<0.2	<0.2	0	0	<.005	<.005	0.001	0.001	<.0005	<.0005
8/1/96	0.222	0.222	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
9/1/96	0.221	0.221	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
10/1/96	0.208	0.208	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
11/1/96	0.182	0.182	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
12/1/96	0.199	0.199	<0.10	<0.10	0	0	<.005	<.005	0	0	<.0002	<.0002
1/1/97	0.284	0.284	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
2/1/97	0.279	0.279	<0.1	<0.1	0	0	<.005	<.005	0	0	<.0002	<.0002
3/1/97	0.175	0.175	0.070	0.070	0	0	<.001	<.001	0	0	<0.0002	<0.0002
4/1/97	0.080	0.080	0.030	0.030	0	0	<.001	<.001	0	0	<0.0002	<0.0002
5/1/97	0.078	0.078	<0.03	<0.03	0	0	<.001	<.001	0	0	<.0002	<0.0002
6/1/97	0.076	0.076	<.03	<.03	0	0	<0.001	<0.001	0	0	<.0002	<.0002
7/1/97	0.075	0.075	<.030	<.030	0	0	<.001	<.001	0	0	<.0002	<.0002
8/1/97	0.502	0.502	<0.200	<0.200	0	0	<.005	<.005	0	0	<.0002	<.0002
9/1/97	0.255	0.255	<0.10	<0.10	0	0	<0.005	<0.005	0	0	<0.0002	<0.0002
10/1/97	0.277	0.277	<0.10	<0.10	0	0	<.005	<.005	0	0	<.0002	<.0002

TABLE 2
OUTFALL 002 DATA FROM HISTORICAL DISCHARGE MONITORING REPORTS
JANUARY 6, 1998

DATE	CHLORINE (tot.)				MERCURY (tot.)			
	(lb/day)		(mg/l)		(lb/day)		(mg/l)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
2/1/85							<.0002	<.0002
3/1/85							<0.0002	<0.0002
4/1/85							0.0002	0.0002
1/1/96	0	0	<0.011	<0.011	0	0	<0.0002	<0.0002
2/1/96	0	0	<0.011	<0.011	0	0	<.0002	<.0002
3/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
4/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
5/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
6/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
7/1/96	0	0	<.010	<.010	0	0	<.0002	<.0002
8/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
9/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
10/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
11/1/96	0	0	<.011	<.011	0	0	<.0002	<.0002
12/1/96	0	0	<.0002	<0.0002	0	0	<.0002	<0.0002
1/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
2/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
3/1/97	0	0	<.011	<.011	0	0	<.0002	<0.0002
4/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
5/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
6/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
7/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
8/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002
9/1/97	0	0	<0.011	<0.011	0	0	<0.0002	<0.0002
10/1/97	0	0	<.011	<.011	0	0	<.0002	<.0002

EXHIBIT I-10

REQUEST FOR CONTINUED APPROVAL OF ALTERNATIVE MOLYBDENUM TEST PROCEDURES

REQUEST FOR
CONTINUED APPROVAL OF ALTERNATIVE MOLYBDENUM TEST PROCEDURES

On April 1, 1977, Mr. John C. White, Region VI EPA Administrator, approved the Molycorp thiocyanate colorimetric method for the determination of molybdenum (letter attached). Molycorp had submitted data to demonstrate the comparability of the standard atomic absorption method and the thiocyanate colorimetric method. Since approval of the method, Molycorp's laboratory continues periodically to split samples with other labs and perform other quality control work to verify the molybdenum analyses.

Examples of the results are shown below:

	Molycorp's Lab Method	AA Method
Outfall 002	2.14	2.19 *
Q/C 9945	0.133	0.139
Outfall 001	2.50	2.55 Molycorps Louviers plant

* Split grab sample of 3/21/91 with ACZ Labs Steamboat Springs, CO.

Molycorp, Inc. hereby requests a continued renewal of the approval for the alternative test procedure for the determination of molybdenum. Enclosed for review are copies of original request from Molycorp for approval of the procedure(without exhibits); a description of the procedure and the approval from the Regional Administrator.

Please be advised that all molybdenum values reported in our Discharge Monitoring Reports are results of analyses performed by the approved alternative method

David R.Shoemaker
Mine Manager

David R Shoemaker

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
FIRST INTERNATIONAL BUILDING
1201 ELM STREET
DALLAS, TEXAS 75270

April 1, 1977

Mr. C. R. Sacrison
General Manager
Molycorp, Inc.
Questa, New Mexico 87556

Dear Mr. Sacrison:

The data which you submitted on February 9, 1977 has been reviewed. The procedure for the analyses of molybdenum and the comparability testing data indicate that the method is very good. In fact, the standard deviations indicate greater precision for the alternate method than for the standard method in four of the five samples. The mean recovery for seven aliquots at the two discharge points was 96 percent.

In view of these data, the Molycorp thiocyanate colorimetric method is approved for NPDES Permit No. NM0022306 discharges No. 001 and 002. If during an inspection by the State of New Mexico, Environmental Improvement Agency or the U. S. Environmental Protection Agency, it is found that the test method is inappropriate, we reserve the right to withdraw approval.

Your efforts are appreciated. If you have any questions, please do not hesitate to call or write.

Sincerely,

John C. White

John C. White
Regional Administrator

cc: Joe Pierce, Chief
Water Quality Division
Environmental Improvement Agency
P. O. Box 2348
Santa Fe, NM 87503

Molycorp

Molycorp, Inc. · Questa, New Mexico 87556 · (505) 586-0212

February 9, 1977

Mr. John C. White
Regional Administrator
U.S. EPA
1201 Elm Street
Dallas, Texas 75270

Re: Application for Alternative Test Procedure (40 CFR 136.4)

Dear Mr. White:

Pursuant to Molycorp's December 6, 1976 request for an alternative test procedure for molybdenum for NPDES permit #NM 0022306, the EPA requested comparability testing to provide data on the equivalency of the standard and alternate methods.

For discharges 001 and 002, comparability data from analyses by Molycorp of effluent samples representative of normal operating conditions, and of effluent samples plus standard solution, is hereby submitted. For discharge 001, comparability data from analysis by the New Mexico Bureau of Mines and Mineral Resources of an effluent sample representative of normal operating conditions, is also presented. Since there is normally very little variation in the molybdenum concentration at each discharge, it was neither appropriate nor possible to obtain samples of varying concentrations from either discharge. It should be noted that the molybdenum concentration in discharge 001 is quite a bit different from that in 002. Therefore, although the methods are not compared on varying concentrations from the same source, they are compared at two different molybdenum concentrations. No data is included for discharge 003 because molybdenum is not detectable in that discharge. All comparability testing was performed according to the instructions provided by EPA. The Standard Method used was the EPA approved test procedure (digestion followed by atomic absorption) as specified in 40 CFT 136.3, and the Alternate Method used was the Colorimetric Determination of Molybdenum, as attached.

Table I: Effluent Sample From Discharge 001, Representative of Normal Operating Conditions, analysis by Molycorp.

Aliquot	Standard Method	Alternate Method
1	1.87	1.91
2	1.86	1.91
3	1.84	1.91
4	1.84	1.91
5	1.87	1.91
6	1.83	1.93
7	1.84	1.90
Avg ±	1.85 ± .02	1.91 ± .009

Table II: Discharge 001, Effluent Sample Plus Standard Solution, analysis by Molycorp.

Aliquot		Standard Method	Alternate Method
1		3.76	3.65
2		3.78	3.69
3		3.73	3.63
4		3.75	3.62
5		3.82	3.66
6		3.86	3.67
7		3.73	3.66
	Avg ±	3.78 ± .05	3.65 ± .02

Source of Standard Solution:
0.3752 grams of Climax high purity MoO_3 (99.5% MoO_3) was used to prepare 250 ml of 1000 ppm Mo standard solution. A portion of the 001 discharge sample analyzed as shown in Table I was spiked with this solution to approximately double the Mo concentration. The amount added was approximately 1.9 ppm.

Table III: Effluent Sample From Discharge 001, Representative of Normal Operating Conditions, analysis by New Mexico Bureau of Mines and Mineral Resources.

Aliquot		Standard Method	Alternate Method
1		1.9	2.0
2		2.0	2.0
3		2.1	2.0
4		2.1	1.9
5		2.0	2.0
6		1.8	2.0
7		1.9	2.0
	Avg ±	2.0 ± .11	2.0 ± .04

Table IV: Effluent Sample From Discharge 002, Representative of Normal Operating Conditions, analysis by Molycorp.

Aliquot		Standard Method	Alternate Method
1		3.27	3.26
2		3.23	3.16
3		3.29	3.11
4		3.26	3.15
5		3.26	3.18
6		3.23	3.18
7		3.19	3.32
	Avg ±	3.25 ± .03	3.19 ± .07

Table V: Discharge 002, Effluent Sample Plus Standard Solution, analysis by Molycorp.

Aliquot	Standard Method	Alternate Method
1	6.39	6.39
2	6.35	6.45
3	6.42	6.42
4	6.55	6.44
5	6.48	6.40
6	6.48	6.39
7	6.42	6.42
Avg ±	6.44 ± .07	6.42 ± .02

Source of Standard Solution:
0.3752 grams of Climax high purity MoO_3 (99.95% MoO_3) was used to prepare 250 ml of 1000 ppm Mo standard solution. A portion of the 002 discharge sample analyzed as shown in Table IV was spiked with this solution to approximately double the Mo concentration. The amount added was approximately 3.3 ppm.

The standard deviations, precision data, indicate greater precision for the alternate method in four of the five tables above.

With respect to accuracy data for the alternate method, a sample from discharge 00 was spiked with 2 ppm Mo, the mean recovery for seven aliquots was [illegible].

For a sample from discharge 002 spiked with 4 ppm Mo, the mean recovery for seven aliquots was 99%.

Although additional statistical analyses of the above data could be performed, we feel that the above analyses demonstrate the precision and accuracy of the proposed alternative test procedure. This data should complete the requirements for the application for an alternative test procedure.

Respectfully submitted

C. R. Sacrison
General Manager

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Encl.

Bcc: R. G. Dewey
Carter Trimble
Howard Twitty

COLORIMETRIC DETERMINATION OF MOLYBDENUM
Molycorp, Inc.

Reagents:

1. Sulphuric acid solution: 2 parts H_2O - 1 part H_2SO_4.
2. Ferric chloride solution: Dissolve 35 grams of ferric ammonium sulfate : 6 lb. bottle of concentrated hydrochloric aci
3. Butyl carbitol: Diethylene glycol mono-butyl ether (Dowanol D
4. Thiacyanate solution: 10% KCNS in H_2O.
5. Stannous chloride solution: 112 grams $SnCl_2.2\ H_2O$
   100 ml concentrated HCl
   Heat above mixture until all stannous chloride is dissolved and solution is clear. Dilute to 1 liter with H_2O.

Procedure for Water Samples:

1. Bring total molybdenum into solution with HNO_3 as described in Section 4.1.3 EPA manual entitled, *Methods for Chemical Analysis of Water and Wastes*, 1974.

2. Transfer an appropriate aliquot of the solution to a 100 ml volumetric flask. Select the aliquot size that it contains from 0.05 to 1.0 mg Mo. Prior concentrati of sample may be required to bring sample into this concentration range.

3. Add in succession the following reagents:

   A. Sulphuric acid solution to bring aliquot to approximately pH 7.
   B. 10 ml ferric chloride solution.
   C. 20 ml butyl carbitol - mix well.
   D. 10 ml KCNS solution - mill well for ½ a minute.
   E. 7 ml $SnCl_2$ solution - mix well.

   Dilute to the mark with H_2O. Mix well and allow to stand for 30 minutes. Read O.D. or % T at 465 mu. Use a reagent blank.

4. Prepare a calibration curve by transferring 0.1, 0.3, 0.5, 0.7, and 1.0 mg of Mo into 100 ml volumetric flasks and proceed as in step (3) for color development. Also prepare a blank in the same manner.

5. Determine sample Mo content using the standard curve.

Molycorp, Inc. · Questa, New Mexico 87556 · (505) 586-0212

December 6, 1976

Mr. John C. White
Regional Administrator
U.S. EPA
1201 Elm Street
Dallas, Texas 75270

RE: Application for alternative test procedure (40 CRF 136.4 as revised July 1, 1975)

Dear Mr. White:

Molycorp, Inc. Questa, New Mexico 87556, hereby requests approval of an alternativ test procedure for molybdenum for the reporting on discharges 001, 002, and 003 of NPDES permit NM 0022306, issued by the United States EPA.

Justification for said request has three components:

First, for over ten years, analytical analysis of molybdenum has provided the means for meeting economic criteria established for mining and milling activities by Molycorp at Questa. After extensive testing and comparison of methods, the proposed procedure was developed to maximize accuracy and reproducibility and to minimize interferences. Other procedures, including the recommended EPA method utilizing atomic absorption with nitrous oxide - acetylene, were not found to be as analytically satisfactory as the proposed procedure. In summary, since the economics of mining and milling at this site are dependent on accurate analytical molybdenum analysis, selection of the best test procedure for molybdenu was of utmost importance.

Second, the proposed procedure (with slight modifications) was one of the procedur recommended by the Molybdenum Project. (See enclosure Exhibit 1, by Robert Meglen and Michael Glaze, April, 1973.) Since the objective of the Molybdenum Project's research was to develop information on the biology of molybdenum, analytical accuracy would be a prerequisite for studying this topic. Thus the recommendation of the proposed procedure by the Molybdenum Project supports the analytical merit of said procedure.

Third, splits made with the EPA in October, 1976 show excellent agreement between results obtained in our lab using the proposed procedure, and the results obtained in the EPA Surveillance and Analysis in Ada, Oklahoma using the approved EPA method. Marshall Roberts, the EPA Chemist in Ada, was impressed with the analytical agreement and suggested that approval of the herein requested alternative procedure should not pose a problem.

Below is a description of the proposed test procedure:

COLORIMETRIC DETERMINATION OF MOLYBDENUM
Molycorp, Inc.

Reagents:

1. Sulphuric acid solution: 2 parts H_2O - 1 part H_2SO_4.
2. Ferric chloride solution: Dissolve 35 grams of ferric ammonium sulfate 6 lb. bottle of concentrated hydrochloric ac
3. Butyl carbitol: Diethylene glycol mono-butyl ether (Dowanol
4. Thiacyanite solution: 10% KCNS in H_2O.
5. Stannous chloride solution: 112 grams $SnCl_2.2\ H_2O$
   100 ml concentrated HCl
   Heat above mixture until all stannous chloride is dissolved and solution is clear. Dilute to 1 liter with H_2O.

Procedure for Water Samples:

1. Bring total molybdenum into solution with HNO_3 as described in Section 4.1.3 EPA manual entitled, *Methods for Chemical Analysis of Water and Wastes*, 1974.

2. Transfer an appropriate aliquot of the solution to a 100 ml volumetric flask. Select the aliquot size that it contains from 0.05 to 1.0 mg Mo. Prior concentra of sample may be required to bring sample into this concentration range.

3. Add in succession the following reagents:

   A. Sulphuric acid solution to bring aliquot to approximately pH 7.
   B. 10 ml ferric chloride solution.
   C. 20 ml butyl carbitol - mix well.
   D. 10 ml KCNS solution - mill well for ½ a minute.
   E. 7 ml $SnCl_2$ solution - mix well.

   Dilute to the mark with H_2O. Mix well and allow to stand for 30 minutes. Read O.D. or % T at 465 mu. Use a reagent blank.

4. Prepare a calibration curve by transferring 0.1, 0.3, 0.5, 0.7, and 1.0 mg of Mo into 100 ml volumetric flasks and proceed as in step (3) for color development Also prepare a blank in the same manner.

5. Determine sample Mo content using the standard curve.

Below are references to published studies which discuss the applicability of the alternate test procedure to water analysis, and which discuss problems with the atomic absorption method.

Exhibit 1: This exhibit describes test procedures for Mo used by the Molybdenum Project. Discussion of problems with the atomic absorption method (EPA approved) on pp. 7-9 is of importance. The colorimetric method, essentially the same as the proposed test procedure, is presented beginning on p. 9. In introducing the method, the following statement is made: "Water samples can be routinely analyzed with precision limits of about ± 5 µg/l."

Exhibit 2: This exhibit discusses interferences which arise when utilizing the atomic absorption method. It should be noted that colorimetric analysis (the proposed test procedure) is utilized to evaluate the effectiveness of removing interferences for the atomic absorption method. In other words, the proposed test procedure is used as an accurate method to evaluate the accuracy of the atomic absorption method.

The following references are to published studies which utilize the proposed test procedure for research purposes:

Brian G. Katz and Donald D. Runnells, "Experimental Study of Sorption of Molybdenum by Desert, Agricultural and Alpine Soils", in *Trace Substances in Environmental Health VIII*, 1974. A Symposium, D. D. Hemphill, Ed., University of Missouri, Columbia.

Donald D. Runnells, Willard R. Chappell, and Robert Meglan, *The Molybdenum Project Geochemical Aspects*, Geological Society of America, Special Paper 155, 1975.

Franklin W. Briese and Roger M. Jorden, *Analysis of Trace Balance for Aqueous Systems"*, presented at First Annual NSF Trace Contaminants Conference, Oak Ridge, Tennessee, August 8-10, 1973.

Brian G. Katz and Donald D. Runnells, "The Ability of Selected Soils to Remove Molybdenum from Industrial Wastewaters", in *Transport and the Biological Effects of Molybdenum in the Environment*, A progress Report to NSF.

W. James Clawson, "A Review of Molybdenum Problems in Livestock in California." A contribution to the *Transport and the Biological Effects of Molybdenum in the Environment, A Progress Report to National Science Foundation* for the period January 1, 1974. Published by the Molybdenum Project, University of Colorado, Boulder Colorado 80302. Editor W. R. Chappell.

Transport and the Biological Effects of Molybdenum in the Environment, A Progress Report to National Science Foundation, January 1, 1974.

Molycorp, Inc. herein requests approval of an alternative test procedure (40 CFR 1

Respectfully submitted,

C. R. Sacrison
General Manager

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SECTION II

GENERAL FORM 1 AND FORM 2C

GENERAL 1

EPA

ENVIRONMENTAL PROTECTION AGENCY

GENERAL INFORMATION

Consolidated Permits Program

(Read the "General Instructions" before starting.)

I. EPA I.D. NUMBER: F NM0022306 D

LABEL ITEMS

I. EPA I.D. NUMBER

III. FACILITY NAME

V. FACILITY MAILING ADDRESS

VI. FACILITY LOCATION

10-14-98 M

NM0022306 981014
MOLYCORP INC. QUESTA DIV.
DAVID R SHOEMAKER, GEN. SUPT.
P. O. BOX 469
QUESTA NM 87556

GENERAL INSTRUCTIONS

If a preprinted label has been provided, affix it in the designated space. Review the information carefully; if any of it is incorrect, cross through it and enter the correct data in the appropriate fill-in area below. Also, if any of the preprinted data is absent *(the area to the left of the label space lists the items that should appear)*, please provide it in the proper fill-in area(s) below. If the label is complete and correct, you need not complete Items I, III, V, and VI *(except VI-B which must be completed regardless)*. Complete all items if no label has been provided. Refer to the instructions for detailed item descriptions and for the legal authorizations under which this data is collected.

II. POLLUTANT CHARACTERISTICS

INSTRUCTIONS: Complete A through J to determine whether you need to submit any permit application forms to the EPA. If you answer "yes" to any questions, you must submit this form and the supplemental form listed in the parenthesis following the question. Mark "X" in the box in the third column if the supplemental form is attached. If you answer "no" to each question, you need not submit any of these forms. You may answer "no" if your activity is excluded from permit requirements; see Section C of the instructions. See also, Section D of the instructions for definitions of bold-faced terms.

SPECIFIC QUESTIONS	MARK 'X' YES	NO	FORM ATTACHED	SPECIFIC QUESTIONS	MARK 'X' YES	NO	FORM ATTACHED
A. Is this facility a publicly owned treatment works which results in a discharge to waters of the U.S.? (FORM 2A)		X		B. Does or will this facility *(either existing or proposed)* include a concentrated animal feeding operation or aquatic animal production facility which results in a discharge to waters of the U.S.? (FORM 2B)		X	
C. Is this a facility which currently results in discharges to waters of the U.S. other than those described in A or B above? ([redacted])	X			D. Is this a proposed facility *(other than those described in A or B above)* which will result in a discharge to waters of the U.S.? (FORM 2D)		X	
E. Does or will this facility treat, store, or dispose of hazardous wastes? (FORM 3) 2D+2C		X		F. Do you or will you inject at this facility industrial or municipal effluent below the lowermost stratum containing, within one quarter mile of the well bore, underground sources of drinking water? (FORM 4) 2D+2C		X	
G. Do you or will you inject at this facility any produced water or other fluids which are brought to the surface in connection with conventional oil or natural gas production, inject fluids used for enhanced recovery of oil or natural gas, or inject fluids for storage of liquid hydrocarbons? (FORM 4) 2C+2D		X		H. Do you or will you inject at this facility fluids for special processes such as mining of sulfur by the Frasch process, solution mining of minerals, in situ combustion of fossil fuel, or recovery of geothermal energy? (FORM 4)		X	
I. Is this facility a *proposed* stationary source which is one of the 28 industrial categories listed in the instructions and which will potentially emit 100 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5) 2C+2D		X		J. Is this facility a proposed stationary source which is NOT one of the 28 industrial categories listed in the instructions and which will potentially emit 250 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5)		X	

III. NAME OF FACILITY

1 SKIP

IV. FACILITY CONTACT

A. NAME & TITLE *(last, first, & title)*	B. PHONE *(area code & no.)*
2 SHOEMAKER DAVID MINE MANAGER	505 586 7601

V. FACILITY MAILING ADDRESS

A. STREET OR P.O. BOX

3 P O BOX 469

B. CITY OR TOWN	C. STATE	D. ZIP CODE
4 QUESTA	NM	87556

MAY 21 1998

VI. FACILITY LOCATION

A. STREET, ROUTE NO. OR OTHER SPECIFIC IDENTIFIER

5

B. COUNTY NAME

TAOS

C. CITY OR TOWN	D. STATE	E. ZIP CODE	F. COUNTY CODE *(if known)*
6			

CONTINUED FROM THE FRONT

VII. SIC CODES *(4-digit, in order of priority)*

A. FIRST	B. SECOND
7 1061 (specify) METAL MINING FERRO ALLOY ORES	7 (specify)
C. THIRD	**D. FOURTH**
7 (specify)	7 (specify)

VIII. OPERATOR INFORMATION

A. NAME: 8 MOLYCORP, INC.

B. Is the name listed in Item VIII-A also the owner? ☐ YES ☒ NO

C. STATUS OF OPERATOR *(Enter the appropriate letter into the answer box; if "Other", specify.)*
F = FEDERAL
S = STATE
P = PRIVATE
M = PUBLIC *(other than federal or state)*
O = OTHER *(specify)*

D. PHONE *(area code & no.)*: A

E. STREET OR P.O. BOX: P. O. BOX 469

F. CITY OR TOWN: B QUESTA

G. STATE: NM

H. ZIP CODE: 87556

IX. INDIAN LAND
Is the facility located on Indian lands? ☐ YES ☒ NO

X. EXISTING ENVIRONMENTAL PERMITS

A. NPDES *(Discharges to Surface Water)*: 9 N NM0022306	**D. PSD** *(Air Emissions from Proposed Sources)*: 9 P
B. UIC *(Underground Injection of Fluids)*: 9 U	**E. OTHER** *(specify)*: 9 (specify)
C. RCRA *(Hazardous Wastes)*: 9 R	**E. OTHER** *(specify)*: 9 (specify)

XI. MAP

Attach to this application a topographic map of the area extending to at least one mile beyond property bounderies. The map must show the outline of the facility, the location of each of its existing and proposed intake and discharge structures, each of its hazardous waste treatment, storage, or disposal facilities, and each well where it injects fluids underground. Include all springs, rivers and other surface water bodies in the map area. See instructions for precise requirements.

XII. NATURE OF BUSINESS *(provide a brief description)*

Mining and Milling Operations Producing Molybdenum Disulfide Concentrate.

XIII. CERTIFICATION *(see instructions)*

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this application and all attachments and that, based on my inquiry of those persons immediately responsible for obtaining the information contained in the application, I believe that the information is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

A. NAME & OFFICIAL TITLE *(type or print)*	B. SIGNATURE	C. DATE SIGNED
David R. Shoemaker Mine Manager	David R. Shoemaker	4/13/98

COMMENTS FOR OFFICIAL USE ONLY

C

☆ U.S. Government Printing Office : 1985 - 486-785/329

Please print or type in the unshaded areas only.

EPA I.D. NUMBER (copy from Item 1 of Form 1) NM0022306

Form Approved
OMB No. 2040-0086
Approval expires 5-31-92

FORM 2C NPDES

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY
APPLICATION FOR PERMIT TO DISCHARGE WASTEWATER
EXISTING MANUFACTURING, COMMERCIAL, MINING AND SILVICULTURAL OPERATIONS
Consolidated Permits Program

I. OUTFALL LOCATION

For each outfall, list the latitude and longitude of its location to the nearest seconds and the name of the receiving water.

A. OUTFALL NUMBER (list)	B. LATITUDE			C. LONGITUDE			D. RECEIVING WATER (name)
	1. DEG.	2. MIN.	3. SEC.	1. DEG.	2. MIN.	3. SEC.	
001	36	41	49	105	37	53	Red River
002	36	41	29	105	37	53	Red River
004	36	41	08	105	41	51	Red River
005	36	41	41	105	31	48	Red River

II. FLOWS, SOURCES OF POLLUTION, AND TREATMENT TECHNOLOGIES

A. Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item B. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined *(e.g., for certain mining activities)*, provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

B. For each outfall, provide a description of: (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and storm water runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

1. OUTFALL NO. (list)	2. OPERATION(S) CONTRIBUTING FLOW		3. TREATMENT	
	a. OPERATION (list)	b. AVERAGE FLOW (include units)	a. DESCRIPTION	b. LIST CODES FROM TABLE 2C-1
001	Process water from milling operations and tailings disposal, including mine dewatering, runoff from waste rock piles, and Interceptor wells collection.	No discharge during term of permit due to temporary shut down of operation. Historic discharge 0.7 MGD (during production operations)	PRIMARY: pH adjustment with lime and settling in tailings impoundment to remove suspended rock particles and heavy metal precipitates.	2-K 1-U
001 Cont.			SECONDARY: Ion exchange process to convert MoO_4 ions in tailings water to $CaMoO_4$ precipitate for return to mill circuit.	2-J
002	Seepage from tailings impoundment	.317 MGD (during production operations)		
004	Stormwater	No Discharge during term of existing permit	Solids settling	1-U
005	Stormwater	No Discharge	Solids Settling	1-U

OFFICIAL USE ONLY *(effluent guidelines sub-categories)*

CONTINUED FROM THE FRONT

C. Except for storm runoff, leaks, or spills, are any of the discharges described in Items II-A or B intermittent or seasonal?

☐ YES *(complete the following table)* ☐ NO *(go to Section III)*

1. OUTFALL NUMBER *(list)*	2. OPERATION(s) CONTRIBUTING FLOW *(list)*	3. FREQUENCY a. DAYS PER WEEK *(specify average)*	3. FREQUENCY b. MONTHS PER YEAR *(specify average)*	4. FLOW a. FLOW RATE *(in mgd)* 1. LONG TERM AVERAGE	4. FLOW a. FLOW RATE *(in mgd)* 2. MAXIMUM DAILY	4. FLOW b. TOTAL VOLUME *(specify with units)* 1. LONG TERM AVERAGE	4. FLOW b. TOTAL VOLUME *(specify with units)* 2. MAXIMUM DAILY	4. FLOW c. DURATION *(in days)*
001	Flotation Mill and Mine Dewatering	7	12	0.7* MGD	4.29* MGD			Continuous
002	Tailing Seepage Collection	7	12	.317 MGD	0.602 MGD			Continuous
004	Stormwater (No Discharge)							
005	Stormwater (No Discharge)							

*estimated

III. PRODUCTION

A. Does an effluent guideline limitation promulgated by EPA under Section 304 of the Clean Water Act apply to your facility?

☒ YES *(complete Item III-B)* ☐ NO *(to to Section IV)*

B. Are the limitations in the applicable effluent guideline expressed in terms of production *(or other measure of operation)*?

☐ YES *(complete Item III-C)* ☒ NO *(go to Section IV)*

C. If you answered "yes" to Item III-B, list the quantity which represents an actual measurement of your level of production, expressed in the terms and units used in the applicable effluent guideline, and indicate the affected outfalls.

1. AVERAGE DAILY PRODUCTION a. QUANTITY PER DAY	b. UNITS OF MEASURE	c. OPERATION, PRODUCT, MATERIAL, ETC. *(specify)*	2. AFFECTED OUTFALLS *(list outfall numbers)*

IV. IMPROVEMENTS

A. Are you now required by any Federal, State or local authority to meet any implementation schedule for the construction, upgrading or operation of wastewater treatment equipment or practices or any other environmental programs which may affect the discharges described in this application? This includes, but is not limited to, permit conditions, administrative or enforcement orders, enforcement compliance schedule letters, stipulations, court orders, and grant or loan conditions.

☐ YES *(complete the following table)* ☒ NO *(go to Item IV-B)*

1. IDENTIFICATION OF CONDITION, AGREEMENT, ETC.	2. AFFECTED OUTFALLS a. NO.	2. AFFECTED OUTFALLS b. SOURCE OF DISCHARGE	3. BRIEF DESCRIPTION OF PROJECT	4. FINAL COMPLIANCE DATE a. REQUIRED	4. FINAL COMPLIANCE DATE b. PROJECTED

B. OPTIONAL: You may attach additional sheets describing any additional water pollution control programs *(or other environmental projects which may affec your discharges)* you now have underway or which you plan. Indicate whether each program is now underway or planned, and indicate your actual c planned schedules for construction. ☐ MARK "X" IF DESCRIPTION OF ADDITIONAL CONTROL PROGRAMS IS ATTACHED

 CONTINUE ON PAG

CONTINUED FROM PAGE 2

EPA I.D. NUMBER (copy from Item 1 of Form 1)
NM0022306

V. INTAKE AND EFFLUENT CHARACTERISTICS

A, B, & C: See instructions before proceeding — Complete one set of tables for each outfall — Annotate the outfall number in the space provided. NOTE: Tables V-A, V-B, and V-C are included on separate sheets numbered V-1 through V-9.

D. Use the space below to list any of the pollutants listed in Table 2c-3 of the instructions, which you know or have reason to believe is discharged or may be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it to be present and report any analytical data in your possession.

1. POLLUTANT	2. SOURCE	1. POLLUTANT	2. SOURCE
NONE			

VI. POTENTIAL DISCHARGES NOT COVERED BY ANALYSIS

Is any pollutant listed in Item V-C a substance or a component of a substance which you currently use or manufacture as an intermediate or final product or byproduct?

☐ YES *(list all such pollutants below)* ☒ NO *(go to Item VI-B)*

I. BIOLOGICAL TOXICITY TESTING DATA

Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last 3 years?

X YES *(identify the tests) and describe their purposes below)* ☐ NO *(go to Section VIII)*

001 - There has been no discharge from 001 during term of this permit. Attached as Exhibit II-I are biomonitoring results from 1/92.

002 - Attached as Exhibit I-8 are biomonitoring results from 1996 and 1997 (through October).

004 - There has been no discharge from 004 during the term of this permit.

005 - There has been no discharge from 005 during the term of this permit.

VIII. CONTRACT ANALYSIS INFORMATION

Were any of the analyses reported in Item V performed by a contract laboratory or consulting firm?

N/A

☐ YES *(list the name, address, and telephone number of, and pollutants analyzed by, each such laboratory or firm below)* ☐ NO *(go to Section IX)*

A. NAME	B. ADDRESS	C. TELEPHONE *(area code & no.)*	D. POLLUTANTS ANALYZED *(list)*

X. 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 assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system 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.

A. NAME & OFFICIAL TITLE *(type or print)*	B. PHONE NO. *(area code & no.)*
David R. Shoemaker Mine Manager	505-586-7601
C. SIGNATURE	**D. DATE SIGNED**
David R. Shoemaker	4/13/98

EXHIBIT II-1

OUTFALL 001

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages. SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item I of Form 1)*: NM0022306

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

OUTFALL NO. 001

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS (specify if blank) a. CONCENTRATION	b. MASS	4. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*								mg/l	lb/day			
b. Chemical Oxygen Demand *(COD)*			12.8	472	10.4	60	2	"	"			
c. Total Organic Carbon *(TOC)*								"	"			
d. Total Suspended Solids *(TSS)*			5.0	181	3.5	20	2	"	"			
e. Ammonia *(as N)*								"	"			
f. Flow	VALUE		VALUE 4.29		VALUE 0.688		14	MGD		VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM 7.5	MAXIMUM 7.6	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK 'X' a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)		X								mg/l	lb/day			
b. Chlorine, Total Residual		X								"	"			
c. Color		X								color units				
d. Fecal Coliform		X								MPN/100 ml				
e. Fluoride (16984-48-8)	X				2.40	86	2.15	13.2	2	mg/l	lb/day			
f. Nitrate-Nitrite *(as N)*	X									"	"			

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X' a. BELIEVED PRESENT	2. MARK 'X' b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	4. UNITS b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
g. Nitrogen, Total Organic (as N)		X								mg/l	lb/day			
h. Oil and Grease		X								"	"			
i. Phosphorus (as P), Total (7723-14-0)	X									"	"			
j. Radioactivity														
(1) Alpha, Total	X									pCi/l				
(2) Beta, Total	X									"				
(3) Radium, Total		X								"				
(4) Radium 226, Total		X								"				
k. Sulfate (as SO_4) (14808-79-8)	X									mg/l	lb/day			
l. Sulfide (as S)	X									"	"			
m. Sulfite (as SO_3) (14265-45-3)	X									"	"			
n. Surfactants	X									"	"			
o. Aluminum, Total (7429-90-5)	X									"	"			
p. Barium, Total (7440-39-3)	X									"	"			
q. Boron, Total (7440-42-8)		X								"	"			
r. Cobalt, Total (7440-48-4)		X								"	"			
s. Iron, Total (7439-89-6)	X				0.290	11	0.195	< 2.2	2	"	"			
t. Magnesium, Total (7439-95-4)	X									"	"			
u. Molybdenum, Total (7439-98-7)	X				0.77	28.7	0.63	4.4	2	"	"			
v. Manganese, Total (7439-96-5)	X				0.130	4.4	0.085	< 2.2	2	"	"			
w. Tin, Total (7440-31-5)		X								"	"			
x. Titanium, Total (7440-32-6)		X								"	"			

CONTINUE ON PAGE V-3

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
NM0022306	001

CONTINUED FROM PAGE 3 OF FORM 2-C

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (if available) (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (if available) (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)	X										mg/l	lb/day			
2M. Arsenic, Total (7440-38-2)	X	X				< 0.01		< 0.01		2	"	"			
3M. Beryllium, Total, 7440-41-7)	X		X								"	"			
4M. Cadmium, Total (7440-43-9)	X	X				0.02	2.2	< 0.01		2	"	"			
5M. Chromium, Total (7440-47-3)	X		X								"	"			
6M. Copper, Total (7440-50-8)	X	X				0.080	2.9	0.065	< 2.2	2	"	"			
7M. Lead, Total (7439-92-1)	X	X				0.110	4.4	0.105	< 2.2	2	"	"			
8M. Mercury, Total (7439-97-6)	X	X				0.240	< 2.2	< 0.2		2	ug/l	"			
9M. Nickel, Total (7440-02-0)	X		X								mg/l	"			
10M. Selenium, Total (7782-49-2)	X		X								"	"			
11M. Silver, Total (7440-22-4)	X		X								"	"			
12M. Thallium, Total (7440-28-0)	X		X								"	"			
13M. Zinc, Total (7440-66-6)	X	X				0.017	< 2.2	0.014	< 2.2	2	"	"			
14M. Cyanide, Total (57-12-5)	X		X			< 0.001		< 0.001		2	"	"			
15M. Phenols, Total	X		X								"	"			
DIOXIN															
2,3,7,8-Tetrachlorodibenzo-P-Dioxin (1764-01-6)	X		X	DESCRIBE RESULTS											

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)	X		X								ug/l	lb/day			
2V. Acrylonitrile (107-13-1)	X		X								"	"			
3V. Benzene (71-43-2)	X		X								"	"			
4V. Bis (Chloromethyl) Ether (542-88-1)	X		X								"	"			
5V. Bromoform (75-25-2)	X		X								"	"			
6V. Carbon Tetrachloride (56-23-5)	X		X								"	"			
7V. Chlorobenzene (108-90-7)	X		X								"	"			
8V. Chlorodibromomethane (124-48-1)	X		X								"	"			
9V. Chloroethane (75-00-3)	X		X								"	"			
10V. 2-Chloroethylvinyl Ether (110-75-8)	X		X								"	"			
11V. Chloroform (67-66-3)	X		X								"	"			
12V. Dichlorobromomethane (75-27-4)	X		X								"	"			
13V. Dichlorodifluoromethane (75-71-8)	X		X								"	"			
14V. 1,1-Dichloroethane (75-34-3)	X		X								"	"			
15V. 1,2-Dichloroethane (107-06-2)	X		X								"	"			
16V. 1,1-Dichloroethylene (75-35-4)	X		X								"	"			
17V. 1,2-Dichloropropane (78-87-5)	X		X								"	"			
18V. 1,3-Dichloropropylene (542-75-6)	X		X								"	"			
19V. Ethylbenzene (100-41-4)	X		X								"	"			
20V. Methyl Bromide (74-83-9)	X		X								"	"			
21V. Methyl Chloride (74-87-3)	X		X								"	"			

CONTINUE ON PAGE V-5

CONTINUED FROM PAGE V-4

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS *(continued)*															
22V. Methylene Chloride (75-09-2)	X		X								ug/l	lb/day			
23V. 1,1,2,2-Tetrachloroethane (79-34-5)	X		X								"	"			
24V. Tetrachloroethylene (127-18-4)	X		X								"	"			
25V. Toluene (108-88-3)	X		X								"	"			
26V. 1,2-Trans-Dichloroethylene (156-60-5)	X		X								"	"			
27V. 1,1,1-Trichloroethane (71-55-6)	X		X								"	"			
28V. 1,1,2-Trichloroethane (79-00-5)	X		X								"	"			
29V. Trichloroethylene (79-01-6)	X		X								"	"			
30V. Trichlorofluoromethane (75-69-4)	X		X								"	"			
31V. Vinyl Chloride (75-01-4)	X		X								"	"			
GC/MS FRACTION – ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)	X		X								"	"			
2A. 2,4-Dichlorophenol (120-83-2)	X		X								"	"			
3A. 2,4-Dimethylphenol (105-67-9)	X		X								"	"			
4A. 4,6-Dinitro-O-Cresol (534-52-1)	X		X								"	"			
5A. 2,4-Dinitrophenol (51-28-5)	X		X								"	"			
6A. 2-Nitrophenol (88-75-5)	X		X								"	"			
7A. 4-Nitrophenol (100-02-7)	X		X								"	"			
8A. P-Chloro-M-Cresol (59-50-7)	X		X								"	"			
9A. Pentachlorophenol (87-86-5)	X		X								"	"			
10A. Phenol (108-95-2)	X		X								"	"			
11A. 2,4,6-Trichlorophenol (88-06-2)	X		X								"	"			

CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)	X		X								ug/l	lb/day			
2B. Acenaphtylene (208-96-8)	X		X								"	"			
3B. Anthracene (120-12-7)	X		X								"	"			
4B. Benzidine (92-87-5)	X		X								"	"			
5B. Benzo *(a)* Anthracene (56-55-3)	X		X								"	"			
6B. Benzo *(a)* Pyrene (50-32-8)	X		X								"	"			
7B. 3,4-Benzo-fluoranthene (205-99-2)	X		X								"	"			
8B. Benzo *(ghi)* Perylene (191-24-2)	X		X								"	"			
9B. Benzo *(k)* Fluoranthene (207-08-9)	X		X								"	"			
10B. Bis *(2-Chloro-ethoxy)* Methane (111-91-1)	X		X								"	"			
11B. Bis *(2-Chloro-ethyl)* Ether (111-44-4)	X		X								"	"			
12B. Bis *(2-Chloroisa-propyl)* Ether (102-60-1)	X		X								"	"			
13B. Bis *(2-Ethyl-hexyl)* Phthalate (117-81-7)	X		X								"	"			
14B. 4-Bromo-phenyl Phenyl Ether (101-55-3)	X		X								"	"			
15B. Butyl Benzyl Phthalate (85-68-7)	X		X								"	"			
16B. 2-Chloro-naphthalene (91-58-7)	X		X								"	"			
17B. 4-Chloro-phenyl Phenyl Ether (7005-72-3)	X		X								"	"			
18B. Chrysene (218-01-9)	X		X								"	"			
19B. Dibenzo *(a,h)* Anthracene (53-70-3)	X		X								"	"			
20B. 1,2-Dichloro-benzene (95-50-1)	X		X								"	"			
21B. 1,3-Dichloro-benzene (541-73-1)	X		X								"	"			

CONTINUE ON PAGE V-7

CONTINUED FROM PAGE V-6

EPA I.D. NUMBER (copy from Item 1 of Form 1): NM0022306

OUTFALL NUMBER: 001

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS *(continued)*															
22B. 1,4-Dichlorobenzene (106-46-7)	X		X										ug/1	lb/day	
23B. 3,3'-Dichlorobenzidine (91-94-1)	X		X										"	"	
24B. Diethyl Phthalate (84-66-2)	X		X										"	"	
25B. Dimethyl Phthalate (131-11-3)	X		X										"	"	
26B. Di-N-Butyl Phthalate (84-74-2)	X		X										"	"	
27B. 2,4-Dinitrotoluene (121-14-2)	X		X										"	"	
28B. 2,6-Dinitrotoluene (606-20-2)	X		X										"	"	
29B. Di-N-Octyl Phthalate (117-84-0)	X		X										"	"	
30B. 1,2-Diphenylhydrazine *(as Azobenzene)* (122-66-7)	X		X										"	"	
31B. Fluoranthene (206-44-0)	X		X										"	"	
32B. Fluorene (86-73-7)	X		X										"	"	
33B. Hexachlorobenzene (118-74-1)	X		X										"	"	
34B. Hexachlorobutadiene (87-68-3)	X		X										"	"	
35B. Hexachlorocyclopentadiene (77-47-4)	X		X										"	"	
36B. Hexachloroethane (67-72-1)	X		X										"	"	
37B. Indeno *(1,2,3-cd)* Pyrene (193-39-5)	X		X										"	"	
38B. Isophorone (78-59-1)	X		X										"	"	
39B. Naphthalene (91-20-3)	X		X										"	"	
40B. Nitrobenzene (98-95-3)	X		X										"	"	
41B. N-Nitrosodimethylamine (62-75-9)	X		X										"	"	
42B. N-Nitrosodi-N-Propylamine (621-64-7)	X		X										"	"	

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS *(continued)*															
43B. N-Nitrosodiphenylamine (86-30-6)	X		X								ug/l	lb/day			
44B. Phenanthrene (85-01-8)	X		X								"	"			
45B. Pyrene (129-00-0)	X		X								"	"			
46B. 1,2,4 - Trichlorobenzene (120-82-1)	X		X								"	"			
GC/MS FRACTION – PESTICIDES															
1P. Aldrin (309-00-2)	X		X								"	"			
2P. α-BHC (319-84-6)	X		X								"	"			
3P. β-BHC (319-85-7)	X		X								"	"			
4P. γ-BHC (58-89-9)	X		X								"	"			
5P. δ-BHC (319-86-8)	X		X								"	"			
6P. Chlordane (57-74-9)	X		X								"	"			
7P. 4,4'-DDT (50-29-3)	X		X								"	"			
8P. 4,4'-DDE (72-55-9)	X		X								"	"			
9P. 4,4'-DDD (72-54-8)	X		X								"	"			
10P. Dieldrin (60-57-1)	X		X								"	"			
11P. α-Endosulfan (115-29-7)	X		X								"	"			
12P. β-Endosulfan (115-29-7)	X		X								"	"			
13P. Endosulfan Sulfate (1031-07-8)	X		X								"	"			
14P. Endrin (72-20-8)	X		X								"	"			
15P. Endrin Aldehyde (7421-93-4)	X		X								"	"			
16P. Heptachlor (76-44-8)	X		X								"	"			

CONTINUE ON PAGE V-9

CONTINUED FROM PAGE V-8

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
NMD ~~002699094~~ 0022306	001

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-57-3)	X		X										ug/l	lb/day	
18P. PCB-1242 (53469-21-9)	X		X										"	"	
19P. PCB-1254 (11097-69-1)	X		X										"	"	
20P. PCB-1221 (11104-28-2)	X		X										"	"	
21P. PCB-1232 (11141-16-5)	X		X										"	"	
22P. PCB-1248 (12672-29-6)	X		X										"	"	
23P. PCB-1260 (11098-82-5)	X		X										"	"	
24P. PCB-1016 (12674-11-2)	X		X										"	"	
25P. Toxaphene (8001-35-2)	X		X										"	"	

EXHIBIT II-2

OUTFALL 002

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages. SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item I of Form 1)*: NM0022306

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

OUTFALL NO: 002

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS *(specify if blank)* a. CONCENTRATION	b. MASS	4. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*	< 3							mg/l	lb/day			
b. Chemical Oxygen Demand *(COD)*	18	54.08	12.4	35.71	5.53	24.6	52	mg/l	lb/day			
c. Total Organic Carbon *(TOC)*	2							mg/l	lb/day			
d. Total Suspended Solids *(TSS)*	20	49.6	10.8	26.50	3.8	22.9	52	mg/l	lb/day			
e. Ammonia *(as N)*	0.07							mg/l	lb/day			
f. Flow	VALUE 0.48		VALUE 0.35		VALUE 0.30		Daily Estim.	MGD		VALUE		
g. Temperature *(winter)*	VALUE 10.7		VALUE 10.1		VALUE 9.7		20	°C		VALUE		
h. Temperature *(summer)*	VALUE 12.0		VALUE 11.4		VALUE 11.0		20	°C		VALUE		
i. pH	MINIMUM 7.38	MAXIMUM 7.57	MINIMUM 7.00	MAXIMUM 7.36			40	STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK 'X' a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)		X								mg/l	lb/day			
b. Chlorine, Total Residual		X	< 0.011	0	< 0.011	0	< 0.011	0	1	"	"			
c. Color		X								color units				
d. Fecal Coliform		X								mpn/ 100 ml				
e. Fluoride (16984-48-8)	X		2.1	5.6	1.9	5.2	1.8	4.5	1	mg/l	lb/day			
f. Nitrate-Nitrite *(as N)*	X		0.14							mg/l	"			

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X' a. BELIEVED PRESENT	2. MARK 'X' b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (if available) (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (if available) (2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	4. UNITS b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (2) MASS	5. INTAKE (optional) b. NO. OF ANALYSES
g. Nitrogen, Total Organic (as N)		X										mg/l	lb/day	
h. Oil and Grease		X										"	"	
i. Phosphorus (as P), Total (7723-14-0)	X		0.04									"	"	
j. Radioactivity														
(1) Alpha, Total	X		31.7									pCi/l		
(2) Beta, Total	X		10.2									"		
(3) Radium, Total	X		0.7									"		
(4) Radium 226, Total	X		0.01									"		
k. Sulfate (as SO_4) (14808-79-8)	X		900									mg/l	lb/day	
l. Sulfide (as S)	X		< 0.02									"	"	
m. Sulfite (as SO_3) (14265-45-3)	X		2									"	"	
n. Surfactants		X										"	"	
o. Aluminum, Total (7429-90-5)	X		0.07	0.5	0.07	0.5	0.008	0.21	10			"	"	
p. Barium, Total (7440-39-3)	X		0.026									"	"	
q. Boron, Total (7440-42-8)		X										"	"	
r. Cobalt, Total (7440-48-4)	X		< 0.01	0.03	< 0.01	0.03	< 0.01	0.025	10			"	"	
s. Iron, Total (7439-89-6)	X		0.2	0.5	0.13	0.3	0.03	0.18	40			"	"	
t. Magnesium, Total (7439-95-4)	X		48.3									"	"	
u. Molybdenum, Total (7439-98-7)	X		2.6	7.0	2.5	6.3	2.4	5.8	40			"	"	
v. Manganese, Total (7439-96-5)	X		1.9	5.5	1.8	4.6	1.7	4.2	40			"	"	
w. Tin, Total (7440-31-5)		X										"	"	
x. Titanium, Total (7440-32-6)		X										"	"	

CONTINUE ON PAGE V-3

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
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CONTINUED FROM PAGE 3 OF FORM 2-C

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER (If available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (If available)		c. LONG TERM AVRG. VALUE (If available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)	X		X	0.002							mg/l	lb/day			
2M. Arsenic, Total (7440-38-2)	X		X	0.005	0	0.005	0	0.005	0	40	"	"			
3M. Beryllium, Total, 7440-41-7)	X		X	0.005	0	0.005	0	0.005	0	10	"	"			
4M. Cadmium, Total (7440-43-9)	X	X		0.005	0.01	0.0037	0.007	0.002	0.006	40	"	"			
5M. Chromium, Total (7440-47-3)	X		X	0.01							"	"			
6M. Copper, Total (7440-50-8)	X	X		0.02	0.05	0.006	0.015	0.0005	0.001	40	"	"			
7M. Lead, Total (7439-92-1)	X	X		0.08	0.2	0.03	0.08	0.003	0.007	40	"	"			
8M. Mercury, Total (7439-97-6)	X		X	0.0002	0	0.0002	0	0.0002	0	40	"	"			
9M. Nickel, Total (7440-02-0)	X		X	0.01							"	"			
10M. Selenium, Total (7782-49-2)	X		X	0.005	0	0.005	0	0.005	0	10	"	"			
11M. Silver, Total (7440-22-4)	X		X	0.002	0	0.002	0	0.002	0	10	"	"			
12M. Thallium, Total (7440-28-0)	X		X	0.002							"	"			
13M. Zinc, Total (7440-66-6)	X	X		0.039	0.1	0.027	0.08	0.003	0.006	40	"	"			
14M. Cyanide, Total (57-12-5)	X	X		0.04	0.1	0.008	0.02	0.0007	0.002	40	"	"			
15M. Phenols, Total	X		X	0.01							"	"			
DIOXIN															
2,3,7,8-Tetrachlorodibenzo-P-Dioxin (1764-01-6)	X		X	DESCRIBE RESULTS											

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK "X" a. TEST INCLUDED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. [illegible] a. CONCENTRATION	b. MASS	5. [illegible] TAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)	X		X								ug/l	lb/day			
2V. Acrylonitrile (107-13-1)	X		X								"	"			
3V. Benzene (71-43-2)	X		X								"	"			
4V. Bis (Chloromethyl) Ether (542-88-1)	X		X								"	"			
5V. Bromoform (75-25-2)	X		X								"	"			
6V. Carbon Tetrachloride (56-23-5)	X		X								"	"			
7V. Chlorobenzene (108-90-7)	X		X								"	"			
8V. Chlorodibromomethane (124-48-1)	X		X								"	"			
9V. Chloroethane (75-00-3)	X		X								"	"			
10V. 2-Chloroethylvinyl Ether (110-75-8)	X		X								"	"			
11V. Chloroform (67-66-3)	X		X								"	"			
12V. Dichlorobromomethane (75-27-4)	X		X								"	"			
13V. Dichlorodifluoromethane (75-71-8)	X		X								"	"			
14V. 1,1-Dichloroethane (75-34-3)	X		X								"	"			
15V. 1,2-Dichloroethane (107-06-2)	X		X								"	"			
16V. 1,1-Dichloroethylene (75-35-4)	X		X								"	"			
17V. 1,2-Dichloropropane (78-87-5)	X		X								"	"			
18V. 1,3-Dichloropropylene (542-75-6)	X		X								"	"			
19V. Ethylbenzene (100-41-4)	X		X								"	"			
20V. Methyl Bromide (74-83-9)	X		X								"	"			
21V. Methyl Chloride (74-87-3)	X		X								"	"			

CONTINUE ON PAGE V-5

CONTINUED FROM PAGE V-4

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1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS *(continued)*															
22V. Methylene Chloride (75-09-2)	X		X								ug/l	lb/day			
23V. 1,1,2,2-Tetrachloroethane (79-34-5)	X		X								"	"			
24V. Tetrachloroethylene (127-18-4)	X		X								"	"			
25V. Toluene (108-88-3)	X		X								"	"			
26V. 1,2-Trans-Dichloroethylene (156-60-5)	X		X								"	"			
27V. 1,1,1-Trichloroethane (71-55-6)	X		X								"	"			
28V. 1,1,2-Trichloroethane (79-00-5)	X		X								"	"			
29V. Trichloroethylene (79-01-6)	X		X								"	"			
30V. Trichlorofluoromethane (75-69-4)	X		X								"	"			
31V. Vinyl Chloride (75-01-4)	X		X								"	"			
GC/MS FRACTION – ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)	X		X								"	"			
2A. 2,4-Dichlorophenol (120-83-2)	X		X								"	"			
3A. 2,4-Dimethylphenol (105-67-9)	X		X								"	"			
4A. 4,6-Dinitro-O-Cresol (534-52-1)	X		X								"	"			
5A. 2,4-Dinitrophenol (51-28-5)	X		X								"	"			
6A. 2-Nitrophenol (88-75-5)	X		X								"	"			
7A. 4-Nitrophenol (100-02-7)	X		X								"	"			
8A. P-Chloro-M-Cresol (59-50-7)	X		X								"	"			
9A. Pentachlorophenol (87-86-5)	X		X								"	"			
10A. Phenol (108-95-2)	X		X								"	"			
11A. 2,4,6-Trichlorophenol (88-06-2)	X		X								"	"			

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TEST REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)	X		X								ug/l	lb/day			
2B. Acenaphtylene (208-96-8)	X		X								"	"			
3B. Anthracene (120-12-7)	X		X								"	"			
4B. Benzidine (92-87-5)	X		X								"	"			
5B. Benzo (a) Anthracene (56-55-3)	X		X								"	"			
6B. Benzo (a) Pyrene (50-32-8)	X		X								"	"			
7B. 3,4-Benzo-fluoranthene (205-99-2)	X		X								"	"			
8B. Benzo (ghi) Perylene (191-24-2)	X		X								"	"			
9B. Benzo (k) Fluoranthene (207-08-9)	X		X								"	"			
10B. Bis (2-Chloro-ethoxy) Methane (111-91-1)	X		X								"	"			
11B. Bis (2-Chloro-ethyl) Ether (111-44-4)	X		X								"	"			
12B. Bis (2-Chloroiso-propyl) Ether (102-60-1)	X		X								"	"			
13B. Bis (2-Ethyl-hexyl) Phthalate (117-81-7)	X		X								"	"			
14B. 4-Bromo-phenyl Phenyl Ether (101-55-3)	X		X								"	"			
15B. Butyl Benzyl Phthalate (85-68-7)	X		X								"	"			
16B. 2-Chloro-naphthalene (91-58-7)	X		X								"	"			
17B. 4-Chloro-phenyl Phenyl Ether (7005-72-3)	X		X								"	"			
18B. Chrysene (218-01-9)	X		X								"	"			
19B. Dibenzo (a,h) Anthracene (53-70-3)	X		X								"	"			
20B. 1,2-Dichloro-benzene (95-50-1)	X		X								"	"			
21B. 1,3-Dichloro-benzene (541-73-1)	X		X								"	"			

CONTINUE ON PAGE V-7

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
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CONTINUED FROM PAGE V-6

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
22B. 1,4-Dichlorobenzene (106-46-7)	X		X										ug/1	1b/day	
23B. 3,3'-Dichlorobenzidine (91-94-1)	X		X										"	"	
24B. Diethyl Phthalate (84-66-2)	X		X										"	"	
25B. Dimethyl Phthalate (131-11-3)	X		X										"	"	
26B. Di-N-Butyl Phthalate (84-74-2)	X		X										"	"	
27B. 2,4-Dinitrotoluene (121-14-2)	X		X										"	"	
28B. 2,6-Dinitrotoluene (606-20-2)	X		X										"	"	
29B. Di-N-Octyl Phthalate (117-84-0)	X		X										"	"	
30B. 1,2-Diphenylhydrazine (as Azobenzene) (122-66-7)	X		X										"	"	
31B. Fluoranthene (206-44-0)	X		X										"	"	
32B. Fluorene (86-73-7)	X		X										"	"	
33B. Hexachlorobenzene (118-74-1)	X		X										"	"	
34B. Hexachlorobutadiene (87-68-3)	X		X										"	"	
35B. Hexachlorocyclopentadiene (77-47-4)	X		X										"	"	
36B. Hexachloroethane (67-72-1)	X		X										"	"	
37B. Indeno (1,2,3-cd) Pyrene (193-39-5)	X		X										"	"	
38B. Isophorone (78-59-1)	X		X										"	"	
39B. Naphthalene (91-20-3)	X		X										"	"	
40B. Nitrobenzene (98-95-3)	X		X										"	"	
41B. N-Nitrosodimethylamine (62-75-9)	X		X										"	"	
42B. N-Nitrosodi-N-Propylamine (621-64-7)	X		X										"	"	

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
43B. N-Nitrosodiphenylamine (86-30-6)	X		X								ug/l	lb/day			
44B. Phenanthrene (85-01-8)	X		X								"	"			
45B. Pyrene (129-00-0)	X		X								"	"			
46B. 1,2,4 - Trichlorobenzene (120-82-1)	X		X								"	"			
GC/MS FRACTION – PESTICIDES															
1P. Aldrin (309-00-2)	X		X								"	"			
2P. α-BHC (319-84-6)	X		X								"	"			
3P. β-BHC (319-85-7)	X		X								"	"			
4P. γ-BHC (58-89-9)	X		X								"	"			
5P. δ-BHC (319-86-8)	X		X								"	"			
6P. Chlordane (57-74-9)	X		X								"	"			
7P. 4,4'-DDT (50-29-3)	X		X								"	"			
8P. 4,4'-DDE (72-55-9)	X		X								"	"			
9P. 4,4'-DDD (72-54-8)	X		X								"	"			
10P. Dieldrin (60-57-1)	X		X								"	"			
11P. α-Endosulfan (115-29-7)	X		X								"	"			
12P. β-Endosulfan (115-29-7)	X		X								"	"			
13P. Endosulfan Sulfate (1031-07-8)	X		X								"	"			
14P. Endrin (72-20-8)	X		X								"	"			
15P. Endrin Aldehyde (7421-93-4)	X		X								"	"			
16P. Heptachlor (76-44-8)	X		X								"	"			

CONTINUE ON PAGE V-9

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EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
NM0022306	002

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-57-3)	X		X										ug/l	lb/day	
18P. PCB-1242 (53469-21-9)	X		X										"	"	
19P. PCB-1254 (11097-69-1)	X		X										"	"	
20P. PCB-1221 (11104-28-2)	X		X										"	"	
21P. PCB-1232 (11141-16-5)	X		X										"	"	
22P. PCB-1248 (12672-29-6)	X		X										"	"	
23P. PCB-1260 (11096-82-5)	X		X										"	"	
24P. PCB-1016 (12674-11-2)	X		X										"	"	
25P. Toxaphene (8001-35-2)	X		X										"	"	

EXHIBIT II-3

OUTFALL 004

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages. SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item I of Form 1)*: NM0022306

OUTFALL NO: 004

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS (specify if blank) a. CONCENTRATION	b. MASS	4. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*												
b. Chemical Oxygen Demand *(COD)*												
c. Total Organic Carbon *(TOC)*												
d. Total Suspended Solids *(TSS)*				NO DISCHARGE								
e. Ammonia *(as N)*												
f. Flow	VALUE		VALUE		VALUE					VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK 'X' a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)														
b. Chlorine, Total Residual														
c. Color														
d. Fecal Coliform														
e. Fluoride (16984-48-8)														
f. Nitrate-Nitrite *(as N)*														

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X'		3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. BELIEVED PRESENT	b. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
			(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
g. Nitrogen, Total Organic (as N)														
h. Oil and Grease														
i. Phosphorus (as P), Total (7723-14-0)														
j. Radioactivity														
(1) Alpha, Total														
(2) Beta, Total														
(3) Radium, Total														
(4) Radium 226, Total														
k. Sulfate (as SO_4) (14808-79-8)														
l. Sulfide (as S)														
m. Sulfite (as SO_3) (14265-45-3)														
n. Surfactants														
o. Aluminum, Total (7429-90-5)														
p. Barium, Total (7440-39-3)														
q. Boron, Total (7440-42-8)														
r. Cobalt, Total (7440-48-4)														
s. Iron, Total (7439-89-6)														
t. Magnesium, Total (7439-95-4)														
u. Molybdenum, Total (7439-98-7)														
v. Manganese, Total (7439-96-5)														
w. Tin, Total (7440-31-5)														
x. Titanium, Total (7440-32-6)														

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CONTINUED FROM PAGE 3 OF FORM 2-C

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8-Tetrachlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TEST INCLUDED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)	X		X								ug/l	lb/day			
2V. Acrylonitrile (107-13-1)	X		X								"	"			
3V. Benzene (71-43-2)	X		X								"	"			
4V. Bis (Chloromethyl) Ether (542-88-1)	X		X								"	"			
5V. Bromoform (75-25-2)	X		X								"	"			
6V. Carbon Tetrachloride (56-23-5)	X		X								"	"			
7V. Chlorobenzene (108-90-7)	X		X								"	"			
8V. Chlorodibromomethane (124-48-1)	X		X								"	"			
9V. Chloroethane (75-00-3)	X		X								"	"			
10V. 2-Chloroethylvinyl Ether (110-75-8)	X		X								"	"			
11V. Chloroform (67-66-3)	X		X								"	"			
12V. Dichlorobromomethane (75-27-4)	X		X								"	"			
13V. Dichlorodifluoromethane (75-71-8)	X		X								"	"			
14V. 1,1-Dichloroethane (75-34-3)	X		X								"	"			
15V. 1,2-Dichloroethane (107-06-2)	X		X								"	"			
16V. 1,1-Dichloroethylene (75-35-4)	X		X								"	"			
17V. 1,2-Dichloropropane (78-87-5)	X		X								"	"			
18V. 1,3-Dichloropropylene (542-75-6)	X		X								"	"			
19V. Ethylbenzene (100-41-4)	X		X								"	"			
20V. Methyl Bromide (74-83-9)	X		X								"	"			
21V. Methyl Chloride (74-87-3)	X		X								"	"			

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1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS *(continued)*															
22V. Methylene Chloride (75-09-2)	X		X								ug/1	lb/day			
23V. 1,1,2,2-Tetrachloroethane (79-34-5)	X		X								"	"			
24V. Tetrachloroethylene (127-18-4)	X		X								"	"			
25V. Toluene (108-88-3)	X		X								"	"			
26V. 1,2-Trans-Dichloroethylene (156-60-5)	X		X								"	"			
27V. 1,1,1-Trichloroethane (71-55-6)	X		X								"	"			
28V. 1,1,2-Trichloroethane (79-00-5)	X		X								"	"			
29V. Trichloroethylene (79-01-6)	X		X								"	"			
30V. Trichlorofluoromethane (75-69-4)	X		X								"	"			
31V. Vinyl Chloride (75-01-4)	X		X								"	"			
GC/MS FRACTION – ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)	X		X								"	"			
2A. 2,4-Dichlorophenol (120-83-2)	X		X								"	"			
3A. 2,4-Dimethylphenol (105-67-9)	X		X								"	"			
4A. 4,6-Dinitro-O-Cresol (534-52-1)	X		X								"	"			
5A. 2,4-Dinitrophenol (51-28-5)	X		X								"	"			
6A. 2-Nitrophenol (88-75-5)	X		X								"	"			
7A. 4-Nitrophenol (100-02-7)	X		X								"	"			
8A. P-Chloro-M-Cresol (59-50-7)	X		X								"	"			
9A. Pentachlorophenol (87-86-5)	X		X								"	"			
10A. Phenol (108-95-2)	X		X								"	"			
11A. 2,4,6-Trichlorophenol (88-06-2)	X		X								"	"			

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK "X" a. TEST REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)	X		X								ug/1	lb/day			
2B. Acenaphtylene (208-96-8)	X		X								"	"			
3B. Anthracene (120-12-7)	X		X								"	"			
4B. Benzidine (92-87-5)	X		X								"	"			
5B. Benzo *(a)* Anthracene (56-55-3)	X		X								"	"			
6B. Benzo *(a)* Pyrene (50-32-8)	X		X								"	"			
7B. 3,4-Benzo-fluoranthene (205-99-2)	X		X								"	"			
8B. Benzo *(ghi)* Perylene (191-24-2)	X		X								"	"			
9B. Benzo *(k)* Fluoranthene (207-08-9)	X		X								"	"			
10B. Bis *(2-Chloro-ethoxy)* Methane (111-91-1)	X		X								"	"			
11B. Bis *(2-Chloro-ethyl)* Ether (111-44-4)	X		X								"	"			
12B. Bis *(2-Chloroiso-propyl)* Ether (102-60-1)	X		X								"	"			
13B. Bis *(2-Ethyl-hexyl)* Phthalate (117-81-7)	X		X								"	"			
14B. 4-Bromo-phenyl Phenyl Ether (101-55-3)	X		X								"	"			
15B. Butyl Benzyl Phthalate (85-68-7)	X		X								"	"			
16B. 2-Chloro-naphthalene (91-58-7)	X		X								"	"			
17B. 4-Chloro-phenyl Phenyl Ether (7005-72-3)	X		X								"	"			
18B. Chrysene (218-01-9)	X		X								"	"			
19B. Dibenzo *(a,h)* Anthracene (53-70-3)	X		X								"	"			
20B. 1,2-Dichloro-benzene (95-50-1)	X		X								"	"			
21B. 1,3-Dichloro-benzene (541-73-1)	X		X								"	"			

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CONTINUED FROM PAGE V-6

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (if available) (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (if available) (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS *(continued)*															
22B. 1,4-Dichlorobenzene (106-46-7)	X		X										ug/l	lb/day	
23B. 3,3'-Dichlorobenzidine (91-94-1)	X		X										"	"	
24B. Diethyl Phthalate (84-66-2)	X		X										"	"	
25B. Dimethyl Phthalate (131-11-3)	X		X										"	"	
26B. Di-N-Butyl Phthalate (84-74-2)	X		X										"	"	
27B. 2,4-Dinitrotoluene (121-14-2)	X		X										"	"	
28B. 2,6-Dinitrotoluene (606-20-2)	X		X										"	"	
29B. Di-N-Octyl Phthalate (117-84-0)	X		X										"	"	
30B. 1,2-Diphenylhydrazine *(as Azobenzene)* (122-66-7)	X		X										"	"	
31B. Fluoranthene (206-44-0)	X		X										"	"	
32B. Fluorene (86-73-7)	X		X										"	"	
33B. Hexachlorobenzene (118-74-1)	X		X										"	"	
34B. Hexachlorobutadiene (87-68-3)	X		X										"	"	
35B. Hexachlorocyclopentadiene (77-47-4)	X		X										"	"	
36B. Hexachloroethane (67-72-1)	X		X										"	"	
37B. Indeno *(1,2,3-cd)* Pyrene (193-39-5)	X		X										"	"	
38B. Isophorone (78-59-1)	X		X										"	"	
39B. Naphthalene (91-20-3)	X		X										"	"	
40B. Nitrobenzene (98-95-3)	X		X										"	"	
41B. N-Nitrosodimethylamine (62-75-9)	X		X										"	"	
42B. N-Nitrosodi-N-Propylamine (621-64-7)	X		X										"	"	

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
43B. N-Nitrosodiphenylamine (86-30-6)	X		X								ug/l	lb/day			
44B. Phenanthrene (85-01-8)	X		X								"	"			
45B. Pyrene (129-00-0)	X		X								"	"			
46B. 1,2,4 - Trichlorobenzene (120-82-1)	X		X								"	"			
GC/MS FRACTION – PESTICIDES															
1P. Aldrin (309-00-2)	X		X								"	"			
2P. α-BHC (319-84-6)	X		X								"	"			
3P. β-BHC (319-85-7)	X		X								"	"			
4P. γ-BHC (58-89-9)	X		X								"	"			
5P. δ-BHC (319-86-8)	X		X								"	"			
6P. Chlordane (57-74-9)	X		X								"	"			
7P. 4,4'-DDT (50-29-3)	X		X								"	"			
8P. 4,4'-DDE (72-55-9)	X		X								"	"			
9P. 4,4'-DDD (72-54-8)	X		X								"	"			
10P. Dieldrin (60-57-1)	X		X								"	"			
11P. α-Endosulfan (115-29-7)	X		X								"	"			
12P. β-Endosulfan (115-29-7)	X		X								"	"			
13P. Endosulfan Sulfate (1031-07-8)	X		X								"	"			
14P. Endrin (72-20-8)	X		X								"	"			
15P. Endrin Aldehyde (7421-93-4)	X		X								"	"			
16P. Heptachlor (76-44-8)	X		X								"	"			

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EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER
NM0022306	004

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-67-3)	X		X										ug/l	lb/day	
18P. PCB-1242 (53469-21-9)	X		X										"	"	
19P. PCB-1254 (11097-69-1)	X		X										"	"	
20P. PCB-1221 (11104-28-2)	X		X										"	"	
21P. PCB-1232 (11141-16-5)	X		X										"	"	
22P. PCB-1248 (12672-29-6)	X		X										"	"	
23P. PCB-1260 (11096-82-5)	X		X										"	"	
24P. PCB-1016 (12674-11-2)	X		X										"	"	
25P. Toxaphene (8001-35-2)	X		X										"	"	

EXHIBIT II-4

OUTFALL 005

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages. SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*: NM0022306

OUTFALL NO: 005

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS *(specify if blank)* a. CONCENTRATION	b. MASS	4. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*												
b. Chemical Oxygen Demand *(COD)*												
c. Total Organic Carbon *(TOC)*				NO	DISCHARGE							
d. Total Suspended Solids *(TSS)*												
e. Ammonia *(as N)*												
f. Flow	VALUE		VALUE		VALUE					VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK 'X' a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)														
b. Chlorine, Total Residual														
c. Color														
d. Fecal Coliform														
e. Fluoride (16984-48-8)														
f. Nitrate-Nitrite *(as N)*														

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X' a. BELIEVED PRESENT	2. MARK 'X' b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	4. UNITS b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	5. INTAKE a. LONG TERM AVERAGE VALUE (2) MASS	5. INTAKE b. NO. OF ANALYSES
g. Nitrogen, Total Organic (as N)														
h. Oil and Grease														
i. Phosphorus (as P), Total (7723-14-0)														
j. Radioactivity														
(1) Alpha, Total														
(2) Beta, Total														
(3) Radium, Total														
(4) Radium 226, Total														
k. Sulfate (as SO_4) (14808-79-8)														
l. Sulfide (as S)														
m. Sulfite (as SO_3) (14265-45-3)														
n. Surfactants														
o. Aluminum, Total (7429-90-5)														
p. Barium, Total (7440-39-3)														
q. Boron, Total (7440-42-8)														
r. Cobalt, Total (7440-48-4)														
s. Iron, Total (7439-89-6)														
t. Magnesium, Total (7439-95-4)														
u. Molybdenum, Total (7439-98-7)														
v. Manganese, Total (7439-96-5)														
w. Tin, Total (7440-31-5)														
x. Titanium, Total (7440-32-6)														

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CONTINUED FROM PAGE 3 OF FORM 2-C

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER *(If available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(If available)*		c. LONG TERM AVRG. VALUE *(If available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8-Tetrachlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. INTAKE a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)	X		X								ug/l	lb/day			
2V. Acrylonitrile (107-13-1)	X		X								"	"			
3V. Benzene (71-43-2)	X		X								"	"			
4V. Bis (Chloromethyl) Ether (542-88-1)	X		X								"	"			
5V. Bromoform (75-25-2)	X		X								"	"			
6V. Carbon Tetrachloride (56-23-5)	X		X								"	"			
7V. Chlorobenzene (108-90-7)	X		X								"	"			
8V. Chlorodibromomethane (124-48-1)	X		X								"	"			
9V. Chloroethane (75-00-3)	X		X								"	"			
10V. 2-Chloroethylvinyl Ether (110-75-8)	X		X								"	"			
11V. Chloroform (67-66-3)	X		X								"	"			
12V. Dichlorobromomethane (75-27-4)	X		X								"	"			
13V. Dichlorodifluoromethane (75-71-8)	X		X								"	"			
14V. 1,1-Dichloroethane (75-34-3)	X		X								"	"			
15V. 1,2-Dichloroethane (107-06-2)	X		X								"	"			
16V. 1,1-Dichloroethylene (75-35-4)	X		X								"	"			
17V. 1,2-Dichloropropane (78-87-5)	X		X								"	"			
18V. 1,3-Dichloropropylene (542-75-6)	X		X								"	"			
19V. Ethylbenzene (100-41-4)	X		X								"	"			
20V. Methyl Bromide (74-83-9)	X		X								"	"			
21V. Methyl Chloride (74-87-3)	X		X								"	"			

CONTINUE ON PAGE V-5

CONTINUED FROM PAGE V-4

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS *(continued)*															
22V. Methylene Chloride (75-09-2)	X		X								ug/l	lb/day			
23V. 1,1,2,2-Tetrachloroethane (79-34-5)	X		X								"	"			
24V. Tetrachloroethylene (127-18-4)	X		X								"	"			
25V. Toluene (108-88-3)	X		X								"	"			
26V. 1,2-Trans-Dichloroethylene (156-60-5)	X		X								"	"			
27V. 1,1,1-Trichloroethane (71-55-6)	X		X								"	"			
28V. 1,1,2-Trichloroethane (79-00-5)	X		X								"	"			
29V. Trichloroethylene (79-01-6)	X		X								"	"			
30V. Trichlorofluoromethane (75-69-4)	X		X								"	"			
31V. Vinyl Chloride (75-01-4)	X		X								"	"			
GC/MS FRACTION – ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)	X		X								"	"			
2A. 2,4-Dichlorophenol (120-83-2)	X		X								"	"			
3A. 2,4-Dimethylphenol (105-67-9)	X		X								"	"			
4A. 4,6-Dinitro-O-Cresol (534-52-1)	X		X								"	"			
5A. 2,4-Dinitrophenol (51-28-5)	X		X								"	"			
6A. 2-Nitrophenol (88-75-5)	X		X								"	"			
7A. 4-Nitrophenol (100-02-7)	X		X								"	"			
8A. P-Chloro-M-Cresol (59-50-7)	X		X								"	"			
9A. Pentachlorophenol (87-86-5)	X		X								"	"			
10A. Phenol (108-95-2)	X		X								"	"			
11A. 2,4,6-Trichlorophenol (88-06-2)	X		X								"	"			

CONTINUE ON REVERSE

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TEST REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)	X		X								ug/1	lb/day			
2B. Acenaphtylene (208-96-8)	X		X								"	"			
3B. Anthracene (120-12-7)	X		X								"	"			
4B. Benzidine (92-87-5)	X		X								"	"			
5B. Benzo *(a)* Anthracene (56-55-3)	X		X								"	"			
6B. Benzo *(a)* Pyrene (50-32-8)	X		X								"	"			
7B. 3,4-Benzo-fluoranthene (205-99-2)	X		X								"	"			
8B. Benzo *(ghi)* Perylene (191-24-2)	X		X								"	"			
9B. Benzo *(k)* Fluoranthene (207-08-9)	X		X								"	"			
10B. Bis *(2-Chloro-ethoxy)* Methane (111-91-1)	X		X								"	"			
11B. Bis *(2-Chloro-ethyl)* Ether (111-44-4)	X		X								"	"			
12B. Bis *(2-Chloroiso-propyl)* Ether (102-60-1)	X		X								"	"			
13B. Bis *(2-Ethyl-hexyl)* Phthalate (117-81-7)	X		X								"	"			
14B. 4-Bromo-phenyl Phenyl Ether (101-55-3)	X		X								"	"			
15B. Butyl Benzyl Phthalate (85-68-7)	X		X								"	"			
16B. 2-Chloro-naphthalene (91-58-7)	X		X								"	"			
17B. 4-Chloro-phenyl Phenyl Ether (7005-72-3)	X		X								"	"			
18B. Chrysene (218-01-9)	X		X								"	"			
19B. Dibenzo *(a,h)* Anthracene (53-70-3)	X		X								"	"			
20B. 1,2-Dichloro-benzene (95-50-1)	X		X								"	"			
21B. 1,3-Dichloro-benzene (541-73-1)	X		X								"	"			

CONTINUE ON PAGE V-7

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CONTINUED FROM PAGE V-6

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
22B. 1,4-Dichlorobenzene (106-46-7)	X		X										ug/1	lb/day	
23B. 3,3'-Dichlorobenzidine (91-94-1)	X		X										"	"	
24B. Diethyl Phthalate (84-66-2)	X		X										"	"	
25B. Dimethyl Phthalate (131-11-3)	X		X										"	"	
26B. Di-N-Butyl Phthalate (84-74-2)	X		X										"	"	
27B. 2,4-Dinitrotoluene (121-14-2)	X		X										"	"	
28B. 2,6-Dinitrotoluene (606-20-2)	X		X										"	"	
29B. Di-N-Octyl Phthalate (117-84-0)	X		X										"	"	
30B. 1,2-Diphenylhydrazine (as Azobenzene) (122-66-7)	X		X										"	"	
31B. Fluoranthene (206-44-0)	X		X										"	"	
32B. Fluorene (86-73-7)	X		X										"	"	
33B. Hexachlorobenzene (118-74-1)	X		X										"	"	
34B. Hexachlorobutadiene (87-68-3)	X		X										"	"	
35B. Hexachlorocyclopentadiene (77-47-4)	X		X										"	"	
36B. Hexachloroethane (67-72-1)	X		X										"	"	
37B. Indeno (1,2,3-cd) Pyrene (193-39-5)	X		X										"	"	
38B. Isophorone (78-59-1)	X		X										"	"	
39B. Naphthalene (91-20-3)	X		X										"	"	
40B. Nitrobenzene (98-95-3)	X		X										"	"	
41B. N-Nitrosodimethylamine (62-75-9)	X		X										"	"	
42B. N-Nitrosodi-N-Propylamine (621-64-7)	X		X										"	"	

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (if available) (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (if available) (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
43B. N-Nitrosodiphenylamine (86-30-6)	X		X								ug/l	lb/day			
44B. Phenanthrene (85-01-8)	X		X								"	"			
45B. Pyrene (129-00-0)	X		X								"	"			
46B. 1,2,4 - Trichlorobenzene (120-82-1)	X		X								"	"			
GC/MS FRACTION – PESTICIDES															
1P. Aldrin (309-00-2)	X		X								"	"			
2P. α-BHC (319-84-6)	X		X								"	"			
3P. β-BHC (319-85-7)	X		X								"	"			
4P. γ-BHC (58-89-9)	X		X								"	"			
5P. δ-BHC (319-86-8)	X		X								"	"			
6P. Chlordane (57-74-9)	X		X								"	"			
7P. 4,4'-DDT (50-29-3)	X		X								"	"			
8P. 4,4'-DDE (72-55-9)	X		X								"	"			
9P. 4,4'-DDD (72-54-8)	X		X								"	"			
10P. Dieldrin (60-57-1)	X		X								"	"			
11P. α-Endosulfan (115-29-7)	X		X								"	"			
12P. β-Endosulfan (115-29-7)	X		X								"	"			
13P. Endosulfan Sulfate (1031-07-8)	X		X								"	"			
14P. Endrin (72-20-8)	X		X								"	"			
15P. Endrin Aldehyde (7421-93-4)	X		X								"	"			
16P. Heptachlor (76-44-8)	X		X								"	"			

CONTINUE ON PAGE V-9

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CONTINUED FROM PAGE V-8

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TEST IND REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-57-3)	X		X										ug/l	lb/day	
18P. PCB-1242 (53469-21-9)	X		X										"	"	
19P. PCB-1254 (11097-69-1)	X		X										"	"	
20P. PCB-1221 (11104-28-2)	X		X										"	"	
21P. PCB-1232 (11141-16-5)	X		X										"	"	
22P. PCB-1248 (12672-29-6)	X		X										"	"	
23P. PCB-1260 (11096-82-5)	X		X										"	"	
24P. PCB-1016 (12674-11-2)	X		X										"	"	
25P. Toxaphene (8001-35-2)	X		X										"	"	

SECTION III

THE CLEAN WATER ACT STATUS OF THE RED RIVER GROUND WATER SEEPAGE ZONES

THE CLEAN WATER ACT STATUS OF THE RED RIVER GROUND WATER SEEPAGE ZONES

In Molycorp's 1993 NPDES permit renewal proceeding, several commenters argued that ground water seeps entering the Red River from Molycorp's property required an NPDES permit. In response, EPA explained that these ground water seeps are not "point sources" under the Act, and referred the commenters to the New Mexico Environment Department ("NMED"), which exercises jurisdiction over ground water. EPA, Response to Comments -- Final Permit Decision, EPA NPDES Permit No. NM0022306, at 4 (1993). In fact, Molycorp is addressing these seeps pursuant to a ground water discharge permitting program administered by NMED.

The issue of whether ground water seepage from Molycorp's property is also subject to the NPDES program was subsequently litigated in a citizen suit brought against Molycorp by a citizens' group in the United States District Court for the District of New Mexico in 1995. This citizen suit resulted in entry of a judgment for Molycorp in September, 1997.[1] The same citizens' group wrote a May 16, 1997 letter to EPA requesting the Agency to assert Clean Water Act jurisdiction over drainage from Molycorp's waste rock piles.

Because these citizens continue to dispute EPA's 1993 decision, Molycorp will provide relevant factual information and legal analysis concerning this issue. The discussion below describes the geology and hydrology of the Red River region, as well as data on Red River water quality since the creation of waste rock piles on Molycorp's property in 1965. (Relevant reports by a hydrogeologist, a soil scientist, and an aquatic biologist are referred to herein, and attached to this analysis.) The factual description is followed by a legal analysis that explains why EPA's determination that NPDES permitting requirements do not apply to these seeps was correct in 1993, and remains so today.

SUMMARY OF FACTS

I. THE GEOLOGIC CONDITIONS OF THE RED RIVER REGION.

A. Volcanic Activity and Formation of Mineral Deposits within the Questa Caldera.

The Questa mining district has a complex volcanic, plutonic, tectonic and hydrothermal history. The mining district is located in the southern portion of the Questa caldera, which had developed over a long period of time, 27 to 25 million years ago. The caldera, approximately 8.5 miles in diameter,

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[1] The Plaintiffs have appealed this decision to the United States Court of Appeals for the Tenth Circuit. This appeal is pending.

They say
several times
that the ahwial Fan
may be acid
generation but
don't offer any
evidence

was an extensional feature to the development of a much larger structure, known as the Rio Grande rift.

The emplacement of mineral deposits occurred during the waning stages of caldera formation and the associated intra-caldera volcanic/plutonic activity, about 24.5 million years ago. These late events were also responsible for hydrothermal alteration of the intra-caldera rocks, intense fracturing of the rocks, and the overall position of Red River canyon.

Intrusion of the southern caldera plutonic rocks into the volcanics caused extensive hydrothermal fluid circulation and alteration of the composition of the original rock-forming minerals in the mining district. As a result, nearly the entire region experienced enrichment of quartz, sulfate minerals, clay minerals and pyrite (iron sulfide).

Numerous areas of high pyrite content in the district resulted from hydrothermal systems that were localized in permeable zones coinciding with low-angle faults or locally intense fracturing. Exposure of these high-pyrite areas to the surface led to oxidation of the pyrite, often accompanied by formation of clay minerals. Where significant concentrations of clay minerals and tectonic preparation exist on steep slopes, rapid erosion occurs from landsliding, slumpage and mud flow, and a scar topography develops. These hydrothermal scars are the most visible geomorphologic feature of the Questa mining district.

B. Effects of Recent Glaciation.

The most recent period of glaciation in this part of the United States ended about 11,000 years ago. This event changed the geomorphology of the Questa district: it deepened the Red River canyon; it accentuated the topography on the north and south sides of the river; and it enhanced the erosional characteristics of some of the scars and other hydrothermally altered areas.

C. Erosion from Hydrothermal Scars.

Hydrothermal scars extend from the Questa mine property east past the town of Red River, and west to the Ranger Station. Seepage and eroded materials from the naturally occurring scars contain sulfuric acid-bearing waters, and anomalous concentrations of metals, sulfates and other sediments. As a result of at least 11,000 years of persistent and rapid erosion, the scars in their present state are deep features devoid of vegetation.

Erosion of the scar areas has also resulted in the creation of alluvial fan deposits along the Red River and tributary creeks that drain canyons where the scar areas are located. Ian P.G. Hutchison, Questa Mine Site and Expert Report (April 23, 1997) ("Hutchison"), at 11, 17. A particularly large alluvial fan exists where Hansen Creek carries sediments into the river in the two mile stretch just above the Molycorp property line. Hansen Creek drains a prominent area of hydrothermal scarring. Chadwick Ecological Consultants, Inc., Aquatic Biological Assessment of the Red River, New Mexico, in the Vicinity of the Questa Molybdenum Mine (April, 1997) ("Chadwick"), at 11. The alluvial fans may be acid-generating.

II. THESE UNUSUAL GEOLOGIC CONDITIONS CONTINUE TO AFFECT THE WATER QUALITY OF THE RED RIVER.

The hydrothermal scars and the surrounding altered rocks have a measurable impact on Red River water quality. The pattern of increases in Red River metal loads, for example, are consistent with contributions from hydrothermal scars occurring in a zone from the Town of Red River to the Ranger Station, beginning about 7 miles above and continuing about 1.5 miles below the Molycorp property lines. William M. Schafer, Expert Report -- William M. Schafer, Ph.D. (April 23, 1997) ("Schafer"), at 3-4. Runoff from these hydrothermal scars contributes significant loadings of salts and metal constituents to the Red River. Hutchison, at 14. The scars are also the source of elevated levels of total dissolved solids (TDS) and aluminum. Schafer, at 7-9. Additionally, heavy sediment loadings that reduce water clarity are contributed by Bitter Creek, Hot 'n Tot Creek, and Hansen Creek above the mine boundary. Each of these creeks drain natural hydrothermal scar areas. Chadwick, at 9-11. Finally, there are more than enough natural scar areas on the mine property itself to account for all of the acidic water flow that enters the Red River adjacent to the mine. Schafer, at 13-14.

Sediment loadings in the river from the hydrothermal scars are responsible for impacts to fish and macroinvertebrate populations. Clay and mud sediment fill the habitat on the river bottom where fish spawn and macroinvertebrates live. Although increased concentrations of dissolved aluminum may also play a role, (Chadwick, at 36, 45) high sediment levels apparently are primarily responsible for the negative impacts to fish in all reaches of the river downstream from the town of Red River. Chadwick, at 64-66. Excess sediment levels make the river section below Hansen Creek unsuitable for supporting all but a few trout. Sampling of fish populations reveals an 89% reduction of trout in the river between the town of Red River and a point below the confluence of the Red River and Hansen Creek. Chadwick Ecological Consultants, Inc., Fall 1997 Data Addendum: Red River Aquatic Biological Assessment (February, 1998) ("Chadwick Addendum"), at 10. This reduction occurs *before* the river passes the mine property.

The sampling station at Bitter Creek (4 miles above the mine) is the only station to have exceeded EPA aquatic life standards for metals (in 1988). Schafer, at 15. However, the single largest biological impact on the river above the mine is from Hansen Creek. Chadwick, at 36; Chadwick Addendum, at 7. The decrease in trout density below Hansen Creek is more dramatic than that upstream, reducing trout populations to low levels above the reach of river adjacent to Molycorp's property. Chadwick, at 59, 61; Chadwick Addendum, at 7.

Adjacent to the Molycorp property, impacts on fish and macroinvertebrate populations appear to be no greater than those upstream. One area of detrimental impact is the reach below Capulin Canyon, where excessive sediments, and perhaps dissolved aluminum, make the river unsuitable for maintaining trout populations. This effect, too, is attributable to erosion from hydrothermal scar areas -- in this case located in Capulin Canyon. Chadwick, at 15, 48.

Significantly, the river reaches adjacent to Molycorp are no worse now than they were in 1965, before any effects from open pit mining and the creation of the waste rock piles would have been felt in the river. Metal, TDS, and sulfate loadings have not increased in this period. Schafer, at 2-3. Alkalinity loads have not changed since 1965 either, which indicates that if low pH waters are in fact

moving toward the river, their contribution has not changed since the development of the open pit. Schafer, at 8.

Fish densities were in fact higher in 1997 samples than they were in 1960. Chadwick, at 59. Although more efficient fish collection methods may account for part of this increase, stormwater controls at the mine site, which prevent the kind of stormwater runoff loadings found in Hansen Creek (Chadwick, at 37), may have actually served to improve water quality in the river adjacent to the mine in recent years. Without such controls, additional stormwater runoff from natural scar areas on the mine property would continue to flow into the river unchecked.

III. THE QUESTA MINE HAS NOT HARMED, AND MAY HAVE IMPROVED, THE CONDITION OF THE RED RIVER.

As the preceding discussion shows, most of the negative impacts on the river occur upstream of the Molycorp mine property as the result of drainage from hydrothermal scar areas. In fact, the evidence indicates that the opening of the Molycorp's open pit mine in 1965 and subsequent creation of waste rock piles has not harmed the Red River. Moreover, certain mine activities, such as mine dewatering, pumping of water supply wells, and stormwater collection, improve river water quality.

A. Mine Dewatering and Supply Well Pumping.

In 1979, Molycorp began development of a new underground mine at the Questa site. (The older underground mine dates to 1919, long before Molycorp took title to the property.) Molycorp was compelled to begin dewatering both the new and old underground workings to keep them dry enough for mining. The dewatering process was interrupted when the mine shut down in 1991, but pumping resumed in September, 1995 and continues to the present day.

The mine dewatering process is one of several mining activities that results in reductions of constituent loads to the Red River. Hutchison, at 13. The water pumped from the mine is initially used in the mine's ore processing facilities, and then pumped to the tailings area eight miles away from the mine. The underground pumping creates a large drawdown cone in the ground water table. That cone intercepts most of the ground water passing through the site, including water that has percolated down from waste rock piles. The contours of this cone extend from the Goathill Creek area (to the west), and the area under the Sugar Shack, South Middle, and Sulfur Gulch waste rock piles (to the east). Hutchison, at 8. Dr. Hutchison, who used groundwater elevation data and topographic maps to determine the extent of the cone, found that "virtually all the ground water flow in the mine's capture area is being pumped out of the area and does not migrate to the Red River." Hutchison, at 9.

The other mining-related activity with a positive impact on the condition of the Red River is the pumping of the supply wells at the mill site and Columbine Park, which reduces the volume of ground water seep into the river.

B. Surface Runoff Management.

In addition to ground water management, Molycorp has instituted extensive surface water control at the mine. Surface drainage from the Sulfur Gulch area at Questa, which formerly had been a significant source of natural acidic drainage to the Red River, is now captured in the Molycorp open pit. Surface drainage from the Goathill Gulch area at Questa, which formerly had been a significant source of natural acidic drainage to the Red River, is now captured in the Molycorp caving operation. Surface drainage from the upper Capulin Canyon area at Questa, just below the waste rock piles about 2.5 miles from the Red River, is also captured, and transported through a borehole across Goat Hill to the caving operation. Like water captured to dewater the mine, the captured surface water is used for processing the ore, then is pumped to the tailings area about eight miles from the mine property.

IV. SURFACE RUNOFF AND GROUNDWATER FLOW PATHWAYS AT THE QUESTA MINE PROPERTY.

Flow to the Red River consists of two components: surface runoff and ground water. Schafer, at 2. Surface runoff from the mine area is currently permitted under Molycorp's NPDES permit at outfalls 004 and 005, although there has been no discharge through these outfalls since 1993. Other surface drainage is covered under Molycorp's Multi-Sector permit.

A. Infiltration Through the Waste Rock Piles.

Ground water could be affected by surface water infiltration from the mine area, including its waste rock piles. The potential flow pathways downward from the waste rock piles are numerous, variable in direction and quite difficult to define. Hutchison, at 14. They may include the underlying unsaturated alluvium, underground hydrothermal scar areas, or fractured bedrock above the ground water table (or a combination of any of these). Lateral spreading may occur in these zones. Hutchison, at 4. Hence, in Dr. Hutchison's words:

Migration of this widespread diffuse source therefore continues to be neither discernible, confined nor discrete. It is generally not discernible as it occurs as a subtle increase of moisture content on the surface of soil particles and in the large number of interconnected fractures that occur in bedrock. It is unbounded as it occurs over a widespread area, and finally, it is not discrete as it occurs in millions of pores and fractures in the soils and bedrock. Hutchison, at 4.

Infiltration through the waste rock piles migrates slowly down past the unsaturated zone and alluvium, into the fractured rock and deep bedrock below the level of the Red River, and eventually mixes with ground water. That ground water moves, in general, either into the dewatered workings of the underground mine, to deep bedrock below the Red River, or to the Red River. Hutchison, at 5. A complex area of faults and structural fractures at the site form zones of varying permeability. The intersection of the fractures and faults produces millions of potential migration pathways for ground water. Hutchison, at 5. Permeable bedrock occurs at considerable depths below the Questa mine site, and Molycorp personnel have observed water draining into the deep underground mine

workings through the large number of faults and fractures. Hutchison, at 8. Most of the faults and fractures, however, are laterally discontinuous (they pinch and swell). See, for example, Hutchison, at 20. One fault that traverses the upper portion of Capulin Canyon, for example, provides a deep migration pathway for water into the bedrock *below* the Red River. Hutchison, at 19.

B. The Underground Cone of Depression.

Underground pumping has created a cone of depression that prevents most water that drains from the waste rock piles from entering the Red River. Dr. Ian Hutchison has determined that this cone of depression captures percolation from the Capulin Canyon waste rock pile (which is pumped to the caving area), from the Goathill Gulch, and Sugar Shack West waste rock piles, and most of the western portions of Sugar Shack South and Middle, and Sulfur/Spring Gulch piles. Hutchison, at 9-10. Although the Spring Gulch pile and the eastern portions of Sugar Shack South, Middle, and Sulfur/Spring Gulch piles lie outside the capture area, the potential for constituents from these piles reaching the Red River is low for various reasons. Hutchison, at 10. Each of these piles contains nonacid-generating black andesite, aplite, and granite. Also, the potential for drainage from the Sulfur/Spring Gulch pile is further reduced by the decline, a downward sloping tunnel that passes under the Sulfur/Spring Gulch pile and may intercept ground water infiltration from that waste rock pile. Hutchison, at 10.

V. NATURE AND SOURCE OF THE RED RIVER SEEPAGE ZONES ADJACENT TO THE MINE PROPERTY.

Diffuse ground water seepage enters the Red River in several wide zones along the Molycorp property line, as well as along other locations adjacent to the river both upstream and downstream of the mine. The seepage zones typically have the appearance of wet soils or shallow fractured bedrock from which water seeps from the pore spaces at varying rates. Hutchison, at 7.

A. Location of the Seepage Zones.

Most of these seepage zones are not in close proximity to the waste rock piles. Hutchison, at 16. The Capulin seepage zone is approximately 8,000 feet downgradient from the Capulin waste rock pile, but only 5,000 feet downgradient from a natural scar area. The Capulin zone is located in a fan delta deposit of alluvium containing naturally occurring acid-generating mineralization, which makes the deposit itself a likely source of low-pH and metal constituents in the seepage zone. Hutchison, at 16. This seepage zone has been identified as one source of the white precipitate that sometimes appears in the river. Chadwick, at 15.

The Highway 38 seepage zone is located approximately 2,500 feet downgradient from part of the Sugar Shack West waste rock pile. The Cabin seepage zone is downgradient from a small natural drainage area, and 1,500 feet away from a large natural scar area and the Sugar Shack South waste rock pile. The Portal seepage zone is 500 to 1,000 feet downgradient from a large natural scar area and the Sugar Shack South waste rock pile. The Sulphur Gulch seepage zone is close to the toe of the Sulphur Gulch waste rock pile, and also less than 1,000 feet from a large natural scar area.

Despite the latter seepage zone's proximity to a waste rock pile, it has among the lowest constituent loadings of any Red River seepage zone -- TDS and sulfate concentrations there, for instance, are far less than in Hansen Creek. Hutchison, at 17.

B. Sources of Seepage Constituents.

Dr. Schafer has examined the seepage zones and concluded that there is no geochemical basis for determining whether they contain constituents from the waste rock piles. Schafer, at 4. The data do not allow for a conclusion as to whether constituent loadings to the river through the seeps are derived from the waste rock piles, natural scar areas, or from alluvial deposits in the river and its tributaries. Hutchison, at 3. Water in contact with either the waste rock or the hydrothermal scars has the same geochemical "signature," which precludes any conclusion that increases in the concentration of specific metals at the seeps are attributable to one source or the other. Schafer, at 3.

Circumstantial evidence points, however, to the fact that the natural scar areas are just as likely to be the source of constituent loadings into the river as the waste rock piles. The white aluminum precipitate being formed in the river at the Capulin seepage zone is apparently identical to the white precipitate observed at Hansen Creek, in the river above the Molycorp property and near the scene of drainage from a natural hydrothermal scar area. Chadwick, at 11, 15. (The Capulin seepage zone, too, is downgradient from a natural scar area as well as a waste rock pile, but 3,000 feet closer to the natural scar. Hutchison, at 16.) Dissolved aluminum increases in the river also can be clearly traced to natural sources upriver from the mine. Schafer, at 9.

Furthermore, acidic water represents less than 10% of the total flow into the Red River adjacent to the mine. While only 66 acres of scar areas would be sufficient to produce this flow at typical ground water recharge rates, there are 160 acres of undisturbed hydrothermal scars in the basin along this stretch of the river. Schafer, at 14. Moreover, undisturbed non-scar mineralized material, and acid-generating substances in the fan delta deposits are also potential sources of acidic runoff or ground water seepage into the Red River. Hutchison, at 10.

There are also reasons why TDS loading would be greater from a natural scar area than from a waste rock pile. To begin with, the waste rock piles contain a large proportion of gravel and boulder-sized material which would typically provide only a fraction of constituent loading compared to the finer-grained sands and silts that predominate in scar areas. Hutchison, at 13. Also, since the scar areas contain more uniform material, they are more uniformly flushed by rainfall and infiltration, leading to increased potential for leaching out constituents. This scar uniformity is in contrast with the waste rock piles, in which infiltration tends to be more varied and less pervasive, and infiltration water contacts only a portion of the material, thus reducing the mass of potentially leachable constituents. Hutchison, at 14.

As for contribution from the waste rock piles, the natural process of attenuation presents a good reason -- in addition to the capture of water by the mine dewatering process described earlier -- why the waste rock piles probably do not contribute significant loadings to the Red River seeps. As a general rule, the further that ground water travels, the more the constituent concentrations are dependent on the natural properties of the pathway -- here alluvium and fractured bedrock.

Hutchison, at 6. The original source constituents are subject to an attenuation process by the alluvium and fractured bedrock through which they migrate. The capacity of bedrock and alluvium to attenuate metals may be exhausted only after a great number of decades or centuries. Schafer, at 12. The quality of the underground mine water furnishes important evidence of the attenuation capacity in the fractured bedrock. In fact, water pumped out of the Questa mine is characterized by neutral pH, high TDS and sulfate, and reduced metal concentrations, which is typical of changes that occur during attenuation. Hutchison, at 10. This result accords with the fact that the abundance of alkaline and calc-alkaline volcanic host rocks in the area, as well as secondary alteration minerals such as gypsum, provide natural neutralization (and attenuation) capacity for migrating acidic water. Hutchison, at 11.

LEGAL ANALYSIS

Section 301(a) of the Clean Water Act makes it unlawful to discharge a pollutant without an NPDES permit. 33 U.S.C. § 1311(a). The term "discharge of a pollutant" under the Act means "any addition of any *pollutant* to navigable waters from any *point source*." *Id.* at § 1362(12)(A) (emphasis supplied). As the following legal analysis shows, ground water seepage to the Red River from Molycorp's property is not a "discharge of a pollutant" because:

1. discharges to ground water do not require an NPDES permit;

2. even if discharges to ground water did require an NPDES permit, no permit is required for these seeps because it is not known whether constituents in the seeps originated from mining activity (the waste rock piles); and

3. even if the seeps contained pollutants originating from the waste rock piles, they still would not be a discharge from a "point source."

I. DISCHARGES TO GROUND WATER DO NOT REQUIRE AN NPDES PERMIT.

Pollutants from the waste rock piles are obviously not being directly discharged to the Red River, but may be infiltrating into ground water. Hence the first legal question that arises is whether discharges to ground water come under the jurisdiction of the NPDES program.

It is unquestioned that *isolated* ground water is not covered under the Act. *Exxon Corp. v. Train*, 554 F.2d at 1310, 1329 (5th Cir. 1977). Federal courts are divided, however, as to whether discharges to *tributary* ground water -- ground water that is hydrologically connected to surface waters -- fall under the jurisdiction of the Clean Water Act's NPDES permitting program. Several

federal district courts have concluded that the Act excludes ground water discharges regardless of where the ground water ultimately drains.[2]

Other districts courts have found that the NPDES program reaches ground water pollution that eventually finds its way to a surface water.[3]

The two federal circuit courts of appeals that squarely addressed this issue have held that Clean Water Act permitting requirements are inapplicable to discharges to tributary groundwater. In *Village of Oconomowoc Lake v. Dayton Hudson Corp.*, 24 F.3d 962, 965 (7th Cir. 1994), the Seventh Circuit held, "Neither the Clean Water Act nor the EPA's definition asserts authority over ground waters, just because these may be hydrologically connected with surface waters." The Fourth Circuit also refused to read the Act to encompass tributary ground water; the court gave deference to an Army Corps of Engineers interpretation to the same effect. *Town of Norfolk v. U.S. Army Corps of Engineers*, 968 F.2d 1438, 1451 (1st Cir. 1992).

Recently a federal district court in Oregon has held that the Clean Water Act "as written, as intended by Congress, and as applied in Oregon for over two decades does not regulate even hydrologically-connected groundwater." *Umatilla Waterquality Protective Association, Inc. v. Smith Frozen Foods*, 962 F.Supp. 1312, 1318 (D. Or. 1997). On rehearing, the *Umatilla* court rejected the claim that certain "tentative assertions" by EPA in recent years that the Clean Water Act's NPDES permit requirement is applicable to hydrologically connected ground water were entitled to deference. *Umatilla Waterquality Protective Association, Inc. v. Smith Frozen Foods*, 1997 U.S. Dist. LEXIS 16458, *2 (D. Or. 1997). To resolve the hydrological connection issue, the court applied the "common-sense" distinction between discharges to navigable waters and discharges to an intervening medium. The *Umatilla* Court discussed the application of this distinction to air emissions from an incineration stack by the Court of Appeals for the Tenth Circuit in its recent decision, *Chemical Weapons Working Group, Inc. v. U.S. Dept. of the Army*, 111 F.3d 1485 (10th Cir. 1997):

In essence, the Tenth Circuit distinguished discharges where navigable waters were the immediate destination from discharges where the pollutants actually mixed in with an intervening medium: the former could constitute discharges to navigable water for Clean Water Act purposes, while the latter were, in common-sense terms, discharges . . . to the intervening medium and not discharges to navigable water. . . . The same logic applies equally persuasively to discharges to groundwater: such

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[2] *Kelley v. United States*, 618 F.Supp. 1103, 1106-07 (W.D. Mich. 1985). *Umatilla Waterquality Protective Association, Inc. v. Smith Frozen Foods*, 962 F.Supp. 1312, 1318 (D.Or. 1997), *rehearing denied*, 1997 U.S. Dist. LEXIS 16458 (Sept. 23, 1997); *United States v. ConAgra, Inc.*, No. 96-0134-S-LMB, slip. op. (D. Idaho, Dec. 31, 1997).

[3] *Williams Pipe Line Co. v. Bayer Corp.*, 964 F.Supp. 1300, 1319 (S.D. Iowa 1997); *Friends of Santa Fe County v. Lac Minerals, Inc.*, 892 F.Supp. 1333, 1358 (D.N.M. 1995); *Washington Wilderness Coalition v. Hecla Mining Co.*, 870 F.Supp. 983, 990 (E.D. Wash. 1994); *Sierra Club v. Colorado Refining Co.*, 838 F.Supp. 1428 (D.Colo. 1993); *McClellan Ecological Seepage Situation v. Weinberger*, 707 F.Supp. 1182, 1196 (E.D.Cal. 1988).

discharges are, in common-sense terms, discharges to groundwater -- not discharges to navigable waters subject to the NPDES permit requirement. *Umatilla,* 1997 U.S. Dist. LEXIS 16458 at *10-11.

The weight of these recent judicial authorities comes down strongly on the side of excluding ground water from the purview of the NPDES program. It is clear that Congress did not intend discharges to ground water, regardless of whether it is tributary or isolated ground water, to be covered under the Clean Water Act.[4]

II. EVEN IF DISCHARGES TO GROUND WATER REQUIRED NPDES PERMITS, NO PERMIT IS REQUIRED FOR SEEPAGE FROM MOLYCORP'S PROPERTY BECAUSE IT IS NOT KNOWN WHETHER ANY POLLUTANTS IN THE SEEPS ORIGINATED FROM MINING ACTIVITY (WASTE ROCK PILES).

Even if discharges to tributary ground water were covered by Clean Water Act permitting requirements, such requirements would still not apply to Molycorp because it is unknown whether pollutants from the waste rock piles actually enter the Red River through the seepage zones.

A. Waste Rock Pile Pollutants Are Captured by Dewatering

As noted in the factual discussion above, the underground mine dewatering process, whereby the underground workings are kept dry through pumping, has created a hydrological cone of depression that captures virtually all of the water infiltrating the waste rock piles. Hutchison, at 9. This means that most of the metal constituents and other pollutants from the waste rock piles are intercepted before they could enter the Red River through the ground water seeps.[5]

B. It Is Unknown Whether Water Seeping into the Red River Contains Pollutants from the Waste Rock Piles.

Any pollutants entering the river at the seepage zones cannot be traced to the waste rock piles, or to any other human activity at the mine. In fact, it is unknown whether seepage fed by waste rock could ever be reliably distinguished, based on water chemistry differences or any other basis, from seepage fed by natural scar materials. Schafer, at 10-13.

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[4] The relevant legislative history of the Clean Water Act is discussed below at pages 16-17. An excellent, more detailed discussion of the relevant legislative history, statutory provisions, and EPA interpretations appears in *Exxon Corp. v. Train,* 554 F.2d at 1310, 1319-30.

[5] Due to the dewatering of the underground mine, the only known discharge of pollutants from the waste rock piles into the Red River occurs at the mine's tailings area, to which water from the underground mine is transported. Discharges into the Red River from the tailings area occur from outfalls 001 and 002, which are regulated by Molycorp's existing NPDES permit.

Dr. Hutchison found that the underground cone of depression formed by the mine dewatering process captured most of the water infiltrating the mine waste rock piles. Hutchison, at 8. Although some waste rock pile infiltration may be outside the capture zone, Dr. Hutchison explained that because these piles are made up of non-acid generating black andesite, aplite, and granite, they have a low potential for seepage of constituents. Hutchison, at 9-10. Thus it is unknown whether the waste rock piles contribute pollutants to the Red River.

In fact, most of the water quality problems in the Red River stem from sources upstream of Molycorp, especially drainage from acid-generating alluvium and natural hydrothermal scars such as those found in the area drained by Hansen Creek. In fact, fish sampling indicates that the river's trout populations diminish by 89% *before* the river reaches the mine boundaries. Chadwick Addendum, at 10. Hydrothermal scar areas also occur on Molycorp's own property, and there is no way to distinguish whether any pollutants entering the river at the seeps originally come from those scar areas, the waste rock piles, or some other mineralized area on site. Schafer, at 10-13. Indeed, loadings probably leach at a higher rate from the scar areas than from the waste rock piles that are acid-generating: the scars are composed of more uniform, finer-grained materials than the waste rock piles, so the scars would tend to facilitate more complete flushing and leaching by rainwater and snow melt. Hutchison, at 13-14. Also, migration of metal and acidity through the carbonate bedrock could be slowed for many decades or centuries by attenuation. Leaching from the pre-existing scar areas into the ground water table would have a head start (of about 12,000 years) in consumption of bedrock attenuation capacity compared with the waste rock piles, which have existed since 1965. Schafer, at 12.

As noted above, it is doubtful whether discharges to tributary ground water are encompassed by NPDES requirements at all. In the case of the Questa mine, this doubt is compounded by the uncertainty about whether ground water affected by waste rock pile infiltration is tributary to the river. Leading experts who have studied the Red River at the mine site have concluded:

> The available data does not allow for a determination whether constituent loadings in Red River are derived from overburden piles, scar areas, or from alluvial deposits in tributary and Red River channels.

Hutchison, at 3.

> Water in contact with either mine waste rock or natural hydrothermal scars has the same geochemical "signature". Consequently, increases in the concentration of specific metals such as zinc or manganese in seeps or in the Red River adjacent to the mine site do not indicate that seepage was contributed by mine waste rock sources. . . .
>
> There is no geochemical basis for determining the location, timing or amount of acidic drainage and associated constituents, also known as acid rock drainage (ARD), contributed to the Red River by the mine waste rock.

Schafer, at 3-4.

As these experts explain at length in their reports, several factors account for this uncertainty. The first factor is the diffuse migration pathways for drainage from the waste rock piles, which are poorly understood. Waste rock pile drainage may actually be migrating into the deep, fractured bedrock *below* the Red River. Hutchison, at 7-8. The second factor is the geochemical attenuation processes that retard or eliminate many of the waste rock pile constituents as they migrate through the alluvium and fractured bedrock, producing neutralized pH and reduced metal concentrations. Hutchison, at 7, 10-11; Schafer, at 12-13. The third factor is the natural background sources of constituents in the river, derived from the hydrothermal scars as well as mineralized fractured bedrock and alluvium, which cannot readily be distinguished from mining sources such as the waste rock piles. Hutchison, at 7, 11; Schafer, at 3-4.

In sum, since the constituents in the seeps cannot be traced to mining activity (the waste rock piles), it would be inappropriate to apply NPDES controls to regulate the seeps.

III. EVEN IF POLLUTANTS FROM THE WASTE ROCK PILES REACHED THE RIVER, THEY WOULD NOT ENTER THE RIVER FROM A "POINT SOURCE."

Even if pollutants from the waste rock piles could be traced to water that seeps into the Red River, the NPDES permitting program would not apply to the seeps. For NPDES permitting requirements to apply, the pollutants would have to enter the river by means of a "point source," which is defined as follows:

The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. . . .33 U.S.C. § 1362(14). This definition requires a "discernible, confined and discrete conveyance" of the pollutant. The definition of point source therefore "exclude[s] natural rainfall drainage over a broad area." *Sierra Club v. Abston Const. Co.*, 620 F.2d 41, 44 (5th Cir. 1980). It also "excludes unchanneled and uncollected surface waters." *Appalachian Power Co. v. Train*, 545 F.2d 1351, 1373 (4th Cir. 1976).

It is clear that there is no point source that conveys pollutants from the waste rock piles to the Red River. There are only three conceivable possibilities: the waste rock piles themselves, the ground water, or the seeps. However, none of these are "point sources" within the meaning of the Act.

A. The Waste Rock Piles Are Not Point Sources.

One theory that can be quickly discarded is that the waste rock piles become a point source when rain water percolates through them into ground water that eventually drains into the Red River.[6] Without

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[6] This is the theory raised by legal counsel for the environmental groups Amigos Bravos and New Mexico Citizens for Clean Air, in a letter last year to EPA requesting that it assert Clean Water Act jurisdiction over drainage from the Questa mine waste rock piles. Letter from Grove

some human collection or channeling activity, a waste rock pile is not a point source even for *surface* water drainage, let alone drainage underground. *Appalachian Power Co. v. Train*, 545 F.2d at 1373; *Sierra Club v. Abston Const. Co.*, 620 F.2d at 45 ("Simple erosion over the material surface [of a waste rock pile] . . . , does not constitute a point source discharge, absent some effort to change the surface, to direct the waterflow or otherwise impede its progress.").

There is no collection or channeling of underground drainage at the Questa mine waste rock piles. As Dr. Hutchison notes in his report, "There are no discernible, confined and discrete conveyances of constituents from the mine's overburden piles." Hutchison, at 3. Instead, drainage through the piles is diffuse: "To the extent they represent potential sources of constituents, the overburden piles . . . are widespread, diffuse seepage sources, with the amount of constituent loading varying within the source area." Hutchison, at 4. In short, the waste rock piles fail to present the kind of "circulating or drainage *system*" found sufficient to constitute a point source by the Tenth Circuit when it examined the combination of overflowing sumps, ditches, hoses, and pumps at a gold ore leaching facility in *United States v. Earth Sciences*, 599 F.2d 368, 374 (10th Cir. 1979).

The legislative history of the Clean Water Act confirms that Congress viewed infiltration by rain water and snow melt through waste rock piles as *nonpoint* source pollution. Section 304(f) of the Act directs EPA to develop information on such "*nonpoint* sources of pollutants" as:

> (B) mining activities, including runoff and siltation from new, currently operating, and abandoned surface and underground mines. . . .

42 U.S.C. § 1314(f)(B). A Senate committee report shows that these mining nonpoint sources were understood to include waste rock piles, where water percolating through the piles drains into ground water:

> Information [on non-point source pollution] must be generated on problems related to leaching of ores and waste piles, *and acid from the dissolving of acid salts formed on exposed spoil surfaces or added to groundwater percolating through spoil or waste dumps.*

"Federal Water Pollution Control Act Amendments of 1971," Report of the Senate Committee on Public Works, Report No. 92-414, 92d Cong. 1st Sess. 53 (1971) (emphasis added); reprinted in "A Legislative History of the Water Pollution Control Act Amendments of 1972," Congressional Research Service No. 93-1, Vol. 2, at 1471 (1973). Percolation from waste rock piles clearly falls under the nonpoint source classification that Congress intended for "disparate runoff caused primarily by rainfall around activities that employ or cause pollutants." *United States v. Earth Sciences*, 599 F.2d at 373.

T. Burnett to Sam T. Coleman, Director, Compliance Assurance and Enforcement Division, EPA Region VI (May 16, 1997).

B. The Imputed Ground Water Pathway Is Not A Point Source.

As described above, most ground water beneath the waste rock piles at the Questa mine site is captured by the dewatering operation before it reaches the Red River. Moreover, even if some of the ground water did reach the Red River, the imputed ground water pathway (for constituents draining from the waste rock piles and mixing with the water table within the underground mine, and then seeping into the river) would not be a point source. Once constituents from the waste rock piles mix with ground water, there cannot be a discernible, confined, or discrete conveyance -- a point source -- under the Clean Water Act. 33 U.S.C. § 1362(14). Ground water flow is neither discrete nor confined. In fact, EPA has described ground water explicitly as a "nonpoint source" in a recent regulation.[7]

As a matter of statutory interpretation, ground water is a poor candidate to be a point source because ground water pollution was not meant to be regulated by the NPDES program at all. Congress did not intend the Clean Water Act to regulate ground water in the same fashion as surface water. In fact, the Act repeatedly distinguishes "navigable waters" and "ground waters." 33 U.S.C. §§ 1252(a), 1254(a)(5), and 1256(e)(1). While various sections of the Act refer to the problem of ground water pollution, they do not impose NPDES or other legal mechanisms to control it. As the Fifth Circuit concluded in *Exxon Corp. v. Train*, 554 F.2d at 1322 (5th Cir. 1977):

> [A] clear pattern of congressional intent with respect to ground waters emerges upon close examination of those sections of the Act that deal with the subject. That pattern is one of federal information gathering and encouragement of state efforts to control groundwater pollution -- but not of direct federal control over ground water pollution.

The report of the Senate Committee on Public Works that accompanied the bill that became the Clean Water Act noted that the Committee rejected several bills that would have provided authority for establishing federal standards over ground water. The basis for rejecting these bills was the belief that Congress should not interfere with the existing "complex and varied" State jurisdiction over ground water. S. Rep. No. 414, 92d Cong., 1st Sess. 73 (1971), 2 *Leg. Hist.* 1491, U.S. Code Cong. & Admin. News 1972, p. 3739.

The House of Representatives rejected a floor amendment that would have brought ground water under the enforcement provisions of the Act. The amendment was proposed by Rep. Aspin, who clearly believed the bill that passed did not regulate pollution of ground water. 118 Cong. Rec. 10666 (1972), 1 *Leg. Hist.* 589 (remarks of Rep. Aspin); *Exxon Corp. v. Train*, 554 F.2d at 1328-29.

---

[7] The definitions section of EPA's Water Quality Guidance System for the Great Lakes Region defines "load allocation" as "the portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources or to natural background sources. . . . Nonpoint sources include: in-place contaminants, direct wet and dry deposition, *groundwater inflow*, and overland runoff." 40 C.F.R. § 132.2 (1997) (emphasis supplied).

As one of the first courts to interpret the Act noted, "The failure of the proposed amendment strongly militates against a judgment that Congress intended a result that it expressly declined to enact." *United States v. GAF Corp.*, 389 F.Supp. 1379, 1384 (S.D. Tex. 1975) (citation omitted).

C. **The Red River Seepage Zones Are Not Point Sources.**

The seeps that drain ground water into the Red River through the banks adjacent to Molycorp and neighboring properties likewise are not point sources. Drainage from the seeps is diffuse, rather than discrete and confined. Hutchison, at 4. They are also not the result of any human activity, and probably existed long before mining began on the Molycorp property.

EPA discussed the non-point source nature of this seepage in its Response to Comments in Molycorp's 1993 permit renewal proceeding, when it refused the requests of certain commenters to require NPDES permitting of the seeps:

> ISSUE NO. 9
>
> Various commenters have expressed concern with ground water seepage to the Red River and suggest that *this ground water may be infiltrated from the mine* and tailings areas, in addition to natural sources. Some commenters believe that seepages of this type represent "point sources" under the NPDES permitting program. Several have cited case law such as *Sierra Club v. Abston Construction Co., Inc.*, 620 F.2d 41 (5th Cir. 1980).
>
> RESPONSE NO. 9
>
> *While EPA understands the concern of these commenters for the possible impact of ground water seepage on the Red River, we do not agree that these are "point sources" under the NPDES permitting program.* Ground water is regulated by the State through the NMED [New Mexico Environment Department].
>
> We are familiar with the case law citation which relates to EPA authority to require the construction and control of surface discharges (proscribed "point sources" of pollution) in instances where the operator has not applied the proper control and construction to the sources. However, the issue of seepage of ground water, which may have been infiltrated through porous soil, is a different matter. We recommend that the commenters continue to pursue this issue through the NMED.

EPA, Response to Comments -- Final Permit Decision, EPA NPDES Permit No. NM0022306, at 4 (1993) (emphasis supplied). (In fact, NMED currently is requiring Molycorp to implement a comprehensive program to regulate this ground water seepage.)

In a 1995 citizen suit brought against Molycorp in United States District Court for the District of New Mexico, two environmental groups raised the same issue, claiming that the Red River seeps were point sources in need of regulation under the NPDES program. In support of their claim, the groups submitted a letter the EPA Region VIII Water Management Division Director, which stated

that "EPA has been reevaluating the definition of "point source" to require NPDES discharge permits for seeps and other less obvious discharges." Letter to Dan Fraser, from Max H. Dodson, EPA Region VIII Water Management Division, at 2 (December 22, 1993). Nothing in the Dodson letter, however, asserts that diffuse ground water seepages from waste rock or spoil piles at mines constitute "point sources" regulated by the NPDES program. More importantly, no EPA interpretation or judicial decision supports such a position. The drainage from the Red River seeps is diffuse rather than "confined and discrete," and thus fails to fit the definition of "point source" under the Clean Water Act.

CONCLUSION

For the foregoing reasons, the zones of seepage into the Red River from the Molycorp property are not subject to the NPDES permit program.

Report # 036006

nm 22306

Three Dimensional Geometric Model of Molycorp's QuestaTailings Facility

6WQ-SG
DEC - 8 1997

Prepared for:

UNOCAL
MOLYCORP
Questa, New Mexico

Prepared by:

Robertson GeoConsultants Inc.
Vancouver, BC

October, 1997

Report No. 036006/1

Three Dimensional Geometric Model of Molycorp's Questa Tailings Facility

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October 1997

Report No. 036006/1

THREE DIMENSIONAL GEOMETRIC MODEL OF MOLYCORP'S QUESTA TAILINGS FACILITY

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THREE DIMENSIONAL GEOMETRIC MODEL OF MOLYCORP'S QUESTA TAILINGS FACILITY

1.0 Introduction and Terms of Reference

Molycorp, Inc. (Molycorp) has retained Robertson GeoConsultants Inc. (RGC) in association with Steffen, Robertson & Kirsten (US) Inc. (SRK) to complete a geometric model of the Questa Tailings facility. This model has been developed as part of the requirements to the New Mexico Environmental Department (NMED) under Discharge Plan 933 for the development of a closure plan for the existing tailings facility. It provides the geometric understanding of the sequence and age of tailings deposition within the impoundments.

In late October 1996, the site was visited by representatives of RGC and SRK in an effort to reconstruct the history of tailings deposition at the Questa Mine. The depositional history, constructed from drawings, maps and production reports, in conjunction with results from the drill sampling program undertaken in December 1996 (SRK Report No. 09208.04/2, January, 1997a) were used to develop a three-dimensional geometric model of the Questa tailings facility.

2.0 Questa Tailings Depositional History

The Questa tailings facility is located near highway No. 3, approximately one mile west of the town of Questa, New Mexico (Figure 2.1). The Sangre de Cristo Mountains which host the Questa orebody are to the east of the tailings and the Guadalupe mountains are to the west. The Red River, which runs south of the tailings facility, flows westward from the Sangre de Cristos towards the Rio Grande. It is along this river that the tailings slurry is piped westward from the Questa mill and flows 8 miles to the tailings area. Deposition in the Questa mine tailings facility began in the mid 1960's and has continued intermittently until the present. The impoundments cover approximately 550 acres of land and contain approximately 96,000,000 tons of tailings.

Tailings deposition has occurred predominantly in two areas, section 36 bounded to the south by Dam No. 1, and section 35, bounded to the south by Dam No. 4. A third area, also in section 35 but bounded to the south by Dam No. 5A, is the area that is currently receiving Questa's tailings (Figure 2.2).

Mining operations at Questa have consisted of both open pit and underground operations and, due to the fluctuating price of molybdenum, were intermittently halted

for relatively short periods of time. The following is a chronological description of the depositional history of tailings within the Questa tailings facility.

1965

Open pit operations commenced.

1966

Dam No. 1 (section 36) was constructed of earth fill material to an elevation of 7460'. It was raised to 7520' in 1969-1970 and further raised to its present elevation of 7525' in 1971. All tailings were deposited behind this dam until 1971.

1969

A northern confinement dam, in section 36, was constructed of cycloned tailings to an elevation of 7520', it was named Dam No. 2.

1970

A small 10' dam, Dam No. 3, was constructed at the north end of section 35; it was breached shortly afterwards.

1971

Dam No. 1 was raised to 7525', and Dam No. 4 (section 35) was constructed to 7440'. From this time on, the tailings were split and deposited behind both dams from 1971 until 1991.

Internal berms were also constructed in this year, located in section 35, north of Dam No. 4. Berm No. 1 (southern-most berm) and berm No. 2 (northern-most berm) are both seen in a 1976 airphoto. In 1985, the berm No. 1 was covered with tailings and berm No. 2 was still active. In the 1991 airphoto, berm No. 2 was nearly completely covered.

1973

Dam No. 3A, on the west side of section 35, was built to an average elevation of 7532'. It was shorter on the west end and taller on the east end of the dam.

A temporary impoundment, shown on a 1973 design drawing, located between the two large tailings areas, was built for tailings deposition during times of major construction. This area was referred to on a work sheet as the Rice Paddy and is referred to here as such. It's elevation is approximately 7550', the holding capacity is estimated at 890,000 tons; therefore, at 18,000 tpd, this represents approximately 3 months of deposition.

The tailings here are contemporaneous with tailings deposited in section 36 between 1973 and 1974.

Pre-1974

Tailings were also deposited in the "work area" behind Dam No. 1A; they are contemporaneous with tailings deposited behind Dam No. 1 in the time period between 1966 and 1967, prior to Dam No. 1 being raised to 7484', and are approximately 65' deep. This area was covered when the east diversion ditch was constructed around 1974.

1975

Dam No. 1B was constructed of earth fill to an elevation of 7560' and is a perimeter dam located upstream of Dam No. 1 running parallel to the east diversion ditch.

Dam No. 2A was constructed of earth fill to an elevation of 7560' when property was acquired north of Dam No. 2. Deposition of tailings north of Dam No. 2 occurred from various locations along Dam No. 2A, usually for days or hours at a time. It is approximated that deposition in this area occurred intermittently between 1975 and 1985, contributing to approximately 70 to 80' of tailings near the dams.

"Old" Dam No. 1C was also constructed in 1975, it was made of cycloned tailings and was located approximately 650' north of, and parallel to Dam No. 1. It reached an elevation of 7560'.

1980

Dam No. 2B, a cycloned tailings dam, was built in areas just in front of Dam No. 2A to an elevation of 7580'. It was subsequently covered when Dam No. 2A was raised to an elevation 7584' in 1981-1982. The area north of Dam No. 2 was covered in the 1986, and the 1991 airphoto shows established vegetation on the area.

1981-1982

"New" Dam No. 1C was built from earth fill material. It was stepped back from (south of) "old" Dam No. 1C, and raised to its present elevation of 7584'.

Underground operations commenced.

1983

Open pit operations ended.

1984

The tailings inspection report reported a 50:50 split in the tailings deposition between section 36 and section 35, it is believed to be more of a 60:40 split in the long term, the larger amount being deposited in section 36.

1986-1989

No tailings were discharged between February 28, 1986 and October 12, 1989.

1990

Dam No. 5A was constructed in the old west decant channel on the north side of Dam No. 3A. It was made of earth fill and reached an elevation of 7525' and was designed to be raised to an elevation of 7540'. Deposition behind Dam No. 5A commenced in March 1991 and continued until January 1992.

1992-1996

No tailings were discharged between January, 1992 and October, 1996.

1996

Deposition of tailings re-commenced in mid October, 1996 behind Dam No. 5A.

1997

Current deposition was still behind Dam No. 5A.

3.0 Development of a Geometric Model

The geometric data that was included in the PC XPLOR database consists of:

- digitized topographic data of the tailings area from several topographic maps constructed in different years throughout the mine's life;
- preliminary results from the 4 boreholes sampled (drill logs for the boreholes are provided in Appendix A) as given in SRK Report No. 09208.04 (SRK, 1997a);
- and dates of deposition throughout the depth of the tailings facilities, estimated from yearly production reports (Table 1) with the assumptions of an equal rate of rise in the tailings and a 60:40 split between section 36 and 35 respectively since 1971.

The PC XPLOR database was then used in conjunction with the GEMCOM software program GS32, AutoCAD software and the imaging software CorelDraw to generate three-dimensional figures of the tailings area. Figure 3.1 is a three dimensional

representation of the Questa tailings area prior to tailings deposition. Figure 3.2 illustrates the state of the tailings facility in approximately 1971 at which time Dam No. 4 was constructed and deposition in section 35 commenced. Figure 3.3 depicts the tailings facility in 1975 as tailings were deposited in both sections 35 and 36. Figure 3.4 is a three dimensional view of the tailings facility in approximately 1995, and borehole cross sections of yearly tailings deposition are shown in Figure 3.5.

4.0 Conclusions

Tailings deposition at the Questa Mine has occurred since 1965 covering an area of approximately 550 acres. The chronology of tailings deposition has been outlined in this report. Various software programs were used to develop a three dimensional representation of the Questa tailings facility through time and have been presented herein. Based on the historical reconstruction and three dimensional representation of the Questa tailings it is clear that the four boreholes that extend to the underlying alluvial material that were sampled in December, 1996 have intersected every year of tailings deposition at the Questa Mine. These samples, as well as the numerous surficial and near surface samples collected at various times are considered to be representative of the tailings for all the years of production at the Questa Mine.

This geometric model may be used in conjunction with the geochemical testing results (SRK 1997b) to evaluate the source terms for dissolved constituents in seepage from the Questa tailings impoundments.

5.0 References

Steffen, Robertson and Kirsten (U.S.), Inc. (1997a), Questa Tailings Disposal Facility Drilling Report and Preliminary Cover Modeling Interim Report. Report prepared for Molycorp Inc., January, 1997.

Steffen, Robertson and Kirsten (U.S.), Inc. (1997b), Questa Tailings Facility Geochemical Testing; Final Report. Report prepared for Molycorp Inc., October, 1997.

Various maps, drawings and production reports provided by Molycorp, Inc.

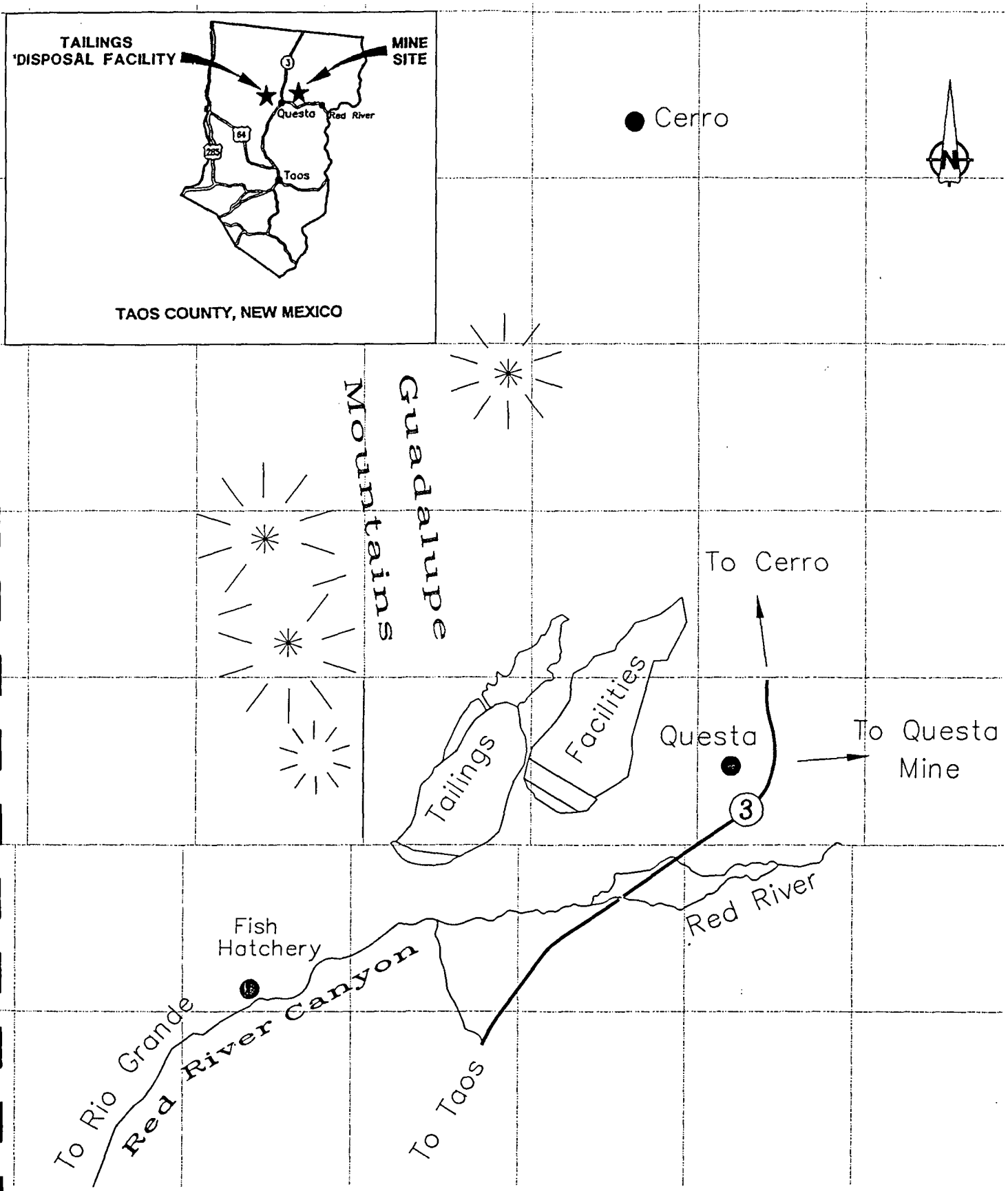
TABLES

Table 1

Yearly Tailings Production.

YEAR	PRODUCTION (TONS)	PERCENTAGE OF TOTAL PRODUCTION
1966	2 945 793	3.07
1967	3 935 784	4.11
1968	3 889 384	4.06
1969	4 320 755	4.51
1970	5 286 225	5.52
1971	6 483 109	6.77
1972	5 327 827	5.56
1973	5 304 236	5.54
1974	5 812 258	6.07
1975	6 067 467	6.34
1976	6 238 184	6.51
1977	5 175 000	5.40
1978	4 380 000	4.57
1979	5 130 000	5.36
1980	5 110 000	5.34
1981	3 101 000	3.24
1982	shut down	-
1983	1 183 000	1.24
1984	3 878 000	4.05
1985	4 357 538	4.55
1986	730 690	0.76
1987	shut down	-
1988	shut down	-
1989	1 054 384	1.10
1990	3 363 787	3.51
1991	2 700 641	2.82
1992	shut down	-
1993	shut down	-
1994	shut down	-
1995	shut down	-
1996	started up 10/96	
1997		
TOTAL	95 775 062	

FIGURES



ROBERTSON GEOCONSULTANTS INC.

Consulting Geotechnical and Environmental Engineers

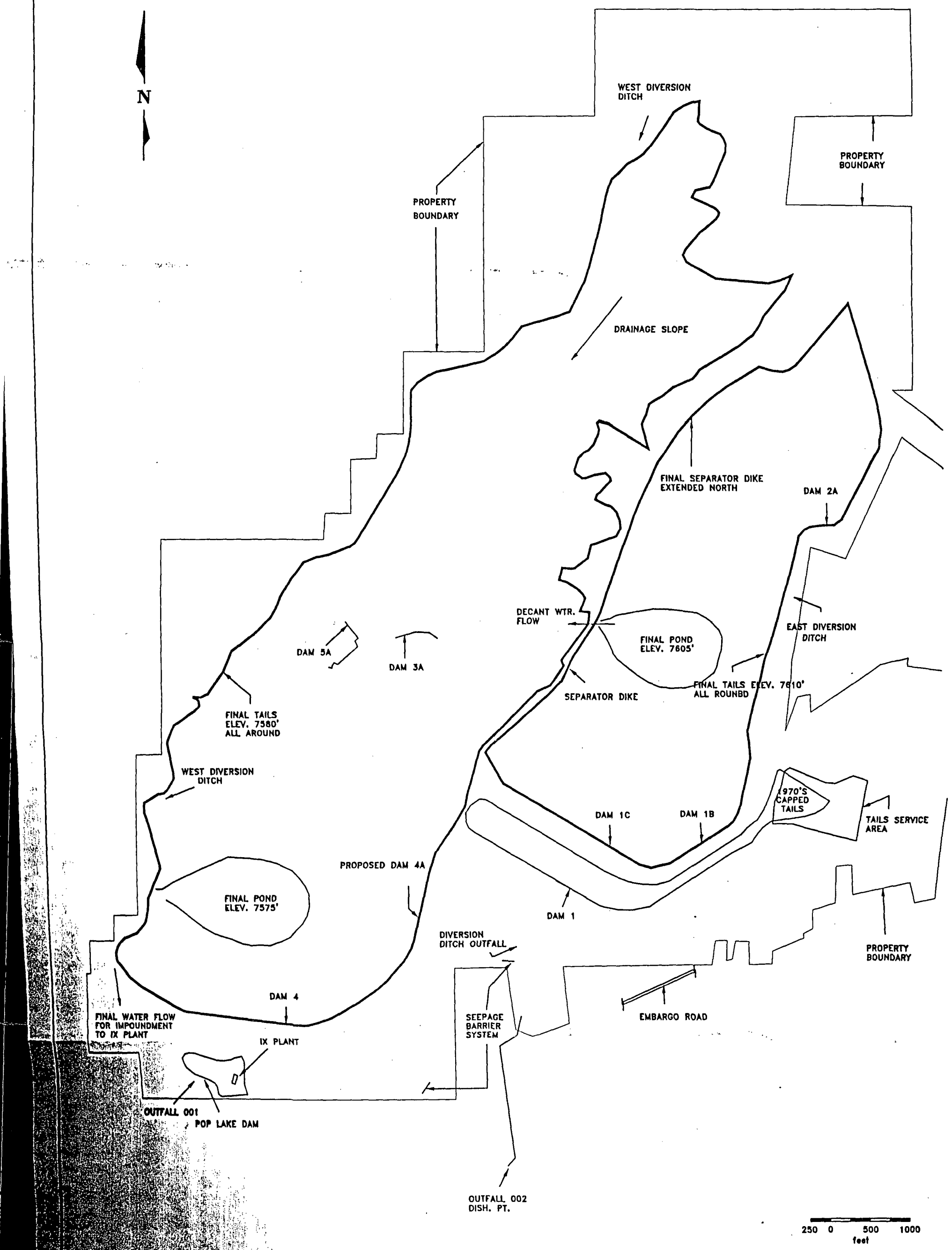
Molycorp, Inc. - New Mexico

Questa Tailings Study

Questa Tailings Facility
Location Map

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
036006	Oct. 1997	1"=6000'		2.1

ments\Questa\dwgs\location-map Tue Oct 21 16:29:25 1997



IN ASSOCIATION WITH:

SRK
STEFFEN ROBERTSON & KIRSTEN (U.S.)
Consulting Engineers & Scientists

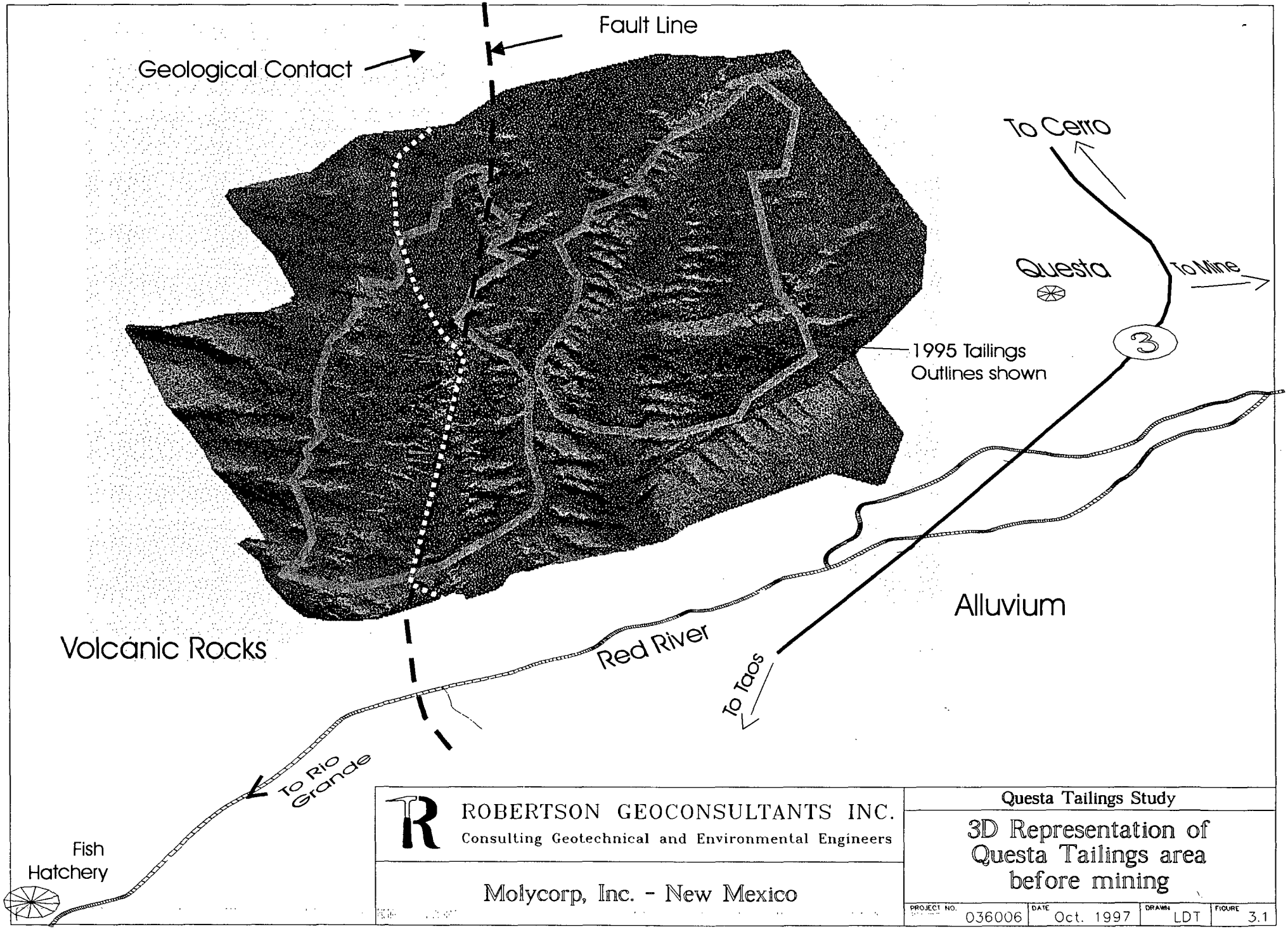
ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

Molycorp, Inc.

Questa Tailings Study

Questa Tailings Facility

PROJECT NO.	DATE	APPROVED
036006	Oct. 1997	



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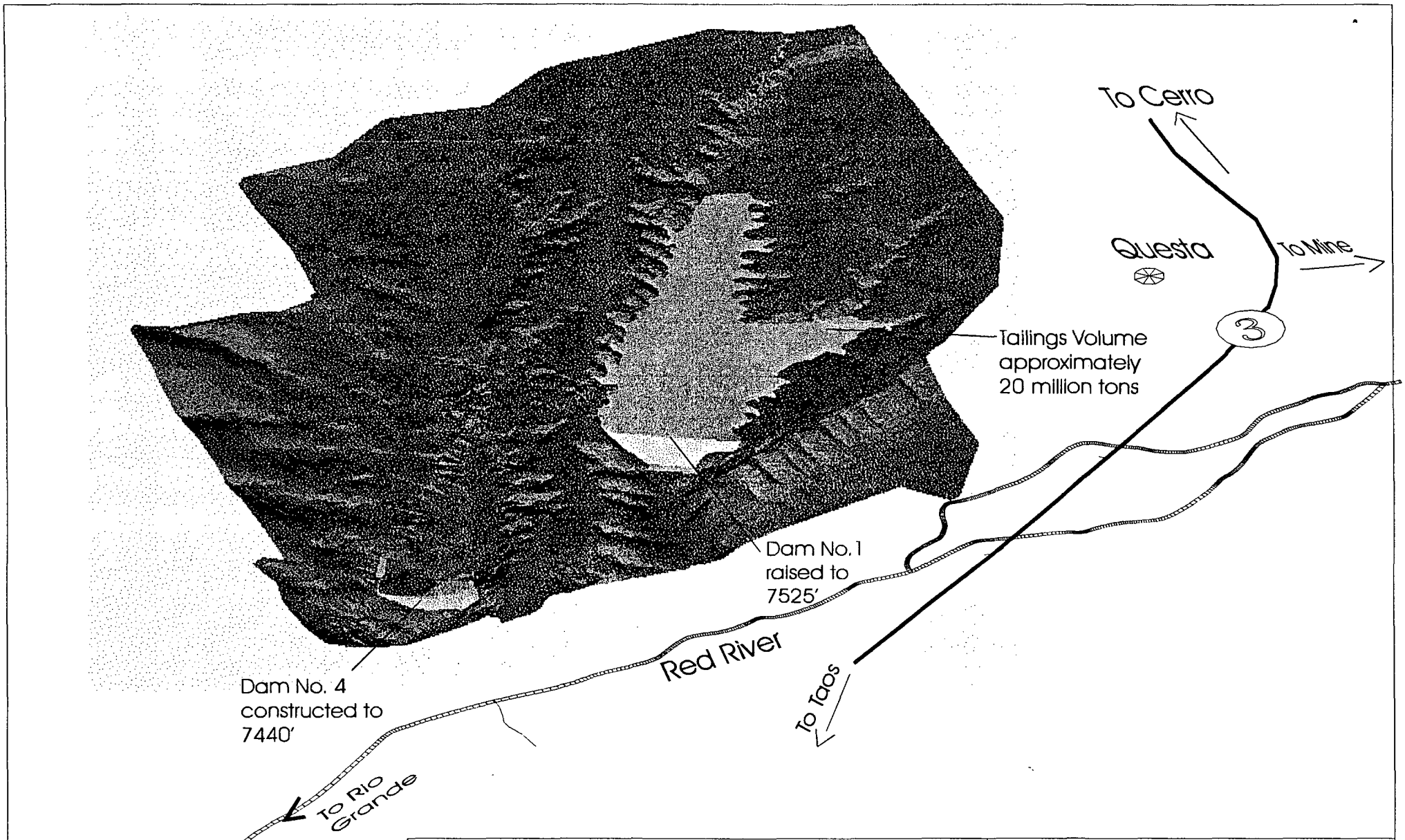
Questa Tailings Study

3D Representation of Questa Tailings area before mining

PROJECT NO.	DATE	DRAWN	FIGURE
036006	Oct. 1997	LDT	3.1



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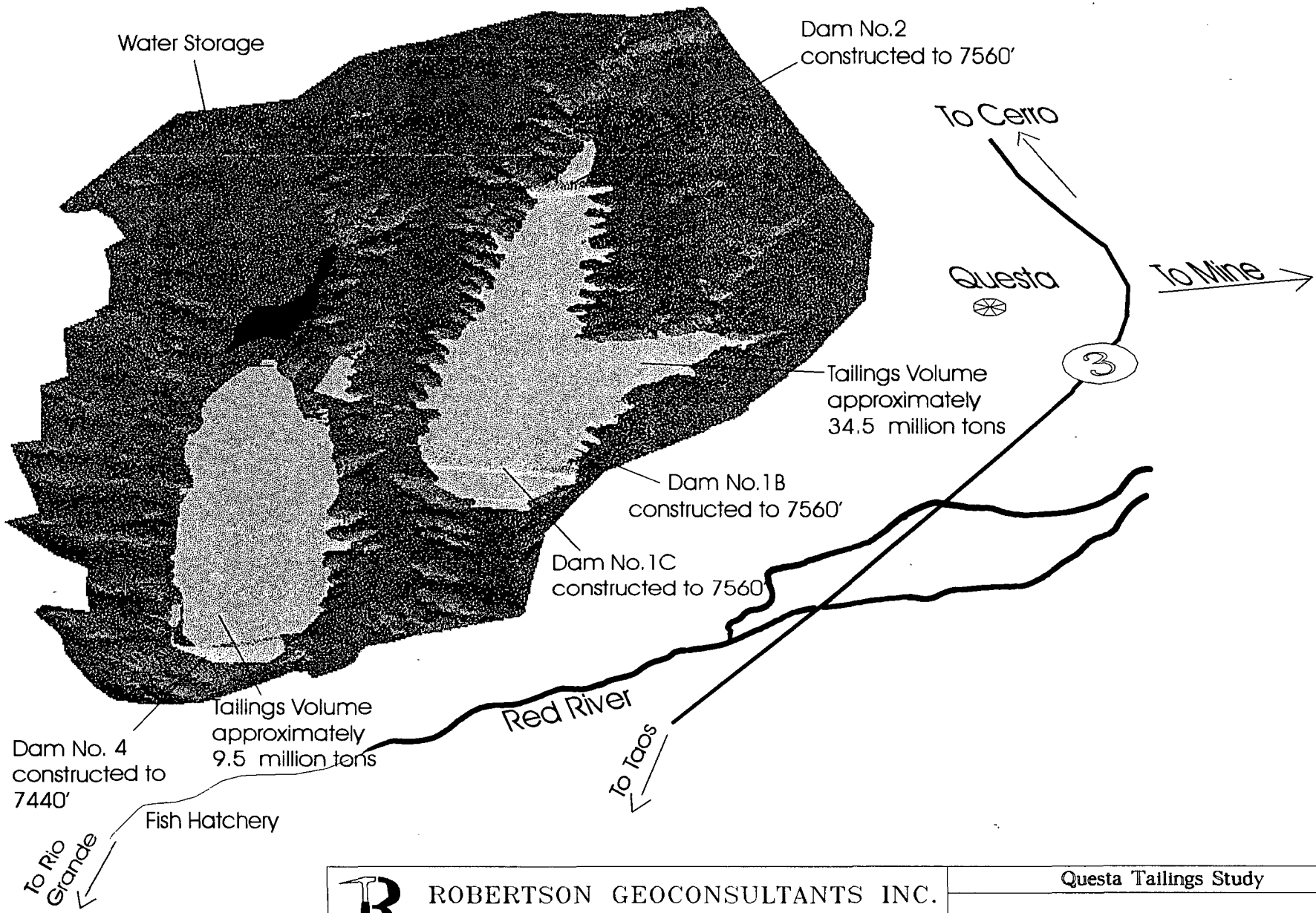
Questa Tailings Study

3D Representation of
Questa Tailings - 1971

PROJECT NO.	DATE	APPROVED	FIGURE
036006	Oct. 1997		3.2



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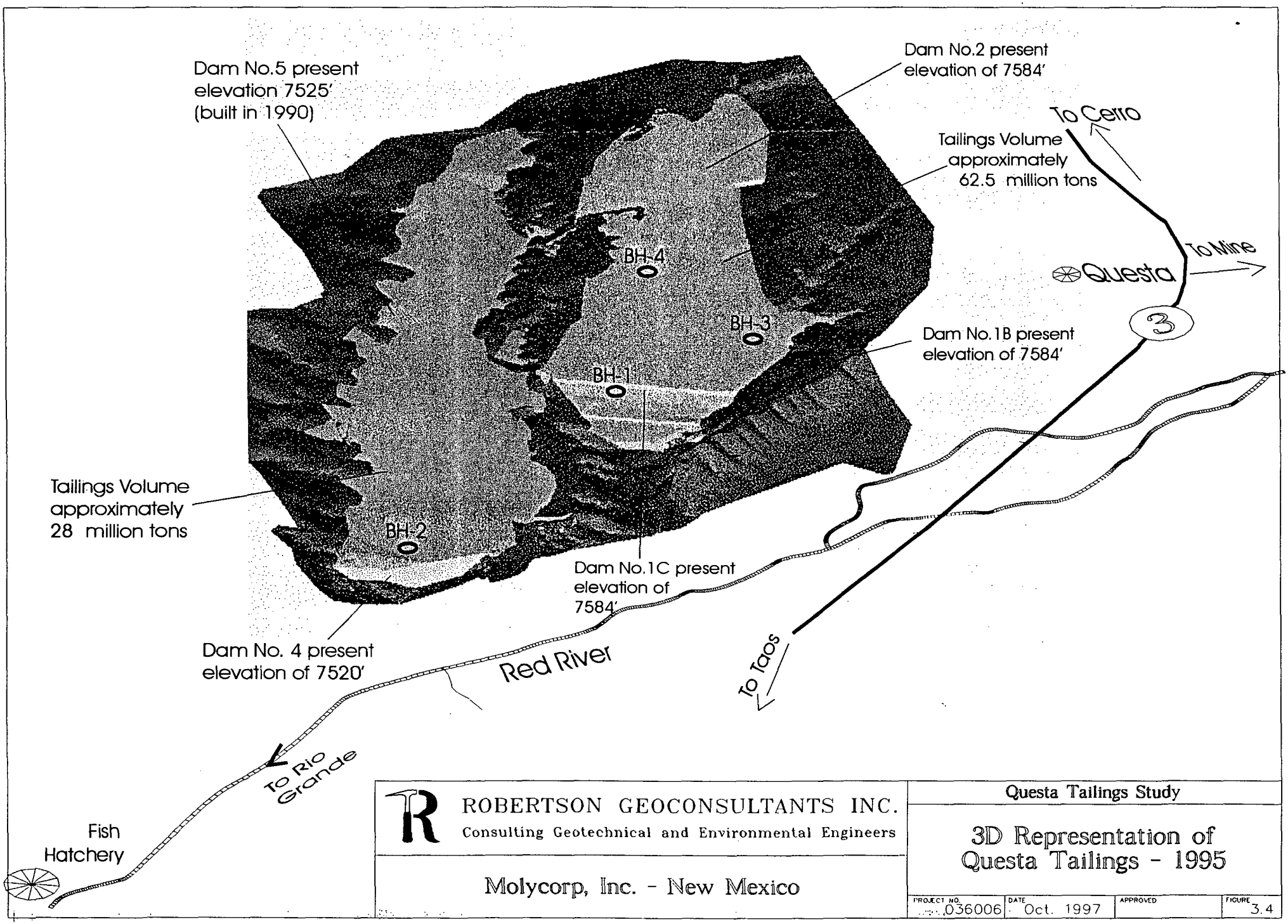
Questa Tailings Study

3D Representation of
Questa Tailings - 1975

PROJECT NO.	DATE	APPROVED	FIGURE
036006	Oct. 1997		3.3


Dam No.5 present elevation 7525' (built in 1990)
Dam No.2 present elevation of 7584'
To Cerro
Tailings Volume approximately 62.5 million tons
To Mine
Questa
3
BH-4
BH-3
BH-1
BH-2
Dam No.1B present elevation of 7584'
Tailings Volume approximately 28 million tons
Dam No.1C present elevation of 7584'
Dam No. 4 present elevation of 7520'
Red River
To Taos
To Rio Grande
Fish Hatchery
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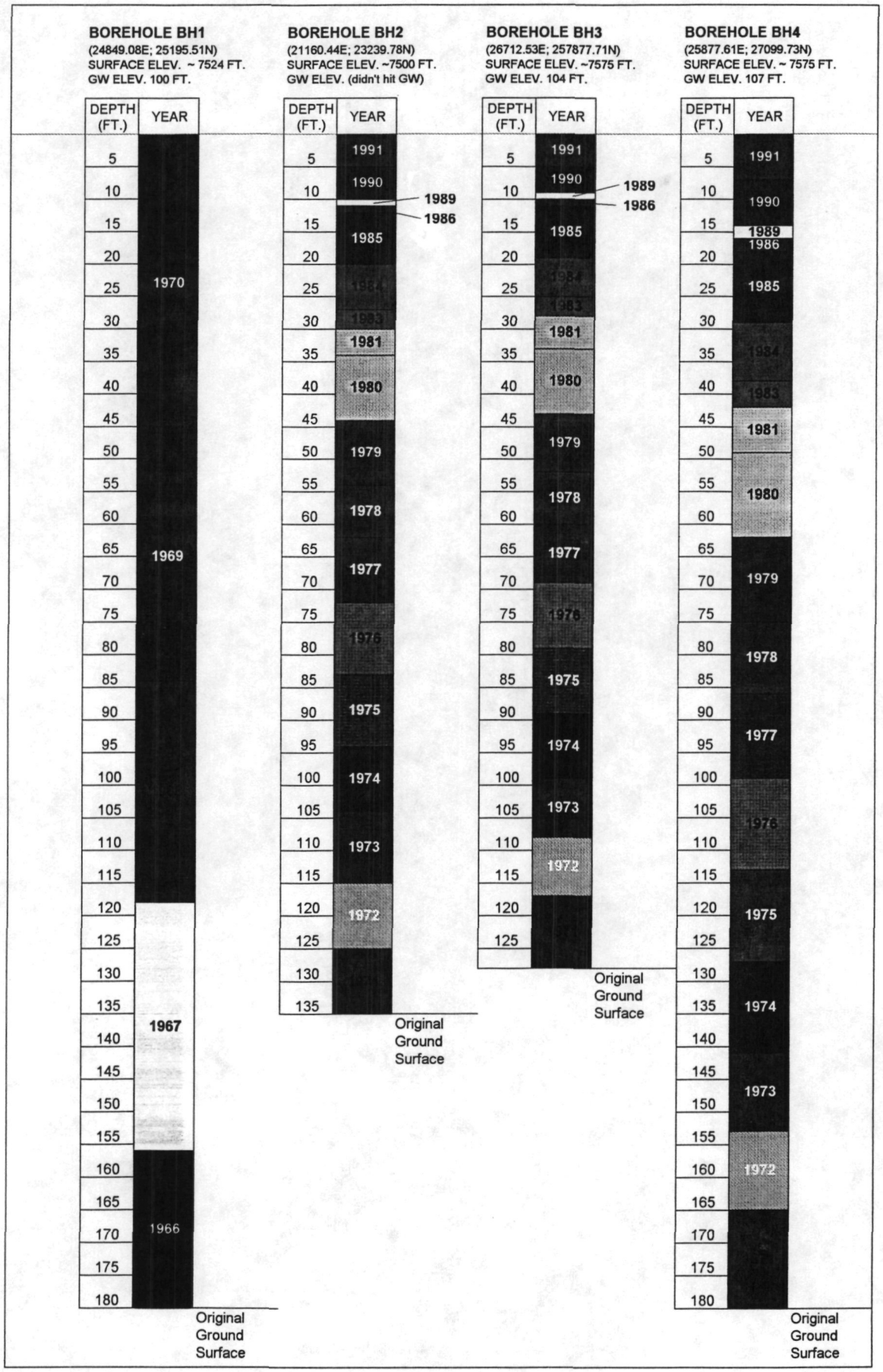
Questa Tailings Study
3D Representation of Questa Tailings - 1995
PROJECT NO. 036006
DATE Oct. 1997
APPROVED
FIGURE 3.4

Figure 3.5.
Borehole Cross Sections with Estimated Year of Deposition versus Depth.



APPENDIX A

BOREHOLE SAMPLE LOGS

BOREHOLE BH1
GROUNDWATER ELEV. 100 FT.

DATE 5/12/96
START 9am
END 11am (waited until 12 for water)

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
1	BH1-1		No Recovery				1970		
2	BH1-2						1970		
3	BH1-3						1970		
4	BH1-4						1970		
5	BH1-5						1970		
6	BH1-6						1970		
7	BH1-7						1970		
8	BH1-8						1970		
9	BH1-9						1970		
10	BH1-10	lt. grey	fine - grained aplite				1970		
11	BH1-11	lt. grey	fine - grained aplite; no visible sulfides (aplite contains small amount of orange colored minerals - possibly staining?)	Ap			1970	7.7	682
12	BH1-12	lt. grey	"	Ap			1970	7.9	406
13	BH1-13	lt. grey	"	Ap			1970	7.6	908
14	BH1-14	lt. grey	"	Ap			1970	7.7	497
15	BH1-15	lt. grey	"	Ap			1970	7.8	462
16	BH1-16	lt. grey	"	Ap			1970	7.6	513
17	BH1-17	lt. grey	"	Ap			1970	7.6	570
18	BH1-18	lt. grey	"	Ap			1970	7.8	473
19	No Sample	lt. grey		Ap			1970		
20	No Sample	lt. grey		Ap			1970		
21	BH1-21	lt. grey	Aplite - no visible sulfides; v. small recovery in SP - v. fine aplite sand - fallen out when raising spoon (?)	Ap	2/2/5		1970	7.8	502
22	BH1-22	lt. grey	"	Ap			1970	7.8	392
23	BH1-23	lt. grey	"	Ap			1970	7.9	434
24	BH1-24	lt. grey	"	Ap			1970	7.8	475
25	BH1-25	lt. grey	"	Ap			1970	7.8	396
26	BH1-26	lt. grey	+ approx. 10% clay	Ap		1% py	1970	7.9	448
27	BH1-27	lt. grey	"	Ap		1% py	1970	7.9	434
28	BH1-28	lt. grey	"	Ap		1% py	1970	7.5	419
29	BH1-29	lt. grey	"	Ap		1% py	1970	7.6	494
30	BH1-30	lt. grey	"	Ap		~2% py	1970	7.6	427
31	BH1-31	lt. grey	"	Ap			1970	7.7	383
32	BH1-32	lt. grey	"	Ap			1970	7.6	369
33	BH1-33	lt. grey	"	Ap			1970	7.5	414
34	BH1-34	lt. grey	"	Ap			1970	7.7	417
35	BH1-35	lt. grey	"	Ap			1970	7.7	397
36	BH1-36	lt. grey	<5% clay	Ap			1970	7.6	450
37	BH1-37	lt. grey	~10% clay	Ap			1970	7.6	525
38	BH1-38	lt. grey	~15% clay	Ap			1970	7.5	619
39	BH1-39	lt. grey	no clay	Ap			1970	7.7	459
40	BH1-40	lt. grey	no clay	Ap		some sulfides	1970	7.7	451
41	BH1-41	lt. grey	Aplite - w no visible sulfides	Ap			1970	7.7	436
42	BH1-42	lt. grey	v. little recovery on SP; few sulfides	Ap	5/7/13		1970	7.6	483
43	BH1-43	lt. grey	no clay	Ap		some sulfides	1970	7.8	415
44	BH1-44	lt. grey	no clay	Ap			1970	7.6	416
45	BH1-45	lt. grey		Ap			1970	7.6	450
46	BH1-46	lt. grey		Ap			1970	7.6	599
47	BH1-47	lt. grey	~10% clay	Ap		some sulfides	1969	7.6	417
48	BH1-48	lt. grey	no clay	Ap		1% py	1969	7.5	414
49	BH1-49	lt. grey	no clay	Ap		1% py	1969	7.6	460
50	BH1-50	lt. grey	no clay	Ap		1% py	1969	7.6	428

BOREHOLE BH1
GROUNDWATER ELEV. 100 FT.

DATE 5/12/96
START 9am
END 11am (waited until 12 for water)

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
51	BH1-51	lt. grey	no clay	Ap			1969	7.6	406
52	BH1-52	lt. grey	25% clay	Ap		1% py	1969	7.5	468
53	BH1-53	lt. grey	no clay	Ap		"	1969	7.6	565
54	BH1-54	lt. grey	no clay	Ap		"	1969	7.6	411
55	BH1-55	lt. grey	no clay	Ap		"	1969	7.5	550
56	BH1-56	lt. grey	~5% clay	Ap		"	1969	7.6	508
57	BH1-57	lt. grey	~5% clay	Ap		"	1969	7.6	521
58	BH1-58	lt. grey	~10% clay	Ap		- 1% sulfides	1969	7.9	393
59	BH1-59	lt. grey	~5% clay	Ap		- 2% sulfides	1969	7.6	463
60	BH1-60	lt. grey	~5% clay	Ap		- 1% sulfides	1969	7.6	453
61	BH1-61	lt. grey	aplite, no clay	Ap		≤ 1% sulfides	1969	7.6	344
62	BH1-62	lt. grey	"	Ap		"	1969	7.4	312
63	BH1-63	lt. grey	"	Ap		"	1969	7.4	269
64	BH1-64	lt. grey	"	Ap		"	1969	7.6	352
65	BH1-65	lt. grey	"	Ap		"	1969	7.5	376
66	BH1-66	lt. grey	"	Ap		"	1969	7.2	375
67	BH1-67	lt. grey	"	Ap		"	1969	7.3	441
68	BH1-68	lt. grey	"	Ap		"	1969	7.3	371
69	BH1-69	lt. grey	~10% clay	Ap		"	1969	7.2	299
70	BH1-70	lt. grey	~5% clay	Ap		"	1969	6.5	463
71	BH1-71	lt. grey	no clay	Ap		"	1969	7.3	467
72	BH1-72	lt. grey	~5% clay	Ap		"	1969	7.3	591
	BH1-72sp	lt. grey	~5% clay	Ap	no count	v. little sulfide	1969	7.5	407
73	BH1-73	lt. grey	<5% clay	Ap		"	1969	7.8	537
74	BH1-74	lt. grey	no clay	Ap			1969	7.6	446
75	BH1-75	lt. grey	no clay	Ap		"	1969	7.7	397
76	BH1-76	lt. grey	no clay	Ap		"	1969	7.6	465
77	BH1-77	lt. grey	<5% clay	Ap		"	1969	7.8	417
78	BH1-78	lt. grey	<5% clay	Ap		"	1969	7.7	478
79	BH1-79	lt. grey	no clay	Ap		"	1969	7.8	415
80	BH1-80	lt. grey	no clay	Ap		"	1969	7.7	402
81	BH1-81	light grey	<5% clay	Ap		few sulfide	1969	7.6	517
82	BH1-82	light grey	<5% clay, contains a cohesive piece of oxidized material	Ap		"	1969	7.8	381
83	BH1-83	light grey	- 20% clay	Ap		"	1969	7.5	508
84	BH1-84	light grey	- 20% clay	Ap		"	1969	7.3	558
85	BH1-85	light grey	- 30% clay	Ap		"	1968	7.7	645
86	BH1-86	light grey	- 30% clay	Ap		"	1968	7.6	600
87	BH1-87	light grey	- 30% clay	Ap		"	1968	7.7	531
88	BH1-88	light grey	<5% clay	Ap		"	1968	8	387
89	BH1-89	light grey	- 10% clay	Ap		"	1968	7.8	616
90	BH1-90	light grey	~5% clay	Ap		"	1968	8	427
91	BH1-91	light grey	~30% clay, contains more water (slightly darker)	Ap		"	1968	7.6	575
92	BH1-92	light grey	<5% clay	Ap		"	1968	7.7	585
	BH1-92SP	light grey	< 5% clay, more water	Ap	no count	"	1968	7.5	591
93	BH1-93	light grey	~30% clay, like 91	Ap		"	1968	7.8	640
94	BH1-94	light grey	~20% clay, "	Ap		"	1968	7.7	546
95	BH1-95	light grey	"	Ap		"	1968	7.3	531
96	BH1-96	light grey	"	Ap		"	1968	7.7	618
97	BH1-97	light grey	"	Ap		"	1968	7.8	576
98	BH1-98	light grey	"	Ap		"	1968	7.4	587
99	BH1-99	light grey	"	Ap		"	1968	7.4	620
100	BH1-100	light grey	much wetter, between 20 - 30% clay	Ap		"	1968	7.3	583

BOREHOLE BH1
GROUNDWATER ELEV. 100 FT.

DATE 5/12/96
START 9am
END 11am (waited until 12 for water)

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
101	BH1-101	light grey	"	Ap		"	1968	7.4	592
102	BH1-102	light grey	"	Ap		"	1968	7.2	632
103	BH1-103	light grey	"	Ap		"	1968	7.6	591
104	BH1-104	light grey	"	Ap		"	1968	7.6	596
105	BH1-105	light grey	a lot drier, more consolidated	Ap		"	1968	7.8	629
106	BH1-106	grey	salt and pepper, andesite, ~20% clay,	An		v. few sulfides	1968	7.6	584
107	BH1-107	"	"	An		-2% sulfide	1968	7.9	610
108	BH1-108	"	"	An		"	1968	7.7	633
109	BH1-109	"	"	An		"	1968	7.7	649
110	BH1-110	"	"	An		"	1968	7.8	628
111	BH1-111	"	"	An		"	1968	7.8	638
112	BH1-112	"	"	An		"	1968	7.8	659
	BH1-112SP		spoon is open a bit so count underestimates hardness - 2ft recovery - less water, ~5% clay, cohesive.	An	7/11/12	112SP - v. few sulfides	1968	7.6	519
113	BH1-113	grey	same as BH1-107 (~20% clay) - ande	An			1968	7.7	610
114	BH1-114	"	"	An			1968	7.8	607
115	BH1-115	"	"	An			1968	7.8	621
116	BH1-116	"	"	An			1968	7.8	683
117	BH1-117	"	"	An			1968	7.5	619
118	BH1-118	"	"	An			1968	7.5	590
119	BH1-119	"	"	An			1967	7.5	576
120	BH1-120	"	"	An			1967	7.5	592
121	BH1-121	grey	andesite (salt and pepper) w - 20% clay, v.few sulfides	An			1967	7.5	596
122	BH1-122		"	An			1967	7.5	632
123	BH1-123		same as above with ~50% clay	An			1967	7.5	702
124	BH1-124		"	An			1967	7.4	639
125	BH1-125		"	An			1967	7.4	680
126	BH1-126		"	An			1967	7.5	621
127	BH1-127		"	An			1967	7.4	664
128	BH1-128		"	An			1967	7.4	612
129	BH1-129		"	An			1967	7.5	621
130	BH1-130		"	An			1967	7.5	655
131	BH1-131		"	An			1967	7.5	647
132	BH1-132		"	An			1967	7.7	608
133	BH1-133		"	An			1967	7.6	610
134	BH1-134		same as above with ~70% clay	An			1967	7.5	632
135	BH1-135		same but drier; 50% clay; 10% FeOx s	An			1967	7.2	1619
136	BH1-136		same with more water; 50% clay	An			1967	7.5	652
137	BH1-137		"	An			1967	7.4	653
138	BH1-138		"	An			1967	7.5	605
139	BH1-139		same but less water; 50% clay	An			1967	7.4	615
140	BH1-140		same with more water; 50% clay	An			1967	7.4	610
141	BH1-141		"	An			1967	7.4	646
142	BH1-142		"	An			1967	7.4	650
143	BH1-143		"	An			1967	7.3	697
144	BH1-144		"	An			1967	7.4	676
145	BH1-145		"	An			1967	7.4	657
146	BH1-146		same; 30% clay	An			1967	7.4	734
147	BH1-147		"	An			1967	7.5	683
148	BH1-148		"	An			1967	7.5	724
149	BH1-149		same with 30% clay balls	An			1967	7.5	645
150	BH1-150		water samples taken were pH=8.5 TDS=1530ppm - 50% clay	An			1967	7.5	700

BOREHOLE BH1
GROUNDWATER ELEV. 100 FT.

DATE 5/12/96
START 9am
END 11am (waited until 12 for water)

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
151	BH1-151		"	An			1967	7.7	634
152	BH1-152		"	An			1967	7.6	663
153	BH1-153		"	An			1967	7.6	660
154	BH1-154		same with 20% clay	An			1966	7.5	660
155	BH1-155		same with, 20% clay; <5% FeOx staining on tails	An			1966	7.5	751
156	BH1-156		same with, 20% clay	An			1966	7.2	792
157	No Sample						1966		
158	BH1-158		same with, 20% clay	An			1966	7.2	749
159	No Sample						1966		
160	BH1-160		same with, 20% clay	An			1966	7.3	680
161	BH1-161		Andesite (salt/pepper) 20% clay; v. few sulfides	An			1966	7.4	665
162	BH1-162		same; 50% clay; Fe Ox staining on clay clumps	An			1966	7.2	1423
163	BH1-163		same, 20% clay; lots more dk. mineral	An		5%	1966	7.3	695
164	BH1-164		same, 20% clay	An		"	1966	7.4	683
165	BH1-165		same, 50% clay in clumps	An		"	1966	7.5	631
166	BH1-166		same, 20% clay	An		"	1966	7.5	646
167	BH1-167		"	An		"	1966	7.5	682
168	BH1-168		"	An		"	1966	7.5	696
169	BH1-169		"	An		"	1966	7.4	724
170	BH1-170		"	An		"	1966	7.4	727
171	BH1-171		"	An		"	1966	7.5	637
172	BH1-172		"	An		"	1966	7.6	616
173	BH1-173		Slimes - all clay	S		"	1966	7.6	693
174	BH1-174		", w 10% sand	S		"	1966	7.6	649
175	BH1-175		"	S		"	1966	7.7	615
176	BH1-176		"	S		"	1966	7.7	662
177	BH1-177		"	S		"	1966	7.7	646
178	BH1-178		"	S		"	1966	7.7	696
179	BH1-179		30% sand; and pebbles and cobbles of Sante Fe Congl.			"	1966	7.5	674
180	BH1-180		Foundation (Sante Fe Congl.) w. some tails.				1966	7.6	684
						AVERAGE		7.6	568
						STD. DEV.		0.2	156

Notes: buckets for collecting samples were cleaned out with snow between samples.

BOREHOLE BH2
GROUNDWATER ELEV. (didn't hit groundwater)

DATE 4/12/96
START 1:30 PM
END 3:35 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
1	No sample		No Recovery				1991		
2	No sample		"				1991		
3	No sample		"				1991		
4	No sample		"				1991		
5	No sample		"				1991		
6	No sample		"				1990		
7	No sample		"				1990		
8	No sample		"				1990		
9	No sample		"				1990		
10	No sample		"				1990		
11	No sample		"				1989		
12	BH2-12sp	brownish grey	mostly cover material - pebbles, sand and some tails		7/13/17		1986	7.5	228
13	No sample						1985		
14	No sample						1985		
15	BH2-15	brown-grey	fine sand more darker minerals than andesite in BH1	An		2% py	1985	7.1	1748
16	BH2-16	brown-grey	same as BH2-15	An			1985	7.2	1794
17	BH2-17	grey	andesite; salt and pepper, fine sand	An			1985	7.1	1076
18	BH2-18	grey	"	An			1985	7	1915
19	BH2-19	grey	"	An		py	1985	7	1887
20	BH2-20	grey	"	An		py	1985	7	1834
21	BH2-21	"	"	An			1984	6.9	2130
22	BH2-22	"	"	An			1984	6.9	2060
23	BH2-23	"	"	An			1984	6.9	1833
24	BH2-24	"	"	An			1984	7.1	1073
25	BH2-25	"	"	An			1984	7	1248
26	BH2-26	"	"	An			1984	7	1290
27	No sample	"	"	An			1984		
28	BH2-28	"	"	An			1983	7	1069
29	BH2-29	"	"	An			1983	7.1	945
30	BH2-30	"	"	An			1983	7.1	1071
31	BH2-31	"	"	An			1981	7.2	1247
32	BH2-32	"	"	An			1981	7.1	1585
33	BH2-33	"	"	An			1981	7.2	1945
34	BH2-34	"	"	An			1981	7.2	1023
35	BH2-35	"	"	An			1980	7.3	939
36	BH2-36	"	"	An			1980	7.1	1929
37	BH2-37	"	"	An			1980	7	2050
38	BH2-38	"	"	An			1980	7	1748
39	BH2-39	"	"	An			1980	7	2060
40	BH2-40	"	"	An			1980	7	1925
41	BH2-41	grey	andesite; salt and pepper, fine sand	An			1980	7	2210
42	BH2-42sp	grey (br. streaks)	highly consolidated, very fine sand, v. little clay, a bit more	An	2/5/9		1980	7.4	2050
	BH2-42	grey	andesite; salt and pepper, fine sand	An			1980	7.2	2000
43	BH2-43	grey	same	An			1980	7	2210
44	BH2-44	grey	same	An			1980	7.1	2030
45	BH2-45	grey	same as previous, except a lot more water	An			1979	7.1	2050
46	BH2-46	grey	"	An			1979	7.1	2050
47	No sample			An			1979		
48	No sample			An			1979		
49	BH2-49	grey	same as BH2-46	An			1979	7.2	2060
50	BH2-50	"	same as previous; except slightly more clay	An			1979	7.2	1974

BOREHOLE BH2
GROUNDWATER ELEV. (didn't hit groundwater)

DATE 4/12/96
START 1:30 PM
END 3:35 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
51	BH2-51	"	salt and pepper, fine sand, v. wet	An			1979	7.2	2020
52	BH2-52	"	"	An			1979	7	1997
53	BH2-53	"	"	An			1979	7.1	1864
54	No sample			An			1979		
55	No sample		"	An			1978		
56	No sample		"	An			1978		
57	No sample		"	An			1978		
58	BH2-58	grey	same salt and peppery, more water, small samples	An			1978	7.1	1468
59	BH2-59	"	"	An			1978	7.2	1345
60	BH2-60	"	"	An			1978	7.1	1804
61	BH2-61	"	"	An			1978	7	1998
62	BH2-62	"	"	An			1978	7	2090
63	No sample			An			1977		
64	BH2-64	grey	same salt and peppery, more water, small samples	An			1977	7.1	2100
65	No sample			An			1977		
66	BH2-66	grey	same salt and peppery, more water, small samples	An			1977	7.1	2050
67	BH2-67	"	"	An			1977	7.2	1644
68	BH2-68	"	"	An			1977	7.2	1964
69	No sample			An			1977		
70	BH2-70	grey	same salt and peppery, more water, small samples	An			1977	7.2	1460
71	BH2-70 to 75	grey	slimes, <5% iron oxide staining, some pieces of harder brown clay w some pebbles	S			1977	7.8	1094
72							1977		
73							1976		
74							1976		
75	BH2-75 to 80	"	"	S			1976	7.2	1777
76							1976		
77							1976		
78							1976		
79							1976		
80							1976		
81	BH2-80 to 85	grey	same	S			1976	7.6	1656
82	BH2-82SP	"	small recovery, clay slime, trace of red	S	2/2/5		1976	7.7	1745
83							1976		
84							1975		
85	BH2-85 to 90	"	"	S			1975	7.3	1788
86							1975		
87							1975		
88							1975		
89							1975		
90							1975		
91	BH2-90 to 95	"	"	S			1975	7.8	1600
92	BH2-92sp		recovery - whole 2 ft. same clayey, salt and peppered material	S			1975	7.8	1695
93							1975		
94							1975		
95	BH2-95 to 100	"	"	S			1974	7.0	1717
96							1974		
97							1974		
98							1974		
99							1974		
100							1974		

BOREHOLE BH2
GROUNDWATER ELEV. (didn't hit groundwater)

DATE 4/12/96
START 1:30 PM
END 3:35 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
101	BH2-100 to 105	"	same clay slimes, 4% iron oxide staining, cohesive balls, v. little sand	S			1974	7.0	1970
102							1974		
103							1974		
104							1974		
105	BH2-105 to 110	"	"	S			1973	7.1	1473
106		"	"				1973		
107		"	"				1973		
108		"	"				1973		
109		"	"				1973		
110		"	"				1973		
111	BH2-110 to 115	"	"	S			1973	8.0	821
112							1973		
113	BH2-112sp	"	"				1973		
114							1973		
115	BH2-115 to 120	"	"	S			1973	7.2	978
116							1972		
117							1972		
118							1972		
119							1972		
120							1972		
121	BH2-120 to 125	grey	"	S			1972		
122							1972		
123							1972		
124							1972		
125	BH2-125 to 130	"	same, (clay, cohesive)	S			1972	7.7	1570
126							1971		
127							1971		
128							1971		
129							1971		
130							1971		
131	BH2-130 to 135	d. reddish brown	sand to cobble sized fragments (subangular) foundation material				1971	7.6	357
132		"	"				1971		
133		"	"				1971		
134		"	"				1971		
135		"	"				1971		
						AVERAGE		7.2	1652
						STD. DEV.		0.2	455

BOREHOLE BH3
GROUNDWATER ELE 104 ft.

DATE 12/3/96
START 12:30 PM
END 2:00 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
1	No sample						1991		
2	No sample						1991		
3	BH3-3	m. brown	cover and tails; 10% pebbles (<1 in.) in sandy matrix				1991	7.6	636
4	BH3-4	grey	fine sand; bi, qtz. amph, k-spar	An			1991	7.3	827
5	BH3-5	grey	fine sand; biotite, qtz, amph, k-spar	An			1991	7.3	797
6	BH3-6	grey	same	An			1990	7.3	832
7	BH3-7	grey	same	An			1990	7.2	939
8	BH3-8	"	same except for a few (<<1%) med. balls of slimes.	An			1990	7.5	679
9	BH3-9	"	"	An			1990		
10	BH3-10	"		An			1990	7.4	698
	BH3-10sp	"	SP has much more clay and water.	An	3/3/03		1989	7.1	486
11	BH3-11	grey	same with ~40% clay balls (slimes)	An			1986	7.5	809
12	BH3-12	"	same w lots of pebbles (1-3in); no slime	An			1985	7.5	1002
13	BH3-13	"	"	An			1985	7.5	605
14	BH3-14	"	almost all grey sand	An			1985	7.5	555
15	BH3-15	"	same; few slimes	An			1985	7.4	756
16	BH3-16	"	same w ~5% clay	An			1985	7.3	946
17	BH3-17	"	"	An			1985	7.3	938
18	BH3-18	"	no clay; all sand	An			1985	7.3	831
19	No sample	"		An			1985		
20	BH3-20	"	<5% clay	An			1984	7.4	757
21	BH3-21	"	same fine sand but w 20% slime	An			1984	7.4	739
22	BH3-22	"	<5% clay	An			1984	7.4	638
23	BH3-23	"	"	An			1984	7.4	586
24	BH3-24	"	"	An			1984	7.3	614
25	BH3-25	lt grey	aplite	Ap			1984	7.3	537
26	BH3-26	"	"	Ap			1983	7.3	660
27	No sample	"	"	Ap			1983	7.2	628
28	BH3-28	"	"	Ap			1983	7.3	541
29	BH3-29	"	"	Ap			1981	7.3	508
30	BH3-30	"	"	Ap		~2%	1981	7.4	486
31	BH3-31	grey		An			1981	7.1	1825
	BH3-31sp	"	only ~8in rec in SP; Andesite; sulfides	An	3/4/06	<1%		7.6	494
32	BH3-32	"	"	An			1981	7.0	2130
33	BH3-33	"	"	An			1981	7.0	1988
34	BH3-34	"	"	An			1980	7.1	1535
35	BH3-35	"	"	An		<1%	1980	7.0	1892
36	BH3-36	"	"	An			1980	7.0	1840
37	BH3-37	"	"	An			1980	7.0	2020
38	BH3-38	"	"	An			1980	7.1	2020
39	BH3-39	"	"	An			1980	7.1	1980
40	BH3-40	"	"	An			1980	7.1	2100
41	BH3-41	grey salt/pepper	same fine sand	An			1980	7.1	1883
42	BH3-42	"	"	An			1980	7.1	1525
43	BH3-43	"	"	An			1980	7.2	1522
44	BH3-44	"	"	An			1979	7.0	1669
45	BH3-45	"	"	An			1979	7.2	1192
46	BH3-46	"	same with few clay balls	An			1979	7.2	900
47	BH3-47	"	"	An			1979	7.2	1066
48	BH3-48	"	"	An			1979	7.2	1147
49	BH3-49	"	"	An			1979	7.1	1736
50	BH3-50	"	"	An			1979	7.1	1365

BOREHOLE BH3
GROUNDWATER ELE 104 ft.

DATE 12/3/96
START 12:30 PM
END 2:00 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
51	BH3-51	"	"	An			1979	7.1	1256
52	BH3-52	"	same but slightly more siliceous	An		<2%	1979	7.1	1112
53	BH3-53	"	"	An			1978	7.2	911
54	BH3-54	"	"	An			1978	7.0	2040
55	BH3-55	"	"	An			1978	7.2	1567
56	BH3-56	"	"	An			1978	7.1	1420
57	BH3-57	"	"	An			1978	7.2	837
58	BH3-58	"	"	An			1978	7.3	759
59	BH3-59	"	"	An			1978	7.3	845
60	BH3-60	"	"	An			1978	7.1	1556
61	BH3-61	"	"	An			1977	7.1	1637
62	BH3-62	"	"	An			1977	7.1	1413
63	BH3-63	"	"	An			1977	7.1	1209
64	BH3-64	"	"	An			1977	7.1	1202
65	BH3-65	lt. grey	aplite	Ap			1977	7.2	973
66	BH3-66	"	"	Ap			1977	7.2	812
67	BH3-67	"	"	Ap			1977	7.1	1073
68	BH3-68	"	"	Ap			1977	7.2	658
69	BH3-69	"	~2% clay balls w light FeOx rims	Ap		<2%	1977	7.3	843
70	BH3-70	"	"	Ap		<2%	1976	7.2	722
71	BH3-71	"	"	Ap			1976	7.4	648
72	BH3-72	"	"	Ap			1976	7.4	795
73	BH3-73	"	+~5% clay balls	Ap			1976	7.4	897
74	BH3-74	"	"	Ap			1976	7.2	1907
75	BH3-75	"	"	Ap			1976	7.1	2070
76	BH3-76	"	"	Ap			1976	7.1	2130
77	BH3-77	"	"	Ap			1976	7.2	1550
78	BH3-78	"	"	Ap			1976	7.1	1451
79	BH3-79	"	"	Ap			1976	7.0	1832
80	BH3-80	"	"	Ap			1975	7.0	1815
81	BH3-81	lt. grey	aplite (no clay)	Ap			1975	7.1	1109
82	BH3-82	"	"	Ap			1975	7.2	658
83	BH3-83	"	"	Ap			1975	7.3	708
84	BH3-84	"	"	Ap			1975	7.2	1064
85	BH3-85	"	"	Ap			1975	7.4	517
86	BH3-86	"	"	Ap			1975	7.3	459
87	BH3-87	"	"	Ap			1975	7.3	561
88	BH3-88	"	"	Ap			1975	7.3	637
89	BH3-89	"	"	Ap			1975	7.3	526
90	BH3-90	"	"	Ap			1974	7.2	605
91	BH3-91	"	"	Ap			1974	7.4	609
	BH3-91SP	"	4" of tails in sp - medi of clay (50%) in both samples	Ap	4/8/11		1974	8.0	506
92	BH3-92	"	moderate amount of clay	Ap			1974	7.5	632
93	BH3-93	"	no clay	Ap			1974	7.5	614
94	BH3-94	"	"	Ap			1974	7.3	586
95	BH3-95	"	"	Ap			1974	7.2	570
96	BH3-96	"	"	Ap			1974	7.1	597
97	BH3-97	"	"	Ap			1974	7.2	499
98	BH3-98	"	"	Ap			1974	7.0	693
99	BH3-99	"	"	Ap			1974	7.1	803
100	BH3-100	"	"	Ap			1973	7.2	548

BOREHOLE BH3
GROUNDWATER ELE 104 ft.

DATE 12/3/96
START 12:30 PM
END 2:00 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
101	BH3-101	"	"	Ap			1973	7.2	633
102	BH3-102	"	samples wet - vadose zone?	Ap			1973	7.1	769
103	BH3-103	"	"	Ap			1973	7.1	859
104	BH3-104	"	water table, 40% clay	Ap			1973	7.1	871
105	BH3-105	"	"	Ap			1973	7.1	818
106	BH3-106	"	little clay	Ap			1973	7.1	776
107	No sample			Ap			1973		
108	BH3-108	lt. grey	little clay	Ap			1973	7.2	741
109	BH3-109	"	~25% clay	Ap			1972	7.2	724
110	BH3-110	"	little clay	Ap			1972	7.2	774
111	BH3-111	"	"	Ap			1972	7.2	757
112	BH3-112	"	"	Ap			1972	7.2	801
113	BH3-113	"	"	Ap			1972	7.2	788
114	BH3-114	"	"	Ap			1972	7.2	797
115	BH3-115	"	~25% clay	Ap			1972	7.2	893
116	BH3-116	"	"	Ap			1972	7.2	893
117	BH3-117	"	"	Ap			1972	7.2	879
118	BH3-118	"	"	Ap			1971	7.2	810
119	BH3-119	"	"	Ap			1971	7.2	773
120	No sample			Ap			1971		
121	BH3-121	lt grey	aplite - 25% clay	Ap			1971	7.2	771
122	BH3-122	"		Ap			1971	7.2	822
123	BH3-123	"		Ap			1971	7.2	793
124	BH3-124	"		Ap			1971	7.2	851
125	BH3-125	"		Ap			1971	7.2	848
126	No sample	"					1971		
127	No sample	"	sludge gunk				1971		
128	No sample	"	foundation				1971		
						AVERAGE		7.2	1006
						STD. DEV.		0.2	474

BOREHOLE BH4
GROUNDWATER ELEV. 107 ft

DATE 5/12/96
START 4:30 PM
END 6:30 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
	No sample						1991		
2	No sample						1991		
3	BH4-3	lt grey	fine grained sand; 20% clay, siliceous but not aplite	Ap		2%	1991	7.2	1714
4	BH4-4	"	fine grained sand; no clay	Ap		2-3%	1991	7.2	1391
5	BH4-5	"	same	Ap		"	1991	7.2	1370
6	BH4-6	"	same but w 30% clay; lots of bi	Ap		"	1991	7.2	1169
7	BH4-7	"	same	Ap		"	1991	7.2	1150
8	BH4-8	"	mostly clay; wetter sample	Ap		"	1990	7.2	843
9	BH4-9	"	same w sl. more water	Ap		"	1990	7.5	835
10	BH4-10	"	same	Ap		"	1990	7.5	727
11	BH4-11	"	slimes	S			1990	7.5	779
12	No sample		slimes				1990		
	BH4-12sp	lt. grey	mostly slimes w 10% sand clumps; lots of bi and py	S	1/1/1	2	1990	7.7	368
13	No sample		no recovery				1990		
14	No sample		"				1990		
15	No sample		"				1989		
16	No sample		"				1989		
17	No sample		"				1986		
18	No sample		"				1986		
19	No sample		"				1985		
20	BH4-20 to 27 (bulk)	grey	bulk sample not able to get individual samples; slime with ~1% Fe ox. staining	S			1985	8.0	443
21		"	"				1985		
22		"	"				1985		
23		"	"				1985		
24		"	"				1985		
25		"	"				1985		
26		"	"				1985		
27		"	"				1985		
28	No sample						1985		
29	No sample						1985		
30	BH4-30	grey	slimes (wet)	S			1984	7.6	513
31	BH4-31	"	slimes w 10% sand	S			1984	7.5	631
32	BH4-32	"	slime w 10% sand; more water	S			1984	7.5	611
33	BH4-33	"	same; more water	S			1984	7.5	568
34	BH4-34	"	"	S			1984	7.2	1704
35	BH4-35	"	slime w 5 % sand	S			1984	7.2	1745
36	BH4-36	"	"	S			1984	7.2	1625
37	BH4-37	"	"	S			1984	7.0	1626
38	BH4-38	"	"				1984		
39	No sample	"	"				1983		
40	No sample	"	"				1983		
41	BH4-40 to 45	grey	slime; v. little sand	S			1983	7.3	1512
42							1983		
43							1981		
44							1981		
45	BH4-45 to 50	grey	slime; no sand; more water	S			1981	7.3	1610
46							1981		
47							1981		
48							1981		
49							1981		
50							1980		

BOREHOLE BH4
GROUNDWATER ELEV. 107 ft

DATE 5/12/96
START 4:30 PM
END 6:30 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
51	BH4-50 to 55	grey	same	S			1980	7.9	1437
52							1980		
53							1980		
54							1980		
55	BH4-55 to 60	grey	same; has 1 1/2in. clump of brown clay with lots of mica	S			1980	7.2	1422
56							1980		
57							1980		
58							1980		
59							1980		
60							1980		
61	BH4-60 to 65	grey	slime w little water or sand	S			1980	7.8	1354
62	BH4-62sp	grey	clay slime w 20% sand, lots of bl, no py. high in silica	S	4/5/9		1980	8.1	830
63							1979		
64							1979		
65	BH4-65 to 70	grey	slime with 20% fine sand	S			1979	7.0	1556
66							1979		
67							1979		
68							1979		
69							1979		
70							1979		
71	BH4-70 to 75	grey	slimes with 10% sand	S			1979	7.9	1683
72							1979		
73							1979		
74							1979		
75	BH4-75 to 80	"	slime with 20% sand; very dry and cohesive	S			1979	7.2	1315
76							1978		
77							1978		
78							1978		
79							1978		
80							1978		
81	BH4-80 to 85	grey	slime w 5% sand and 1 twig	S			1978	7.0	1772
82							1978		
83							1978		
84							1978		
85	BH4-85 to 90	grey	slime w 30% sand	S			1978	7.0	1869
86							1978		
87							1977		
88							1977		
89							1977		
90							1977		
91	BH4-90 to 95	grey	slime w no sand (goopy)	S			1977	7.9	977
92	BH4-92sp	lt grey to grey	slimes w v. little sand	S	2/5/08	2	1977	8.2	641
93							1977		
94							1977		
95	BH4-95 to 100	grey	slime w 10 % sand	S			1977	7.1	1295
96							1977		
97							1977		
98							1977		
99							1977		
100							1976		

BOREHOLE BH4
GROUNDWATER ELEV. 107 ft

DATE 5/12/96
START 4:30 PM
END 6:30 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
101	BH4-100 to 105	grey	slimes with 10% sand; lots of water	S			1976	7.2	936
102							1976		
103							1976		
104							1976		
105	BH4-105 to 110	grey	same	S			1976	7.4	739
106							1976		
107							1976		
108							1976		
109							1976		
110							1976		
111	BH4-110 to 120	grey	salt and pepper texture; andesite approx. 30% clay	An			1976	8.2	534
112							1976		
113							1976		
114							1975		
115							1975		
116							1975		
117							1975		
118							1975		
119							1975		
120							1975		
121	BH4-120 to 125	grey	approx. 40% clay, salt and pepper	An			1975	8.0	465
122	BH4-122sp	grey	spoon split so count is not accurate, fine andesite sand no clay	An	5/8/12		1975	8.2	534
123							1975		
124							1975		
125	BH4-125 to 130	grey	salt and pepper, approx. 20% clay, lots of water	An			1975	7.5	577
126							1975		
127							1975		
128							1974		
129							1974		
130							1974		
131	BH4-130 to 135	grey	salt and pepper, approx. 50% clay	An			1974	7.6	521
132	BH4-132	"	"				1974		
133	BH4-133	"	"				1974		
134	BH4-134	"	"				1974		
135	BH4-135 to 140	grey	salt and pepper; approx 70% clay, less water	An			1974	7.6	479
136							1974		
137							1974		
138							1974		
139							1974		
140							1974		
141	BH4-140 to 145	grey	salt and pepper, 50% clay; lots of water	An			1974	7.6	456
142							1973		
143							1973		
144							1973		
145	BH4-145 to 150	grey	salt and pepper, 50 % clay	An			1973	7.5	430
146							1973		
147							1973		
148							1973		
149							1973		
150							1973		

BOREHOLE BH4
GROUNDWATER ELEV. 107 ft

DATE 5/12/96
START 4:30 PM
END 6:30 PM

DEPTH FT.	SAMPLE NO.	COLOR	DESCRIPTION	TAILINGS TYPE	SP	SULFIDE (%)	YEAR	pH	COND. µS
151	BH4-150 to 155	"	"	An			1973	7.4	429
152							1973		
153							1973		
154							1972		
155	BH4-155 to 160	"	"	An			1972	7.4	473
156							1972		
157							1972		
158							1972		
159							1972		
160							1972		
161	BH4-160 to 165	grey	salt and pepper, 50 % clay	An			1972	7.3	602
162							1972		
163							1972		
164							1972		
165	BH4-165 to 170	"	more sand	An			1972	7.4	507
166							1971		
167							1971		
168							1971		
169							1971		
170							1971		
171	BH4-170 to 175	"	"	An			1971	7.2	1103
172							1971		
173							1971		
174							1971		
175	BH4-175 to 180	"	more sand; include some bedrock material	An			1971	7.2	1068
176							1971		
177							1971		
178							1971		
179							1971		
180							1971		
						AVERAGE		7.5	1000
						STD. DEV.		0.3	478

DM22304

QUESTA TAILINGS FACILITY
GEOCHEMICAL TESTING

FINAL REPORT

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November 4, 1997
SRK Report No. 09211/2

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EXECUTIVE SUMMARY

Objectives

An investigation program has been completed to geochemically characterize the tailings contained in the Questa Mine Tailings Management Facility (TMF). The field work performed for sample collection and selection is described in SRK Report No. 09208.04/2 dated January, 1997. This investigation was required to satisfy part of the data needs for the development of a closure plan for the tailings facility in terms of Molycorp Inc.'s Discharge Plan 933. The investigation included assessments of the:

- mineralogy;
- total metals concentrations;
- prevailing geochemical conditions in the TMF;
- potential for future acid generating; and,
- rates of sulfide mineral oxidation.

Baseline characterization of the tailings was completed using field pH and conductivity tests, standard laboratory static tests, and laboratory leach extraction methods. Further kinetic characterization consisting of enhanced peroxide oxidation tests and humidity cell tests were completed on samples identified during baseline testing as uncertain with respect to acid generation potential, or samples that represented the worst case scenario for acid generation potential within the Questa tailings facility. The USGS geochemical speciation model, MINTEQA2, was used to determine if secondary mineral phases are controlling the solubility of metals in either the leach extraction or humidity cell tests.

Field Tests and Results

All surface and near surface tailings samples had been exposed to oxidizing conditions in the field for periods from 6 to more than 25 years. Field tests on these tailings provide an excellent indication of the long term performance of the tailings. Field observations consisting of paste pH and conductivity measurements indicated that net acid generation is not occurring within the TMF, since all paste pH values were circum neutral to slightly alkaline. Elevated paste conductivities, however, indicate that ongoing oxidation is occurring in the exposed tailings and beneath the present cover. The leach extraction tests confirmed the field observations showing elevated extractable sulfate concentrations.

Static Tests and Results

Acid base accounting test results indicate that, overall, the tailings contained in the TMF are acid consuming. Of the 43 samples tested, 6% are considered potentially acid generating, 80% are considered acid consuming, and 14% fall within the uncertain or "grey" area with NP:AP values between 1.0 and 1.5. The tailings exhibited a mean NP/AP ratio of 2.5, indicating a large overall excess of neutralization potential over acid generating potential.

Kinetic Tests and Results

Enhanced peroxide oxidation tests were performed on select samples of tailings falling in the "grey" area of static testing interpretation (NP:AP ratios between 0.42 and 1.67). Only one of five samples from this "grey" area was potentially acid generating with low capacity, one of the samples remained in the "grey" area and three of the samples are considered acid consuming. This indicates that most of the samples in the "grey" area are acid consuming and that any potential acidity would be of "low capacity".

Accelerated oxidation of the tailings in the humidity cell tests (NP:AP ratios between 0.42 and 4.20) confirmed that the tailings are not likely to become net acid generating. The overall rate of oxidation of the sulfides in the tailings was found to be similar to, or lower than, that reported in the literature for sulfidic tailings. The results also indicate that of the trace metal sulfides, molybdenite is being oxidized preferentially.

Conclusions

The distribution of the ABA results, together with the kinetic behavior of the tailings, suggest that there may be rare, localized thin layers of tailings which, in isolation, could be potentially acid generating. However, the potential for acid generation in such localized layers is low. Any acidic leachate, should it develop in such a localized thin layer, would be neutralized by the excess neutralization potential in underlying layers through which seepage would migrate.

The results from this investigation can be used to complete long-term water quality prediction for ground and surface water discharge from the TMF, following the completion of tailings deposition and implementation of the closure plan measures.

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GROUND WATER

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1.0 INTRODUCTION

1.1 Terms of Reference

In order to develop a closure program for the existing tailings facility at the Questa Mine in New Mexico, Molycorp Inc. (Molycorp) has been conducting geochemical investigations of the facility since 1995. Molycorp retained Steffen Robertson and Kirsten (U.S.) Inc. (SRK) and Robertson GeoConsultants Inc. (RGI) to complete this investigation. This report presents the final results of the geochemical characterization of the facility, and has been prepared to satisfy, in part, the requirements of report submission to the New Mexico Environmental Department under Discharge Plan 933.

A hydrological investigation of the effectiveness of the engineered soil cover is being completed in conjunction with the geochemical investigation. The purpose of these investigations is to predict the short- and long-term drainage quality from the facility. In addition, a geometrical model of the tailings facility is being developed to illustrate geochemical and physical changes, if any, within the facility. Results of the hydrological investigation and the geometric modeling will be presented in separate reports.

The geochemical characterization of the tailings included static and kinetic testing. Initial results of static tests were presented in SRK Report 09211/1, "Questa Tailings Disposal Facility, Geochemical Testing, Interim Report" (June 30, 1997). Since the submission of the interim report, additional static testing has been undertaken. The results of all the static testing and subsequent kinetic testing are summarized herein.

1.2 Background

Tailings have been deposited in the Questa tailings impoundment since open pit mining began in 1965. The open pit mine was active until 1983 after which mining activities progressed underground. The underground operation has remained active since 1983 until the present time, with intermittent closures in 1982, from 1987 to 1988, and from 1992 to 1996.

There are three main areas in the tailings facility as shown in Figure 1.1. Initially, tailings were deposited behind Dam 1 in Section 36. After 1971, as the facility was expanded, tailings were also placed behind Dam 4 in Section 35. Tailings are

currently being placed behind Dam 5A, also in Section 35. In excess of 96,000,000 tons of tailings have been deposited in the facility, and it covers an area of approximately 550 acres. A one foot soil cover was placed on the existing facility after mining ceased in 1992. The cover is composed of unsorted alluvial material that is predominantly clayey gravel taken from the site and was compacted by truck traffic.

1.3 Field Observations

Different ore zones have been mined at Questa, which has resulted in different tailings types or "zones" within the tailings facility. Ore has been mined predominantly from either andesite or aplite host rocks. The mineralogy of the two rock types is somewhat similar except that the andesites have a lower silicate content and higher concentration of mafic (dark) minerals. The andesites at Questa also have a slightly higher sulfide content than the aplites. These mineralogical differences are reflected in the tailings and formed the basis for tailings identification in the field and subsequent classifications used during the geochemical testing program. It is however recognized that individual samples may be mixtures of aplite and andesite derived tailings.

Tailings can also be differentiated based on grain size (e.g. sands versus slimes). However, since most of the tailings are produced from mixtures of aplite and andesite ore, a classification based on the relative abundance of minerals characteristic of each rock type is more descriptive of the tailings themselves.

The fine-grained character of tailings combined with the fact that they are deposited in a slurry generally limits oxidation to surficial exposures. At Questa, tailings currently on the surface of the older sections of the facility have been exposed to the atmosphere longest. The effects of longer-term oxidation on the tailings can, therefore, best be judged from geochemical changes affected in these tailings. A small section of the surface tailings located on the bench between Dam 1 and Dam 1C (Figure 1.1) was deposited approximately 27 years ago and represents tailings produced during the open pit operations. The majority of the current day surface tailings were produced from the underground workings and have been exposed for approximately 6 years.

Based on field observations, only the older surficial tailings show some very localized (indeed rare) evidence of iron staining resulting from oxidation, and this oxidation has had no visible impact on the tailings or the composition of the tailings pore water. The remainder of the tailings have remained grey at the surface, suggesting no significant

oxidation has occurred over the past 6 years of exposure. This was confirmed by the near neutral paste pH results that were obtained from tailings samples taken from surface.

1.4 Objectives

Based on the above observations and results reported in SRK Report Number 09208.04 "Questa Tailings Disposal Facility Assessment of Acid Generating Potential" (SRK, 1996), a more extensive geochemical testing program was undertaken. The objectives of the program were to:

- Characterize the current state of weathering of the tailings throughout the facility;
- Determine the overall potential for acid generation or acid neutralization of the tailings;
- Assess the potential for localized zones with net acid generating characteristics;
- Estimate rates of oxidation reactions in the tailings;
- Identify potentially soluble constituents that may be present in the tailings or may be generated from oxidation; and,
- Identify possible solubility controlling mineral phases that may control constituent concentrations in the tailings pore water.

These issues have been addressed through a conventional static and kinetic testing program adopted for the Questa site. The program was completed in two phases.

2.0 SAMPLING AND TESTING METHODS

2.1 Sample Collection and Handling

A summary of the samples collected from the tailings impoundment, date collected and method of collection, is provided in Table 2.1.

In February 1996, shallow tailings samples were collected from the impoundment using a Vibracore drill and surficial samples were collected by hand. Selected samples were analyzed for acid generating potential, total metals concentrations, and soluble metals concentrations. The sample locations are shown in Figure 2.1.

In December 1996 four holes were drilled through the depth of the impoundment using a reverse circulation hammer drill, and over 400 tailings samples were collected. An additional 9 surface samples were also collected. In addition, water quality samples were collected from the bottom of holes BH1, BH3, and BH4 and analyzed for total metals concentrations. The water table was not intercepted in hole BH2.

To extend the coverage of surficial tailings samples, seven samples were collected in February 1997. Samples were collected using a shovel from depths of up to 40 inches and were forwarded to the SRK Denver office for examination. Subsequently, they were shipped to ACZ Laboratory in Steamboat Springs for further analysis.

In addition, as part of an ongoing program being carried out under Discharge Permit 933, weekly samples of current tailings are collect at the mill. These samples are then composited for each annual quarter and submitted for analyses of metals concentrations. The results are reported to the New Mexico Environment Department by Molycorp. Anlayses of the first three composite samples for 1997 are discussed herein.

2.2 Testing and Methods

The testing program was carried out in a staged manner. Completion of the first phase, comprising static testing methods, was required to allow sample selection for the second phase of testing, comprising kinetic procedures. The first Phase of testing included the following static tests:

- Paste pH and conductivity

- Multi-element metal analyses by ICP of the tailings solids;
- Acid Base Accounting (modified Sobek ABA) tests to determine acid generating potential based on sulfide and alkaline mineral content of samples;
- Mineralogical characterization including x-ray diffractometry and petrography to determine the extent of oxidation within the tailings and the morphology of the sulfide grains;
- Particle size distribution and fractional analysis on surface samples to determine if sulfides are located predominantly in a specific size fraction; and,
- Leach extraction tests (modified EPA 1312 method using the Meteoric Water Mobility Procedure (MWMP) reagent and a 1:1 solid to liquid ratio) to determine current soluble metals content.

The second Phase of testing included limited static testing completed on additional samples, as well as the following kinetic tests:

- Enhanced oxidation tests using hydrogen peroxide addition (modified Net Acid Generation (NAG) test) to assess reactivity of the sulfide and acid neutralizing minerals present in the tailings; and,
- Longer term kinetic testing using humidity cells to estimate the long-term leachate quality.

Details of the test methods are provided in Appendix A. Table 2.2 summarizes the number of samples analyzed via the various tests indicated above. Details of the testing program are provided in Appendix B. The basis for selecting the samples tested is outlined in Section 2.3 below.

2.3 Sample Selection and Testing

2.3.1 Static Testing

Paste pH and conductivity were determined for STET samples.

Samples for acid base account testing and metals analyses were selected on the basis of the distribution of the paste parameters. In addition, samples were selected to represent the estimated variability in composition, age, depth, and sulfide content of the entire sample population.

Leach extraction tests were completed in order to determine the current soluble constituents present in the tailings. The samples chosen for these tests are representative of the different tailings types, age, and ABA balance found within the Questa tailings facility. Therefore, samples selected included surface samples, slimes and tailings characterized as being derived from aplites and andesites ranging in age from 5 to 27 years. Furthermore, samples were selected to represent total sulfur contents ranging from 0.23 to 1.19 % and NP/AP ratios ranging from 0.42 to 5.00.

2.3.2 Kinetic Testing

Enhanced oxidation tests (modified NAG tests, Miller *et al.,* 1997) were carried out in an effort to help define the criteria used to classify samples as potentially acid generating or non-acid generating. This test was, therefore, completed on selected samples that were classified as either potentially acid generating or uncertain with respect to acid generation as defined by the ABA tests, i.e. with an NP/AP ratio of less than 1.5. The NP/AP values of the samples selected ranged from 0.62 to 1.67 and represented all of the tailings types. A cutoff NP/AP of 1.5 is typically used to classify tailings as potentially acid generating (MEND Project No. 1.16.1B, 1991; Blowes and Lambor, 1990; MEND Project No. 1.16.3) compared to an NP/AP of 3 for waste rock. This is because grinding breaks down neutralizing minerals, increasing their surface area, and mixing of the tailings brings these in proximity to the sites of acid generation.

Humidity cell tests were used to estimate oxidation reaction rates, and to establish the rate of acid neutralization by the naturally contained neutralization potential. The leachate chemistry identified potential solubility controlling secondary mineral phases that may limit constituent release from the tailings facility. Samples were specifically selected to be representative of all tailings types. As well, samples were selected on the basis of NP/AP ratio; the generally applied criteria to distinguish potentially acid consuming tailings from potentially acid generating tailings were bracketed to include the area of 'uncertainty' as follows:

- Four of the nine cells contained tailings with NP/AP ratios below 1.5: two were selected from aged surface samples, one was from aplitic tailings and the remainder were from andesitic tailings;
- Three of the humidity cells had NP/AP ratios between 1.5 and 3: one sample was selected from the slimes, one from aplitic tailings, and one from andesitic tailings; and,

- Two cells contained aplite and andesite tailings with NP/AP ratios greater than 3.

Table 2.3 summarizes the characteristics of the nine samples chosen for humidity cell testing.

3.0 RESULTS

3.1 Static Testing

3.1.1 Paste Parameters

Paste pH and conductivity measurements were taken on 402 tailings samples collected during the borehole sampling program. The pH values were consistently near neutral with only three samples exhibiting pH's slightly below 7 (6.5, 6.9, and 6.9 respectively). The mean pH value was 7.4 (range 6.5 to 8.2 with a standard deviation=0.27). The conductivity of the tailings ranged between 228 µS/cm and 2210 µS/cm (mean=901 µS/cm; standard deviation=506 µS/cm).

Figures 3.1 through 3.4 illustrate the pH and conductivity trends with respect to depth and tailings type for each of the four boreholes.

The first borehole (BH1) intersected aplite and andesite tailings, with the andesite tailings occurring below a depth of 106 ft. The upper 10 ft represent slimes. As shown, the water table was encountered at depth of about 100 ft below the surface. The average paste conductivity of the andesite tailings is higher and the average pH slightly lower than that of the aplite tailings. Unusual 'noise' or scatter was observed in the paste pH and conductivity below the water table. The two elevated conductivity observations below the water table are considered to be anomalous since the saturated conditions should result in 'smoothing' of the conductivity.

The second borehole (BH2) intersected mainly andesitic tailings which were characteristically sandy. Slimes were encountered in the upper approximately 10 ft and below 70 ft. No phreatic surface was encountered. Paste pH values were all above 6.9. The variability in paste pH values observed in the slimes was slightly greater than that of the rest of the tailings. However, paste conductivities ranged predominantly from 800 to 2200 µS/cm and were equally variable both for the slimes and the sands.

Borehole 3 (BH3) intersected aplite and andesite tailings. The aplite tailings were encountered at depths of 25 to 30 ft and 65 to 128 ft. No slimes were intersected. The phreatic surface was encountered at a depth of about 104 ft below surface. Paste pH values were within a relatively narrow range for the entire depth of the tailings, with

slightly alkaline values indicated in the upper 30 ft. This layer also exhibited comparatively low paste conductivities. Below this zone, paste conductivities were locally elevated and ranged from 800 to 2200 µS/cm. Below the water table, the smoothing effect of saturated conditions is clearly indicated, particularly for the paste pH values.

The fourth borehole (BH4) intersected mostly slimes and andesite tailings. Slimes were encountered from 11 to 105 ft. The phreatic surface was located at a depth of about 107 ft from surface. This profile shows a greater variability in both pH and conductivity within the slimes fraction when compared to the sandy andesitic tailings.

3.1.2 Mineralogical Examination

Mineralogical characterization of the tailings was undertaken to identify types of both potentially acid generating and acid neutralizing minerals, as well as secondary minerals that are possible sources or sinks of metals. Where applicable, the textures and changes resulting from alteration (i.e. oxidation or dissolution) of certain minerals were documented.

Six tailings samples collected during the reverse circulation drill program were selected for mineralogical examination. The samples examined were composed of andesitic, aplitic, and slimes tailings. Since the objective of this investigation is to assess the effects of weathering, samples were selected from older tailings. The complete mineralogical report is presented in Appendix C and summarized briefly below. The mineralogy in all the tailings products was found to be similar, with mineral abundance estimated as follows (in order of decreasing abundance):

- ~38% quartz (SiO_2),
- ~30% plagioclase feldspar ($(Na,Ca)Al(Si,Al)_3O_8$),
- ~12% potassium feldspar ($KAlSi_3O_8$),
- ~5% biotite ($KMg_3(Si_3Al)O_{10}(OH)_2$),
- ~3% chlorite ($(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$),
- ~3% amphibole ($Ca_2(Fe,Mg)_4Al(Si_7Al)O_{22}(OH,F)_2$),
- ~3% calcite ($CaCO_3$),
- ~3% sulfides including
  - pyrite (FeS_2),
  - sphalerite ($(Zn,Fe)S$),
  - chalcopyrite ($CuFeS_2$),
  - molybdenite (MoS_2),
  - +/- galena (PbS),

  - +/- covellite (CuS),
  - and +/- pyrrhotite ($Fe_{(1-x)}S$),
- ~2% fluorite (CaF_2),
- ~1% muscovite ($KAl_2Si_3AlO_{10}(OH)_2$),
- as well as trace amounts of
  - magnetite (Fe_3O_4),
  - apatite ($Ca_5(PO_4)_3(OH,F,Cl)$),
  - gypsum ($CaSO_4 \cdot 2H_2O$),
  - iron-oxyhydroxides (FeO(OH)),
  - +/- native sulfur (S^o).

Minerals that likely contribute to laboratory neutralization potential include calcite, biotite, plagioclase feldspar, apatite, and minor clay. Of these minerals, calcite is the only mineral to contribute significant neutralization potential at the pH conditions observed throughout the Questa tailings. No barite was identified in the tailings samples examined and, therefore, there is little concern for the potential contribution from barite to the analytical sulfate-sulfur determination.

Minor alteration of minerals due to localized oxidation that occurred after deposition of the tailings was seen in samples BH1-1-107, BH1-135, BH1-176, and BH2-58. These samples also contained between 3% and 5% calcite and had paste pH values above 7 indicating that acidity is effectively being neutralized. Samples BH3-37 and BH3-111 exhibited no signs of oxidation. The degree of alteration of the sulfides in these samples is between 1 and 0 on a relative scale ranging from 0 to 10 of the Sulfide Alteration Index given by Blowes and Jambor (1990). This category is defined by only a few grains of sulfides (pyrite and chalcopyrite in this case) that are weakly altered along the rims and fractures; >95% of the grains have sharp, fresh edges.

Some evidence of molybdenite dissolution was identified in one of the samples. It was, however, not possible to establish when the dissolution had occurred, i.e. prior to processing or after deposition. Most of the molybdenite that has reported to the tailings fraction occurs either as inclusions in other minerals, where encapsulation serves to protect the molybdenite from dissolution, or as very fine grained laths.

The secondary minerals identified include iron-oxyhydroxides, gypsum and possibly native sulfur. Based on the mineralogical examination, these minerals showed no signs of dissolution in the Questa tailings. They are, therefore, interpreted to serve as

sinks for calcium, sulfate, iron, sulfur and possibly for metals such as copper which are commonly sorbed by, or co-precipitated with, iron-oxyhydroxides

Mineralogical characterization of surface samples as reported in SRK (1996) was done with the intent to characterize those samples subjected to atmospheric weathering. Of the four samples examined, three had been exposed to surface conditions for approximately 5 years, and the fourth had been exposed on the surface for approximately 27 years. The only sample reported to have evidence of sulfide oxidation was the oldest sample (T-24B), and all four samples contained excess calcite.

3.1.3 Acid Base Accounting

During Phase 1 of the study, modified Sobek acid base accounting tests were performed on 34 of the 402 borehole samples. As well, two surface samples (T-24B and T-11) collected in February, 1996 that had previously been analyzed by the conventional Sobek ABA method were subjected to the modified Sobek procedure. The ABA tests provide a measure of the neutralization potential (NP) and the acid generation potential (AP) of the sample tested. These parameters are then typically used to classify the material with regard to acid generation potential by assessing both the NNP (NP-AP) and their ratio (NP:AP). Typically for tailings, samples are classified as potentially acid generating if the NP/AP is less than 1 and as non-acid forming if the NP/AP ratio is greater than 1.5. The acid generation potential of any sample falling between these two criteria is uncertain, and generally kinetic testing is required to establish if they would become acid generating. The NNP is used to estimate the overall potential for net acid generation (or acid consumption).

The ABA results from Phase 1 of the testing program are summarized in Table 3.1. The mean NP/AP ratio for these samples is 2.42 (ranging from 0.42 to 5.00; standard deviation=1.34). Excluding the two surface samples that were found to have a low NP/AP ratio, the mean NP/AP for the samples "at depth" in the tailings facility is 2.6. Of these samples, only 6% would be considered potentially acid generating, 14% would be classified as uncertain, and 80% would be considered non-acid forming (i.e. net acid consuming).

The 6% considered to be potentially acid generating on the basis of these results represent solely the aged surface tailings. These two samples were chosen for ABA testing because they showed signs of oxidation and are considered atypical of the

tailings surface. These samples were also atypical of the surficial tailings that have been exposed for 27 years.

The samples that fall within the range of uncertainty with respect to acid generating potential are predominantly composed of andesite tailings. Figure 3.5 represents a plot of NP against AP with respect to tailings type. The additional Phase 2 results as discussed in Section 3.16 have also been included for comparison purposes. Reference lines for the defining classification by NP/AP ratios are also shown.

3.1.4 Tailings Solids Analyses by ICP

Metals concentrations were determined using ICP mass spectrometry for 12 of the surface and near surface samples collected in February of 1996 and 14 of the borehole samples collected in December 1996. These assays were conducted to identify variability in the composition of the tailings within the facility and, in particular, variability between surface samples and those at depth.

Table 3.2 summarizes the ICP results for all the samples including the means and standard deviations for all the elements. The major constituents of the tailings are aluminum, calcium, iron, magnesium, manganese, potassium and sodium, reflecting the presence of common rock forming minerals that compose the bulk of the ore. Samples were not analyzed for silica, but silica is assumed to be the major constituent based on the mineralogy of the ore host rock, as well as the abundance of quartz seen in thin section.

The tailings contain significant concentrations of copper, molybdenum, and zinc. Concentrations of aluminum, arsenic, barium, chromium, copper and magnesium in the surficial and near surface samples collected in the earlier testing program are higher than those in the samples of deeper tailings. These differences are attributed to variability within the ore. The tailings near surface are all temporally consistent whereas samples collected from the boreholes represent a range of ages and, therefore, composition. Generally, however, there is no significant chemical difference between the tailings solids taken from surface and those recovered at depth.

3.1.5 Leach Extraction Tests

Extractable metal contents of the tailings were determined using a modified EPA 1312 method with a leach solution similar to that used in the Meteoric Water Mobility Test

(i.e. pH=5.0 to 5.5) and a liquid to solid ratio of 1:1. This method was used to test 14 of the samples collected during the borehole sampling program, and 2 of the aged surface samples previously tested by the EPA 1312 method, but utilizing de-ionized water as an extractant and a liquid to solid ratio of 2:1. The results are summarized in Table 3.3.

The final pH of all the leach solutions was above neutral. The primary constituents in the leach extracts include Ca, Mg, Mn, Mo, K, Na, and Sr. Sulfate concentrations ranged between 200 and 1660 ppm. Trace concentrations of Ba and Zn were detected in all samples and the concentrations of Al, Sb, As, Cd, Cr, Cu, Fe, Pb, and Ni were low. The average concentrations of Mo, SO_4, and Mn were 4.1 mg/L (standard deviation=2.5 mg/L), 859 mg/L (519 mg/L), and 1.12 mg/L respectively. Those samples with high SO_4 concentrations also reported relatively high Ca concentrations suggesting a control on solution concentrations of Ca and SO_4 by gypsum. In general, the andesite and surface tailings have higher extractable metal contents than the aplite or slime samples. The effect of continued oxidation is clearly evident in the results obtained for the surface samples.

3.1.6 Phase 2 – Additional Surficial and Shallow Samples

Seven additional surface samples were collected and submitted for ABA and leach extraction testing using the modified EPA 1312 method (1:1 solid to liquid ratio using MWMP-leachant).

The ABA results are compared with previous data in Table 3.1. The average total sulfur concentration in the surface samples was approximately twice that of the previous samples (1.3 % compared to 0.6 %) and sulfate concentrations were also slightly higher (0.3 % compared to 0.2%) indicating a higher AP. The NP, however, was similar for both sample sets. The resulting mean NP/AP ratio for the additional surface samples was 1.9 compared to 2.4 for the previous samples. It should, however, be noted that 6 of the 9 samples were collected from the beach, and three from the pond. The pond samples exhibited characteristics similar to the overall sample population (i.e. NP/AP ratio of 2.3). The samples from the beach had higher sulfide contents and an NP/AP ratio of 0.9. This difference is likely a result of i) segregation that had occurred during sample deposition, and ii) atypical tailings generated as a result of changes in operating conditions encountered at shut-down of the mill.

The total extractable metals contents are compared in Table 3.3 with the results from Phase 1 testing. The seven additional surface samples had mean soluble metal concentrations generally similar to the previous sample data. The exceptions to this are calcium and magnesium. The mean molybdenum concentration in the new samples was also similar (5.3 ppm compared to 4.3ppm). Again, the higher extractable metal contents are likely a result of oxidation of the surface and near surface tailings.

3.1.7 Weathering Observations Based on Static and Leach Test Results

Oxidation trends in mine wastes over time are most commonly assessed using laboratory kinetic tests (see Section 3.2.4 below). At Questa, however, tangible field data are also available for the 32 years that tailings have been produced and deposited within the facility. Changes in geochemical characteristics of tailings over this time period can therefore be used to infer oxidation and reaction trends in the tailings. However, only near surface tailings will have been subject to oxidizing conditions. Experience elsewhere (Coggans et al 1991) indicates that the depth of oxygen entry in fine grained tailings containing some sulfide minerals is in the order of few feet to several feet, depending on the reactivity of the tailings. Consequently, the effect of long term oxidation can only be inferred from near surface tailings samples. It is recognized that where any zones or interim surfaces within the tailings were exposed for some time prior to the deposition of a successive layer of tailings, some oxidation may have occurred. Once these interim surfaces were covered by further tailings placement, ongoing oxidation would be limited. Furthermore, in comparison to the existing surface area where up to 27 years of exposure has occurred, the time period for which interim surfaces were exposed to weathering is likely to have been short, and the effect of oxidation is considered to be minimal.

Soluble oxidation products generated within the zone of active oxidation in the near surface tailings will have been transported downward through the tailings profile over the years by infiltration. As these products migrate through the tailings, they will react with the underlying tailings, resulting in the formation of secondary mineral phases that typically control the solubility of constituents released by oxidation. Therefore, changes in tailings at depth can be inferred to result from the accumulation of solubility controlling secondary mineral phases under anoxic conditions. However, it should be noted that the amount of secondary minerals (i.e. relative abundance) that would have formed in the tailings at depth would be:

- directly proportional to the extent of oxidation from which soluble constituents were generated, and
- inversely proportional to the volume (i.e. pore space) within which secondary mineral formation had occurred.

Typically, the relative abundance of these secondary minerals is small, and they generally form at concentrations too low for detection by the standard techniques used in the identification of secondary mineral phases.

Consequently, to assess the effect of oxidation over time, sulfate and sulfide sulfur, NP and metal concentrations were plotted as a function of depth for all of the samples. Extractable metal and sulfate concentrations, obtained from the leach extraction tests, were also plotted with depth. Results are discussed below.

Sulfate, Sulfide, NP Versus Depth

Figure 3.6(a) shows a plot of the percentage of sulfate sulfur as a function of depth, for surficial and near surface (above 27 ft bgs) tailings. The sulfate sulfur concentration decreases with depth. Figure 3.6(b) shows the ratio of sulfate to total sulfur as a percentage. Keeping in mind that most sulfate salts are relatively soluble and therefore mobile, the results indicate that oxidation is most evident in the near surface tailings. Further, the depth of oxygen entry appears to be in the order of 15 to 20 ft.

Figure 3.7 shows sulfide sulfur concentrations and NP versus depth in near surface tailings. Sulfide sulfur concentrations remain fairly constant at less than 1% within 5 ft of the ground surface, whereas concentrations in surface tailings are more varied. NP remains relatively constant with depth (Figure 3.7b).

Age profiles for selected metals show that, in general, the concentration of Al, Mg, Fe, K, Na and Cu are slightly higher in the tailings produced during underground mining (post 1983) compared to the tailings generated from the open pit operations (prior to 1983) (Figures 3.8(a) through 3.8(i)). However, concentrations of Ca, Mo, and Zn in the tailings do not vary significantly with time.

The observed variations are attributed to changes in ore type and mining techniques rather than changes due to processes occurring within the tailings facility.

Leachable Sulfate Versus Depth

Extractable sulfate as a function of depth for the near surface samples is plotted in Figure 3.9 and shows that the soluble sulfate concentration decreases with depth. Furthermore, the older surface samples (27 years old) have higher soluble sulfate concentrations than those samples that have been exposed to weathering for about 6 years. Similar to the analyses for sulfate in the solids, these results confirm that the effect of oxidation is most evident near the surface of the tailings. These results also show an accumulation of extractable soluble sulfate with time, when the results for the older surface tailings are compared to those for the more recently deposited surface tailings.

Leachable Metals Versus Depth

Age profiles for selected extractable metals are given in Figures 3.10(a) through 3.10(j). The profiles that show variation with respect to tailings type for concentrations of Ca, Mg, Mn, and SO_4. Soluble Ca and SO_4 concentrations are slightly greater in the surface samples and andesite tailings than in the aplite tailings or the slimes sample. (The leachate samples that exhibit the highest concentrations of soluble Ca and SO_4 are within the concentration range dictated by gypsum solubility [i.e. 520 mg/L Ca and 1250 mg/L SO_4], are likely in equilibrium and do not reflect the entire water soluble sulfate content. This is discussed in more detail in Section 4.0.) Similarly, extractable magnesium is greater in the surface samples than in the samples "from depth".

Profiles for the remaining elements vary slightly between samples, but no direct correlation between age or tailings type is evident. As well, no obvious difference in extractable metal concentrations between tailings produced from the open pit and those derived from the underground workings exists.

3.1.8 "Fresh" Tailings

As part of the discharge permit, tailings currently being produced at Questa are collected weekly and composited to form quarterly samples that are submitted for determination of total metals concentrations and acid base accounting. Three samples have been analyzed thus far. The fresh tailings samples had sulfide sulfur concentrations of approximately 0.5% and NP/AP ratios of 2 and 2.7. The mean

the mean NP/AP ratio of 2.5 for the older tailings. Metals concentrations were also similar. Molybdenum concentrations, for example, were 198 mg/L and 307 mg/L in the new tailings compared to a mean of 223 mg/L in the older tailings. The conductivity was slightly higher in the new tailings (mean=2060 μS/cm) compared to the older tailings (mean=1149 S/cm).

3.1.9 Water Quality Samples

Results of water quality samples from the drill holes are presented in Table 3.10. Sulfate concentrations in these samples ranged from 890 mg/L to 1300 mg/L. Metals concentrations were low. Molybdenum concentrations in BH1, BH3, and BH4 were 11 mg/L, 1.2 mg/L and 3.5 mg/L, respectively. The sample from BH1 was small so that the detection limit on this sample was higher than normal. Therefore, the result from this sample can be considered anomalous. The results from the other two analyses are comparable to molybdenum concentrations in the intital washes from kinetic tests (see Appendix D).

3.1.10 Discussion of Static Test Results

All of the drillholes were located in currently inactive parts of the tailings facility, and as a result of the sandy nature of the tailings, have drained down so that the phreatic surface is relatively low. The most recently deposited tailings have been in place for about 6 years, and it is reasonable to assume that the process water has been flushed from the tailings. It is therefore concluded that the tailings currently below the soil cover continue to oxidize. This is supported by the low to moderate paste conductivity values. Conductivity provides a measure of sulfate concentrations in the pore water. However, the near neutral pH values indicate that any acidity being generated within the tailings is being effectively neutralized. The observed paste pH and conductivity profiles clearly do not fit typical profiles associated with acid generating tailings. Such tailings are characterized by low pH values and elevated conductivity. This includes BH1 located in the area in which the surface tailings have been exposed for about 27 years. The Questa tailings remain near neutral throughout the entire deposit, and none of the depth profiles show evidence of depressed paste pH near or at the surface of the tailings deposit. At the observed neutral to alkaline pH values, the solubility of most base metals associated with sulfide deposits is low as a result of the formation of either the hydroxide or carbonate secondary minerals.

In comparison to the other three drillholes, the paste conductivity profile observed at BH1 is significantly lower. Assuming similar rates of infiltration at all the drill hole locations, the lower paste conductivity profile indicates that the rate of oxidation in the older tailings is lower than at any of the other locations. This suggests that the more reactive sulfide minerals in the older tailings have been consumed over time, and currently, only less reactive sulfides remain.

Further, the depth profiles of paste conductivity appear to show peaks and low values, typically exhibiting 5 to 6 peaks over a depth of about 100 to 130 ft. If sulphate concentrations in process water or dissolution of gypsum was controlling the sulfate concentrations in pore water, a steady conductivity in the order of 2,000 μS/cm would have been anticipated. The peak conductivity could represent the flush of stored oxidation products that could accumulate between the infiltration events. Hydrological modeling has shown that for the areas overlain by the soil cover, infiltration typically passes from the cover to the tailings once per year, during fall (See RGC Report 052002/1, 1997). If this is the case, the results suggest that wetting fronts are passing through the tailings at a rate of about 20 - 30 ft per year. Furthermore, these results would indicate that oxidation is essentially limited to the surface of the tailings.

Most of the tailings samples collected did not have the potential to generate acid. Exceptions were aged surface tailings, particularly those with sand-sized material as opposed to slimes. However, the more heavily oxidized materials contained soluble metals concentrations similar to those in deeper tailings, indicating secondary mineralization from neutralization is effectively controlling metal mobility.

3.2 Kinetic Testing Results

3.2.1 Geochemical Characteristics of Samples Selected for Kinetic Testing

Tailings produced from each of the host rock types are relatively homogenous. Most significant variations are encountered between tailings that originate from different host rock types. Samples chosen for kinetic testing represent tailings from each of the ore types, as well as the range in physical and static test characteristics that were encountered in the tailings facility.

Acid Base Accounting

Acid base accounting results for the samples selected for kinetic testing are contained in Table 3.4. The table also contains the calculated mean, minimum and maximum values for the entire tailings sample population analyzed during this project.

All samples had paste pH values at or above 7. Paste conductivities ranged from 591 μS/cm to 2480 μS/cm (mean = 1208 μS/cm). The samples for the first six humidity cell tests were selected on the basis of elevated total sulfur concentrations and, therefore, represent "worst case" samples. The mean sulfide sulfur concentration in these samples was 0.61% compared to 0.41% for the sample population as a whole. Similarly, the average NP/AP ratio for these samples was 1.12 compared to 2.42 for all samples.

Samples BH3-111 (cell no. 7) and BH1-123 (cell no. 8) had NP/AP ratios above 3 and are therefore considered to be net acid consuming. However, sample BH1-123 has a relatively high sulfide sulfur concentration (0.38%) whereas sample BH3-111 has a low sulfide sulfur content (0.17%). These samples were selected to establish the effect of variable sulfur grades on leachate chemistry.

Finally, sample BH4-75-80 (cell no. 9) contained a slimes sample that has a relatively high sulfide sulfur content, but is considered to be net acid consuming (NP/AP=2.47).

3.2.1.1 Metals Concentrations

Mean, minimum and maximum metals concentrations are compared to those for all samples tested in Table 3.5. Complete analyses were provided in Table 3.2.

As shown in the table, the samples selected for kinetic testing have higher average concentrations of cadmium, manganese, molybdenum, and zinc than the corresponding averages for all samples analyzed. Concentrations of other metals in the kinetic test sample were generally similar to the sample population on a whole. The ICP analyses suggest that conservative results should be obtained from kinetic testing of these samples.

3.2.1.2 Mineralogical Characterization

Two of the nine samples subjected to kinetic testing were among the suite of samples submitted for mineralogical examination. One of these samples (BH1-176) showed signs of sulfide oxidation whereas the other (BH3-111) did not. Calcite, the main neutralizing mineral, was detected in both samples. The mineralogical composition of the two samples varied only slightly with respect to relative mineral abundance.

3.2.1.3 Leach Extraction Testing

In Table 3.6 the mean, maximum and minimum concentrations obtained in the leach extraction tests for the samples selected for the humidity cell tests are compared with the results for all the samples tested. As shown in the table, extractable constituent concentrations were similar to those observed for all samples.

3.2.2 Enhanced Oxidation Tests

The enhanced oxidation test, as it is referred to in this report, is a slightly modified net acid generation test (NAG) (see Appendix A). Typically the test is used to determine the net acidity remaining after complete oxidation of acid generating minerals (sulfides) with hydrogen peroxide, and complete reaction of the acidity with the neutralizing minerals (carbonates) contained in the test sample.

The net acid generating (NAG) test was designed as an independent measure of the acid generating potential of a sample (Miller, 1997). The criteria proposed in the NAG test protocol (see Appendix A) for the division between non-acid generating, uncertain, and acid generating materials based on the results of the NAG test is generalized as follows:

- Potentially acid forming materials have pH<4
- Uncertain materials have pH values between 4 and 4.5
- Non-acid forming materials have pH values greater than 4.5

The enhanced oxidation testing was carried out as a staged program beginning with 5 samples, 4 of which were classified as potentially acid generating and 1 as uncertain, based on the results of the ABA tests. Following the completion and interpretation of the first 5 results, another suite of 12 samples was proposed. At the time of this report submittal, the additional test had not been completed. Results will be presented in a

supplementary letter report. Results to date are presented in Table 3.7 and are illustrated in Figure 3.11.

As shown in Figure 3.11, a constant increase in pH from the initial time of hydrogen peroxide induced oxidation was observed. The results indicate that the acid neutralization by the carbonate minerals is kinetically limited. The reason for the kinetically controlled neutralization rate is not clear. However, while it takes some time for the carbonates to react, it is clear that acid neutralization does occur.

On the basis of the enhanced oxidation test, the sample originally classified as uncertain (Sample BH1-176) would be considered non-acid generating. Similarly, of the samples classified as potentially acid generating on the basis of ABA criteria, two (Samples T-11 and BH1-72) would be considered non-acid generating, one (Sample BH2-19) would be considered uncertain and one (Sample BH2-37) would be classified as potentially acid generating (low capacity) approaching the uncertain range.

The difference between the results of the rapid oxidation test and the ABA characterization may be a result of secondary mineralization. As discussed below in Section 3.2.3, the alkalinity release rate from the dissolution of calcite is rapid, and more than adequate to neutralize acidity generated from natural oxidation (even under the accelerated conditions in the humidity cells). However, the enhanced oxidation test relies on a strong oxidant (H_2O_2) to rapidly oxidize the sulfides present. The strong oxidant also results in the rapid oxidation of any ferrous iron (released from pyrite oxidation) to ferric iron. Under these conditions, the rate of oxidation far exceeds the rate at which calcite dissolution occurs, and the acidity temporarily 'overwhelms' the rate of alkalinity release. Consequently, the ferric iron that is generated is precipitated directly on the surface of the calcite (similar to observations in alkaline limestone drains (ALD's) which blinds the calcite and prevents further reaction. In nature, pore water displacement would ultimately result in the dissolution of such surface coatings, but under the test conditions, the ferric oxy-hydroxides remain in equilibrium with the leachate, and therefore are not "stripped" from the surfaces of the calcite particles.

The results suggest that an NP/AP ratio of less than 1.5 is applicable for the Questa tailings for identifying the boundary between tailings with net acid consuming or net acid generating characteristics.

3.2.3 Humidity Cell Tests

Nine humidity cell tests were carried out over a period of 20 weeks. Humidity cell set-up conditions are summarized in Table 3.8. Detailed results are presented in Appendix D. In addition to the analytical results for the leachates, Appendix D also contains, calculated metal release rates as well as estimated sulfate generation and carbonate depletion rates. Cell leachate chemistries are also summarized in the figures attached to the results. In plotting these graphs, one half the detection limit was used for concentrations below detection.

Acid Generation and Neutralization

In general, all of the cells showed an initial flush of sulfate salts, as reflected by the sulfate concentration profiles, after which constituent concentrations decreased to stable levels. The initial flush represents the 'washout' of stored oxidation products that were present in the samples prior to testing. After about 5 weeks of testing, concentrations in the leachates exhibited relatively constant levels.

Leachate pH values remained slightly alkaline in all cases. Initially a slight increase in the leachate pH was observed for most cells, and all cells converged to a pH value of between 7.8 and 8.2. None of the samples classified as potentially acid generating on the basis of their NP:AP ratio, including the 27 year old sample, became net acid generating during the testing period.

Total acidity (to pH 8.3) was observed to decrease over time. The release rates for acidity stabilized at approximately 2.5 mg/kg/wk or less by week 3 in all but two of the cells. The acidity release rate, however, had reached this level by week 5 and 9 respectively in Cells 4 and 9. The highest rate of acidity release was observed in Cell 1 which contained the aged surface sample that had been exposed to weathering for approximately 27 years prior to sampling. Most of the acidity released from this cell is accounted for in the initial flush of stored oxidation products.

Some variability was observed in the initial rates of alkalinity release from the humidity cells. However, alkalinity concentrations in the leachates all stabilized towards the end of the testing period at very similar concentrations, with the exception of Cell 9. The similarity in the dissolved alkalinity indicates that the release of the

alkalinity is controlled by dissolution. Furthermore, the rate of dissolution is relatively rapid when it is considered that the NP ranged from 8 to 45 kg $CaCO_3$eq./tonne.

The alkalinity contained in the leachate from Cell 9, which contained the slimes sample, was about 15 mg $CaCO_3$eq/L compared to about 30 mg/L for cells 1 to 8, even though the solid sample contained a relatively high NP (37 $CaCO_3$eq./tonne). However, the fine particle size and the greater surface available for reaction would suggest that the alkalinity would be similar or higher than that in the leachates from the other cells. It is considered probable that leachant 'bypass' or short-circuiting is occurring along the walls of the cell due to the low permeability of the slimes.

The molar ratio of SO_4 : (Ca+Mg) decreased over time and was generally less than 1. This indicates that the rate of release of the carbonate neutralization capacity, represented by calcium and magnesium carbonates, is greater than the rate that acidity is generated from oxidation.

Metals Release

Concentration profiles for selected metals are illustrated Appendix D. In a manner similar to sulfate release, the initial flush of dissolved metals occurred over the first 5 to 10 cycles of testing. Generally, metal concentrations in all of the leachates decreased with time.

The exception was seen in only one sample, the aged surface sample T-24B, for molybdenum. In this case, the concentration of Mo increased from the initiation of the test until approximately week 9 after which it appeared to stabilize. It should be noted that the molybdenum content of this sample (450 ppm) was significantly higher than in any of the other samples.

An initial flush of dissolved manganese was also observed for all tests. By the end of week 2, all of the samples except for T-24B had dropped below 0.02 mg/L. Sample T-24B stabilized at a concentration of less than 0.2 mg/L Mn by week 11. The source of the manganese is not clear, however, it possibly is being leached from chlorite. Alteration of chlorite was not observed during petrographic examination, however, this phenomenon has been reported by Kwong and Ferguson, 1997.

Other Constituents

Fluoride, an anionic species, was detected in the leachate from all the cells. Concentrations in excess of 1.6 mg/L were observed in the initial leach cycle for all nine cells. The only cell that continued to produce fluoride concentrations greater than 1.6 mg/L is sample T-24B. All other cells exhibited decreasing concentrations with time.

Rates of Oxidation

The overall rate of oxidation was estimated from the rate of sulfate production observed after the initial flush of sulfate was complete. The results are summarized in Table 3.9. The table also contains estimated rates of oxidation calculated from the steady state release of dissolved metals.

In general, the rate of oxidation is low, but similar to those reported elsewhere in the literature for sulfide tailings (Coggans et al 1991). The data contained in the table are based on the results to week 20 of testing. An average of the results for cycles 14, 17, 20 was used in the calculations of the metals release rate. The results from cells 1 to 9 are very similar, indicating the intrinsic rate of oxidation for the tailings does not vary significantly with type or geochemical characteristics.

It was not possible to estimate the rate of oxidation for either chalcopyrite or galena due to the relatively high analytical detection limits for copper and lead leachate analyses. However, the results clearly indicate the preferential oxidation of pyrite and molybdenite. In decreasing order, preference of oxidation is estimated to be as follows:

Pyrite/pyrrhotite > molybdenite > sphalerite > arsenopyrite=chalcopyrite.

3.3 Quality Assurance/Quality Control

The quality assurance and quality control (QA/QC) program consisted of duplicate samples submitted for analysis. QA/QC testing was conducted on approximately 10% of all samples submitted for analysis.

Total Metals Concentrations

The results of duplicate analyses of total metal concentrations in solid samples are shown in Figure 3.12. The results indicate that the analytical precision was good for metals determination by ICP. All data fell within a ±20% range.

Leach Extraction Solutions

Duplicate analyses of dissolved metal concentrations in leach extraction solutions are shown in Figure 3.13. The results indicate good analytical precision for analysis of the leach extraction test solutions. All data fell within a ±20% range.

Humidity Cell Leachates

Results of duplicate analyses of metals concentrations in humidity cell solutions for cycles 1 to 17 are shown on Figure 3.14. Both scales are logarithmic. The dashed lines indicate range boundaries of ±20% variation within the a nalyses.

The figure shows that the analytical precision was good, with most of the data falling within the ±20% boundaries. Three percent of the data falling outside the boundaries represents data that are close to the limits of detection, thereby magnifying any differences in the duplicate values. For example, results of 1 mg/L and 2 mg/L in the original and duplicate sample, respectively, indicate high analytical precision although there is a 50% difference in the values.

The remaining data points that fall outside the boundaries, representing 3% of the analyses, can be attributed to analytical error. The error in these twelve analyses was found in analysis for aluminum, arsenic, calcium, magnesium, manganese, molybdenum, phosphorus, silica, selenium, strontium, and zinc (two analyses), and were distributed throughout the duplicate testing program.

4.0 EQUILIBRIUM MODELING

Dissolved constituent concentrations may be limited in both the leach extraction and kinetic (humidity cell) tests as a result of the formation of secondary mineral phases. The same controls will exist in the field and will limit the release of dissolved constituents from the tailings facility. Therefore, geochemical speciation modeling was undertaken of the leachates generated in both the leach extraction and humidity cell tests to identify any secondary mineral phases that may be of importance.

The USGS geochemical equilibrium modeling program MINTEQA2 (Allison et al., 1991) was used to calculate saturation indices for selected leachates. Where applicable, known solid phases were also input as finite solid phases. The results are summarized and discussed below.

4.1 Leach Extraction Results

The leach extraction results from 5 of the 23 samples tested were assessed. Calculated saturation indices are summarized in Table 4.1. MINTEQA2 run descriptions as well as input and output files are provided in Appendix E.

The five samples were selected to represent the range of concentrations for the main elements of interest at Questa, specifically Al, As, Ba, Ca, F, Mg, Mn, Mo, Sr and SO_4 and are representative of each tailings type.

Based on the MINTEQA2 modeling, the ions that may be controlled by the supersaturated mineral phases given in Table 4.1 are Al, Ba, Ca, Fe, F, K and SO_4. The minerals alunite, barite, boehemite, diaspore, ferriydrite, fluorite, gibbsite, gypsum, and jarosite may represent secondary phases resulting from oxidation and neutralization reactions occurring within the tailings facility over time.

Near equilibrium conditions were also indicated for calcite, confirming that the dissolution of this mineral is relatively rapid. As well, the results suggest the presence of iron oxy-hydroxide phases.

4.2 MINTEQA2 Modeling of Humidity Cell Results

Results of the initial wash and the steady state solutions from the humidity cells were also modeled using MINTEQA2 for four representative cells. These four cells bracket the minimum and maximum concentrations for those elements most susceptible to solubility constraints. The MINTEQA2 results for the humidity cells are provided in Appendix F and a summary table of the possible mineral phases and their saturation indices is given in Table 4.2. Due to the relatively high detection limit for iron, a concentration equal to 80 percent of the detection limit was input to the MINTEQA2 model.

4.2.1 Initial Flush

The results of the initial wash, similar to the leach extraction results, are likely most representative of potential equilibrium controls from secondary minerals that exist in the field. Based on the MINTEQA2 results from the initial wash through the humidity cells, the concentration of aluminum in the leachate is likely controlled by the dissolution – precipitation of diaspore or gibbsite. Under the near neutral to alkaline conditions, the impact that feldspar (microcline or sanidine), and the clay mineral halloysite have on the solubility of aluminium is considered insignificant. Barium solubility is being controlled by the solubility of barite. Calcium solubility is being dictated predominantly by gypsum, and the solubility of fluoride is controlled by fluorite. The concentration of iron in solution is likely controlled by precipitation of potassium jarosite and ferrihydrite. The modeling also suggests that the concentration of dissolved silica may be controlled by the precipitation of secondary quartz or other aluminosilicates like the feldspars, clay and zeolite minerals mentioned above. The mineral $Sb(OH)_3$ appears to be limiting the solubility of antimony.

Of the MINTEQA2 predicted phases, the only secondary minerals that were identified by the mineralogical examination were gypsum, iron oxy-hydroxides and an unnamed clay mineral. This suggests that if the other predicted minerals are present as secondary phases, they are present in relatively small quantities, are semi-crystalline or amorphous, or were destroyed during sample preparation for mineralogical characterization. Near equilibrium conditions for calcite and aragonite are indicated.

4.2.2 Steady State Concentrations

The presence of secondary mineral phases in the steady state leachate from the cells would affect the calculation of the oxidation rate. If controlling mineral phases are present, not all of the constituents affected by the secondary minerals would be released to the leachate, and would therefore not be accounted for in the calculation. Therefore, saturation indices were calculated for the leachates from the humidity cells obtained for the steady state conditions, to assess the potential for controlling mineral phases. The results are summarized in Table 4.3, and input and abbreviated output files are provided in Appendix F.

Based on the MINTEQA2 results, with the exception of iron oxy-hydroxides, there appear to be no controlling secondary mineral phases limiting the concentration in the leachate from the cells. This is consistent with the observations for the progression of the leachate concentrations, since all dissolved constituent concentrations decreased with time. It is however noted that co-precipitation or sorption reactions associated with the iron oxy-hydroxides may result in the attenuation of some of the trace constituents.

The results, however, indicate that the rate of oxidation based on sulfate release is likely a fair estimate of the rate of oxidation. Furthermore, if co-precipitation and attenuation did affect trace constituent release from the cells, it would similarly affect trace constituent release from the tailings in the field. The estimated rates of release (oxidation) are therefore considered to be reasonable.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The static and kinetic testing programs indicate the following major conclusions about the characteristics of the Questa tailings and address the issues posed in section 1.3.

The conclusions from the static testing program can be summarized as follows:

- The Questa tailings are currently not acidic, the pH of the tailings is consistently near neutral.
- The surficial tailings and predominantly andesitic tailings has higher sulfide sulfur contents and a higher potential to generate acid than the slime fraction or aplite tailings. The surface tailings samples, however, are considered biased as a result of operational changes during shutdown, and the impact of segregation resulting from beach deposition of tailings.
- Based on the distribution of all the samples tested for ABA, approximately 77% of the tailings are considered non-acid generating (NP/AP $\geq$ 1.5), 14% are considered uncertain (1.5 > NP/AP $\geq$ 1), and 9% are considered to be potentially acid generating (NP/AP < 1). There is evidence therefore for very localized pockets of net acid generation if alkalinity controls are not provided by alkali leachates from overlying layers of tailings. These pockets are predominantly on or near surface, and as such any leachate generated from these areas will pass through the tailings mass. Overall, however, the tailings deposit is considered net acid consuming. Therefore, acidity released from upper regions will be neutralized before exiting the tailings facility. Future burial of these surface tailings will limit their oxidation.
- The minerals that are considered potential sources of acidity and dissolved metals are pyrite, chalcopyrite, molybdenite and sphalerite.
- The minerals that likely contribute to the laboratory neutralization potential, determined using a concentrated strong acid, include calcite, biotite, plagioclase feldspar and minor clay. Of these calcite is the most important since it currently is buffering the porewater in the tailings to near neutral values.

- The drillhole paste conductivity profiles further indicate that continued oxidation is occurring within the tailings, predominantly within the surface layers. The results also show a significant decrease in the rate of oxidation with time.
- Evidence of molybdenite dissolution was detected during mineralogical characterization. Secondary minerals identified by the mineralogical characterization include gypsum, iron-oxyhydroxides and clays of unknown mineralogy.
- Leach extraction tests indicated that readily soluble constituents associated with the tailings include Al, Ca, Mg, Mn, Mo, K, Na, Sr, and SO_4. The primary "contaminants" (i.e. elements with concentrations greater than those defined by the New Mexico groundwater standards) released from the tailings are F, Mn, Mo and SO_4.

The conclusions from the kinetic testing program can be summarized as follows:

- Preliminary enhanced oxidation tests indicate that the 'cut-off' in NP/AP ratio for classification of potentially acid generating for the Questa tailings may be lower than 1.5. Indeed, none of the samples in the humidity cells, which had NP/AP ratios ranging from 0.42 to 4.2, generated acid.
- Alkalinity release from the dissolution of calcite is rapid, and buffers the leachate pH to in excess of 7.0.
- Overall oxidation rates obtained for the tailings are similar to or lower than compared to rates reported in the literature.
- The preference of oxidation of the primary sulfide minerals is estimated to be as follows:

  Pyrite/pyrrhotite > molybdenite > sphalerite > arsenopyrite = chalcopyrite.

Based on the results from the limited geochemical modelling, it is concluded that:

- The possible solubility controlling mineral phases that may be limiting the release of metals from the tailings under field conditions include alunite or gibbsite (Al), barite (Ba), fluorite (F), iron oxy-hydroxides (Fe) and gypsum.
- No solid phase control was indicated for molybdenum, but in conventional water treatment technology, molybdenum is coprecipitated from solution with ferric oxy-

hydroxides. Molybdenum solubility may be controlled in the field by the formation of oxy-hydroxides.

- The solubility of manganese may be controlled by the formation of rhodochrosite ($MnCO_3$)
- It is reasonable to determine the rate of oxidation from sulfate release from the humidity cells.

Overall, there is nothing in the testing programs to indicate that sulfide oxidation will increase over time. Indeed, kinetic test results show that oxidation will decrease in the long term and, therefore, acid generation and production will decrease with time.

5.2 Recommendations

Prediction Modeling

The kinetic testing has provided an indication of the rate at which oxidation is occurring within the tailings. Also, estimates of the rates at which soluble constituents are released have been obtained from the humidity cell tests. These results should now be used to assess the overall long term sulfate and dissolved metal release rates. This should be done in three steps as follows:

1. First, the rate of oxygen flux into the tailings should be estimated on the basis of oxygen diffusion through the tailings cover. It should be noted that other oxygen transport mechanisms such as barometric pumping may need to be evaluated to determine the primary transport mechanism.

2. The oxidation rates determined herein can then be used to estimate the depth of oxygen entry into the tailings, and the rate of constituent release. Together with the hydrological modeling, the resulting pore water concentrations can be estimated.

3. Finally, the pore water quality estimated from step 2 above should be assessed using the MINTEQA2 or equivalent geochemical model to provide equilibrated constituent concentrations that would represent the concentrations in pore water released from the facility.

6.0 REFERENCES

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TABLES

Table 2.1
Summary of Sample Collection and Testing

Sample ID	Date Collected	Weight	Method of Collection	Comments
T-1 to T-24	February, 1996	2 to 5 lbs each	excavated with a shovel and placed in clean plastic bags	21 samples in total.
VC1- to VC6-	February, 1996	1 foot to 9 foot intervals collected	collected with a vibracore drill rig (with 10 foot length hollow barrel) and placed in clean plastic bags	depths of up to 26.5 feet sampled. 21 samples in total.
BH1- to BH4-	December, 1996	1 foot intervals or 5 to 50 foot composites	collected using an AP2000 reverse circulation hammer drill rig, samples placed in clean plastic bags in 5 gallon buckets	BH1 to 180 feet; BH2 to 135 feet; BH3 to 128 feet; BH4 to 180 feet. 402 samples in total.
T-25 to T-32	December, 1996	approx. 10 to 25 lbs each	excavated with a shovel and placed in 5 gallon buckets	sampled to extend surface sampling coverage. 9 samples in total.
97-T-1 to 97-T-7	May, 1997	approx. 2 to 5 lbs.	excavated with a shovel and placed in clean plastic bags	geotechnical and geochemical testing. 7 samples in total.
T4(1)(2)T5(1)(2)(3), T3/971-6 Comp, 1341/97-1	quarterly samples for first 3/4 of 1997			fresh tailings samples. 3 samples in total.

Table 2.2
Summary of Testing Program

Testing Method	Number of Samples Tested		
	Acid Generating Potential Assessment (SRK 1996)	Geochemical Testing Program Phase I (SRK 1997c)	Geochemical Testing Program Phase II
STATIC TESTS			
Paste pH	42	402	
Paste Conductivity	42	402	
Acid Base Accounting	42	36	10
Metals Concentration by ICP	12	14	
Petrographic/XRD	4	6	
Leach Extraction	18	16	7
KINETIC TESTS			
Humidity Cells			9
modified NAG test			5

Table 2.3
Summary of Samples Chosen for Humidity Cell Testing

Cell No.	ACZ Sample No.	SRK Sample No.	Current Location	Weight (g)	Split for CESL (g)	Split for ACZ (g)	Analyses Completed	Criteria	Description				
									Paste pH	Paste Conductivity (µS/cm)	NP	AP	NP/AP
1	none	T-24B (~1970 deposition)	SRK	1319	500	819	Modified Sobek ABA extraction + metals; Modified 1312	aged surface sample, lowest NP/AP encountered	6.58	960	8	19	0.47
2	none	T-11 (~1991 deposition)	SRK	1269	500	769	Modified Sobek ABA extraction + metals; Modified 1312 Metals Assay	aged surface sample	8.35	450	14	22	0.64
3	none	BH1-72sp (unground) (~1969 deposition)	SRK	412	250	162	Modified 1312 extraction + metals	high S content, NP/AP between 1 and 1.5, aplite	7.5	407	~10	~9	~1.11
4	L13155-05	BH2-19 (~1985 deposition)	ACZ	627	250	377	Modified Sobek ABA; EPA 3051 +metals (ICP); Modified 1312 extraction + metals	high S content, NP/AP between 1 and 1.5, andesite	7	1887	33	29	1.14
5	none	BH3-84 (~1975 deposition)	SRK	555	250	305	Modified Sobek ABA EPA 3051 +metals (ICP); Modified 1312 extraction + metals	high S content, NP/AP between 1.5 and 3, aplite	7.2	1064	14	8	~2.6
6	L13155-04	BH1-176 (~1966 deposition)	ACZ	1544	500	1044	Modified Sobek ABA EPA 3051 +metals (ICP); Modified 1312 extraction + metals	high S content, NP/AP between 1.5 and 3, andesite	7.7	662	45	27	1.67
7	L13155-12	BH3-111 (~1970 deposition)	ACZ	159	159	0	Modified Sobek ABA Metals Assay Unmodified 1312	potentially non-acid generating, NP>3, aplite	7.2	757	21	5	4.2
8	L13155-03	BH1-123 (~1967 deposition)	ACZ	1240	500	740	Modified Sobek ABA EPA 3051 +metals (ICP); Modified 1312 extraction + metals	potentially non-acid generating, NP>3, andesite	7.5	702	39	12	3.25
9	L13155-13	BH4-75-80 (~1979 deposition)	ACZ	970	500	470	Modified Sobek ABA EPA 3051 +metals (ICP); Modified 1312 extraction + metals	tailings slimes	7.2	1315	37	15	2.47

Table 3.1
Acid Base Accounting Results

Sample No.	Paste pH	Paste Conductivity (µS/cm)	Total Sulfur %	Sulfate Sulfur %	Sulfide Sulfur %	Neutralization Potential (modified) tons $CaCO_3$ eq./kiloton	Acid Generating Potential (AP) tons $CaCO_3$ eq./kiloton	Net Neutralizing Potential (modified) tons $CaCO_3$ eq./kiloton	NP/AP (modified)
BH1-22	7.8	502	0.17	U	0.17	24	5	19	4.80
BH1-40	7.7	451	0.23	0.06	0.17	21	5	16	4.20
BH1-72	7.3	591	0.31	0.01	0.30	10	9	1	1.11
BH1-92	7.7	585	0.25	0.03	0.22	30	7	23	4.29
BH1-107	7.9	610	0.33	0.03	0.30	39	9	30	4.33
BH1-123	7.5	702	0.55	0.17	0.38	39	12	27	3.25
BH1-135	7.2	1619	0.46	0.15	0.31	35	10	25	3.50
BH1-174	7.6	649	1.18	0.13	1.05	35	33	2	1.06
BH1-176	7.7	662	1.16	0.3	0.86	45	27	18	1.67
BH2-19	7	1887	1.19	0.26	0.93	33	29	4	1.14
BH2-37	7.4	1862	0.96	0.36	0.60	26	19	7	1.37
BH2-42SP	7.4	2050	0.78	0.43	0.35	41	11	30	3.73
BH2-58	7.1	1468	0.73	0.07	0.66	35	21	14	1.67
BH2-70-75	7.8	1094	0.41	0.13	0.28	39	9	30	4.33
BH2-80-85	7.6	1656	0.55	0.26	0.29	39	9	30	4.33
BH2-90-95	7.8	1600	0.43	0.15	0.28	43	9	34	4.78
BH2-100-105	7	1970	0.5	0.2	0.30	41	9	32	4.56
BH2-125-130	7.7	1670	1.01	0.70	0.31	30	10	20	3.00
BH3-16	7.3	946	0.84	0.25	0.59	37	18	19	2.06
BH3-31	7.1	1825	0.92	0.13	0.79	30	25	5	1.20
BH3-37	7	2020	0.93	0.48	0.45	32	14	18	2.29
BH3-51	7.1	1256	0.55	0.18	0.37	33	12	21	2.75
BH3-69	7.3	843	0.42	0.17	0.25	40	8	32	5.00
BH3-84	7.2	1064	0.65	0.39	0.26	14	8	6	1.75
BH3-85	7.4	517	0.34	0.10	0.24	21	8	13	2.63
BH3-111	7.2	757	0.3	0.13	0.17	21	5	16	4.20
BH3-125	7.2	848	0.27	U	0.27	21	8	13	2.63
BH4-30	7.6	513	0.31	0.04	0.27	37	8	29	4.63
BH4-60-65	7.8	1354	0.56	0.19	0.37	36	12	24	3.00
BH4-75-80	7.2	1315	0.61	0.13	0.48	37	15	22	2.47
BH4-110-120	8.2	534	0.31	0.03	0.28	31	9	22	3.44
BH4-120-125	8.0	465	0.30	0.03	0.27	26	8	18	3.25
BH4-135-140	7.6	479	0.28	0.04	0.24	37	8	29	4.63
BH4-170-175	7.2	1103	0.47	0.10	0.37	36	12	24	3.00
T-11	7.5	1410	1.09	0.38	0.71	14	22	-8	0.64
T-24B	7.1	2480	1.12	0.51	0.61	8	19	-11	0.42
Mean*	7.45	1148.81	0.60	0.20	0.41	31	12.8	18.2	2.42
Std. Dev.*	0.31	578.99	0.32	0.16	0.23	9.53	7.14	2.4	1.34
97-T-1			1.220	0.260	0.960	34	30	4.0	1.1
97-T-2			0.980	0.160	0.820	47	26	21.4	1.8
97-T-3			1.580	1.280	0.300	45	9	35.6	4.8
97-T-4			2.220	0.200	2.020	33	63	-30.1	0.5
97-T-5			1.450	0.005	1.445	45	45	-0.2	1.0
97-T-6			0.770	0.090	0.680	36	21	14.8	1.7
97-T-7			0.710	0.250	0.460	28	14	13.6	1.9
Mean*			1.28	0.32	0.96	38.29	29.84	8.44	1.85
Std. Dev.*			0.53	0.43	0.60	7.34	18.67	20.63	1.40

*Statistics for NP-AP and NP/AP were calculated by subtracting and dividing, respectively, the mean and standard deviations for NP and AP.

Table 2

Solids Analyses by ICP for Questa Tailings

Element (mg/kg)	Surface and Near-Surface Tailings Samples												Mean	Std. Dev
	VC1 0-25	VC1 10-20	VC1 20-21.5	VC3 5-7.5	VC3 10-15	VC4 2.5-5	VC4 25-26.5	9208 T-1	9208 T-11	9208 T-13	9208 T-17	9208 T-20		
Aluminum	14400	25100	8000	21400	22300	17700	29100	19700	18000	18000	14100	32200	20000	6664
Antimony	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	0.000
Arsenic	<2	8	2	6	2	2	6	8	4	6	8	8	5.5	2.5
Barium	120	150	30	150	120	150	210	160	150	140	110	220	142.5	48.5
Beryllium	1.5	2.5	0.5	2	2	1.5	3	2	2	1.5	1.5	3	1.9	0.7
Bismuth	6	8	<2	8	4	6	8	6	6	8	6	8	6.7	1.3
Cadmium	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5	0.58	0.19
Calcium	19400	19000	12900	19200	17500	20800	24300	22900	20700	18000	17000	20300	19333	2930
Chromium	154	133	104	144	124	136	124	175	133	161	172	109	139.1	22.9
Cobalt	8	7	3	10	6	11	8	8	12	10	9	7	8.3	2.4
Copper	140	178	87	202	121	216	183	178	178	195	135	152	163.8	37.4
Fluoride	5050	5550	2200	5000	4200	4760	5780	5300	5500	4600	4430	4480	4737.5	940.0
Gallium	<10	10	<10	<10	<10	<10	10	10	<10	<10	<10	10	10	0
Iron	16400	18800	8800	21900	17100	21400	20800	18800	21500	20600	19900	22100	19008	3707
Lanthanum	10	10	30	10	20	10	20	10	10	10	20	20	15.0	6.7
Lead	32	40	76	52	66	52	62	42	48	50	74	72	55.5	14.4
Magnesium	9400	18400	2300	13200	12900	10000	15600	11300	10300	11300	7900	16900	11625	4307
Manganese	510	645	700	535	830	510	645	585	490	530	860	630	622.5	123.2
Mercury	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
Molybdenum	233	257	128	136	272	194	328	206	227	117	198	352	220.7	74.4
Nickel	29	40	6	37	30	33	40	33	36	34	27	40	32.1	9.3
Phosphorus	890	1150	270	1240	860	1170	1670	1260	1250	1120	750	1350	1081.7	353.2
Potassium	8100	11700	2700	10200	9400	9500	12400	9900	9200	9100	5800	12600	9217	2775
Scandium	5	9	<1	7	7	6	8	6	6	6	4	8	6.5	1.4
Selenium														
Silver	0.2	0.6	<2	0.6	0.2	0.8	0.8	0.6	0.8	0.8	0.4	1	0.62	0.26
Sodium	400	400	800	500	500	500	500	500	400	500	700	600	525	122
Strontium	144	178	52	190	140	173	253	166	177	170	91	242	164.7	55.6
Tellurium	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	0.0
Thallium														
Titanium	600	1000	<100	900	800	900	900	900	900	900	700	900	855	113
Tungsten	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	0.0
Uranium	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	0.0
Vanadium	49	74	12	84	58	57	77	57	57	56	43	81	58.8	19.6
Zinc	108	118	116	182	134	156	144	128	134	172	156	146	141.2	22.6

Solids Analyses by ICP for Questa Tailings

Element (mg/kg)	Tailings Samples from Drillhole Sampling Program														mean	standard deviation
	BH1-40	BH1-72	BH1-107	BH1-123	BH1-135	BH1-176	BH2-19	BH2-70-75	BH3-37	BH3-69	BH3-84	BH3-111	BH4-75-80	BH4-110-120		
Aluminum	2140	3460	4800	8050	12900	14400	7900	10100	11600	7820	4970	2730	9140	8270	7734	3771
Antimony	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
Arsenic	1.9	1.5	3.2	2.2	1.9	1.6	2.9	1.3	3.6	2.1	1.7	2	1.7	1.9	2.1	0.7
Barium	6.4	7.2	31	65.3	127	118	70.1	103	96.9	60.9	20.6	10	94.9	42.6	61.0	42.3
Beryllium																
Bismuth																
Cadmium	2.4	2.8	1.3	0.7	1	0.5	0.8	1	1.4	1.7	1.6	1.3	1.3	1.5	1.4	0.6
Calcium	10500	7030	14500	15300	18400	15800	15500	17600	18500	17300	11600	11300	18800	14000	14724	3514
Chromium	<2	2	22	43	65	67	35	44	56	32	11	3	35	36	32	23
Cobalt	<2	2	5	8	11	19	11	8	13	6	4	1	9	6	7	5
Copper	87	73	90	104	104	163	129	123	119	99	90	65	144	107	107	27
Fluoride																
Gallium																
Iron	5150	5440	10000	14800	19700	25900	18300	16700	23100	13300	6900	5220	15600	12700	13772	6693
Lanthanum																
Lead	101	107	57	37	69	26	99	83	54	131	123	74	102	123	85	33
Magnesium	960	1220	5060	7670	12200	12700	7580	9640	11300	6860	2580	1300	7270	5800	6581	4024
Manganese	581	597	748	693	896	728	724	893	1020	853	592	713	800	1130	783	162
Mercury		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.00
Molybdenum	279	255	201	190	229	170	190	272	167	283	200	215	292	222	226	43
Nickel	2	5	19	32	40	58	33	30	39	21	11	4	30	20	25	16
Phosphorus																
Potassium	730	610	1840	3210	5410	5820	3870	4640	5110	3090	1060	920	3490	2500	3021	1808
Scandium																
Selenium	<0.2	0.3	0.2	0.5	0.3	0.9	0.7	0.3	0.4	0.3	0.3	<0.1	0.6	0.2	0.3	0.3
Silver	<1	0.7	0.8	1.4	0.5	2.7	5.7	<0.7	0.8	0.8	0.6	<0.6	<0.7	0.6	0.8	1.7
Sodium	90	90	110	120	240	220	110	220	190	140	80	100	140	230	149	59
Strontium	17	12	40	108	144	189	97	116	92	99	47	25	131	67	85	52
Tellurium																
Thallium	<40	<20	<20	<20	<20	<20	<20	<30	<20	<20	<20	<20	<30	<20	<20	6
Titanium																
Tungsten																
Uranium																
Vanadium	2	4.2	16.7	30.7	51.7	53.5	32.2	38.1	53	26.7	9.3	3.8	28.6	25.7	26.9	18.1
Zinc	276	335	160	93	133	88	107	137	177	202	207	153	175	203	175	69

Tab[illegible]

Leach Extraction Results

Parameter (mg/L)	Borehole Samples																	
	BH1-40	BH1-72SP	BH1-107	BH1-123	BH1-135	BH1-176	BH2-19	BH2-70-75	BH3-37	BH3-69	BH3-84	BH3-111	BH4-75-80	BH4-110 120	Mean	Std. Dev.	Min.	Max.
Aluminum	0.05	0.08	0.08	0.13	0.07	0.11	0.06	0.06	0.04	0.03	<0.03	0.03	0.06	0.07	0.07	0.03	0.03	0.13
Antimony	0.002	0.002	0.002	0.002	0.003	0.002	<0.002	0.004	<0.002	<0.002	<0.002	0.002	0.004	0.004	0.003	0.001	0.002	0.004
Arsenic	0.006	0.001	0.001	0.001	0.001	0.001	<0.001	0.002	<0.001	0.002	<0.001	<0.001	<0.001	0.001	0.002	0.002	0.001	0.006
Barium	0.016	0.016	0.021	0.026	0.034	0.033	0.028	0.029	0.018	0.035	0.025	0.021	0.026	0.014	0.02	0.01	0.01	0.04
Cadmium	<0.0006	0.016	<0.0006	<0.0005	<0.0006	<0.0005	0.0023	0.0007	0.0028	0.0042	0.0023	0.0009	0.0009	<0.0006	0.00	0.01	<0.0006	0.02
Calcium	57.2	86.6	103	109	485	93.6	498	413	535	243	320	124	382	113	254.46	177.83	57.20	535.00
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.02	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	0.00	0.01	0.01
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
Copper	0.01	0.02	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.01	0.01	<0.01	0.01	0.01	0.01	0.00	0.01	0.02
Flouride	2.8	inpg	3.8	inpg	2.7	inpg	inpg	1.9	3	3.4	inpg	1.9	1.9	4	2.82	0.81	1.90	4.00
Iron	<0.01	<0.01	0.03	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01	0.01	0.01	0.03
Lead	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.00	0.00	0.00
Magnesium	7.3	9.6	11	13.4	22.5	4.8	15.4	20.1	29.1	14.2	11.8	7.5	20.4	5.9	13.79	7.08	4.80	29.10
Manganese	0.583	1.88	0.893	1.29	0.561	0.262	1.04	0.804	1.94	1	1.27	0.944	0.854	0.365	0.98	0.50	0.26	1.94
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.00	0.00	0.00
Molybdenum	0.57	6.72	4.73	5.47	6.14	7.66	2.08	8.59	3.17	2.76	0.22	1.77	3.89	5.82	4.26	2.61	0.22	8.59
Nickel	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.00	0.01	0.01
Potassium	21.3	25.8	28.3	30.9	31.1	19.4	26.4	33	43	46.6	22.8	18.1	34	16.2	28.35	8.94	16.20	46.60
Selenium,	0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.003	0.002	0.001	<0.001	<0.002	<0.001	0.00	0.00	<0.001	0.003
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.029	0.041	<0.005	<0.005	<0.005	0.007	0.03	0.02	<0.005	0.04
Sodium	9	22.7	12.8	16	37	44.1	12	28.6	20.3	18.1	12	13.6	27.3	48.1	22.97	12.50	9.00	48.10
Strontium	0.81	6.23	1.55	4.86	6.11	6.01	6.34	6.55	8.17	4.49	4.4	2.22	7.15	2.67	4.83	2.24	0.81	8.17
Thallium	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.00	< 0.2	< 0.2
Vanadium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.00	<0.005	0.00
Zinc	0.01	0.02	0.01	0.01	0.01	<0.01	0.02	0.01	0.02	0.04	0.02	0.01	0.01	0.01	0.02	0.01	<0.01	0.04
pH	7.5	7.4	7.2	7.6	7.5	7.7	7.4	7.3	7.1	7.2	7.5	7.1	7.6	7.6	7.41	0.20	7.10	7.70
Conductivity (µS/cm	0.46	0.74	0.73	0.79	2.33	0.79	2.26	2.01	2.3	1.4	1.61	0.8	1.99	0.92	1.37	0.69	0.46	2.33
Sulfate	200	330	350	350	1590	350	1560	1290	1540	760	990	390	1140	440	805.71	528.30	200.00	1590.00

1:1 liquid to solids ratio

Table 3.3
Leach Extraction Results

Parameter (mg/L)	Surface Samples											
	97-T-1	97-T-2	97-T-3	97-T-4	97-T-5	97-T-6	97-T-7	T-11	T-24B	Mean	Min.	Max.
Aluminum	0.11	0.11	<0.06	0.11	0.12	0.13	0.12	0.06	0.03	0.09	0.03	0.13
Antimony	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	0.002	0.002
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	0.001	0.005	0.001	0.005
Barium	0.036	0.024	0.027	0.021	0.019	0.021	0.025	0.046	0.018	0.03	0.018	0.046
Cadmium	0.0019	0.0011	0.0008	0.0007	0.0017	0.0011	0.0006	0.0011	0.01	0.002	0.0006	0.01
Calcium	549	549	364	268	475	477	299	255	553	421.00	255	553
Chromium	<0.01	<0.01	<0.02	<0.02	<0.01	<0.02	<0.01	<0.01	0.01	0.01	0.01	0.02
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	0.01	0.01	0.02
Copper	0.01	0.01	0.01	0.01	0.01	0.05	0.02	0.01	0.02	0.02	0.01	0.05
Flouride	2	2.3	1.2	1.8	3.3	3.3	2.1	inpg	inpg	2.29	1.2	3.3
Iron	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01
Lead	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.05	0.04	0.04	0.05
Magnesium	24	4.7	31	23.6	32.7	42.7	36.3	18.1	43.4	28.50	4.7	43.4
Manganese	0.139	0.103	0.128	0.04	0.681	0.291	0.071	0.18	4.05	0.63	0.04	4.05
Mercury	0.0005	0.0004	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0004	<0.0002	0.000	0.0002	0.0005
Molybdenum	3.88	3.98	6.2	7.63	4.52	9.12	6.52	4.65	1.35	5.31	1.35	9.12
Nickel	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.01	0.01	0.04
Potassium	18.1	16.1	41.8	33.5	30.8	47.2	41.5	23.9	9.6	29.17	9.6	47.2
Selenium,	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.001	<0.001	0.004	0.00	0.001	0.004
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	0.012	<0.005	<0.005	<0.005	0.01	0.005	0.012
Sodium	4.3	4.1	19.8	17.8	18.2	25.7	21.7	14.8	2.6	14.33	2.6	25.7
Strontium	6.71	4.53	10.4	8.13	6.45	8.24	9.71	6.23	2.65	7.01	2.65	10.4
Thallium	<0.02	<0.02	<0.04	<0.04	<0.02	<0.04	<0.02	< 0.2	< 0.2	0.03	0.02	0.04
Vanadium	<0.005	<0.005	<0.01	<0.01	<0.005	<0.01	<0.005	<0.005	<0.005	0.01	0.005	0.01
Zinc	0.04	0.02	0.02	0.02	0.04	0.02	0.02	0.01	0.16	0.04	0.01	0.16
pH	7.3	6.8	7	7.3	7.2	7.4	7.1	7.5	7.1	7.19	6.8	7.5
Conductivity (µS/cm	2.4	2.36	1.85	1.63	2.6	2.68	1.78	1.41	2.48	2.13	1.41	2.68
Sulfate	1270	1270	930	730	1490	750	1050	810	1660	1106.67	730	1660

1:1 liquid to solids ratio

Table 3.4
Acid-Generating Potential of Humidity Cell Samples

Cell No.	Sample No.	Paste pH	Paste Conductivity (µS/cm)	Total Sulfur %	Sulfate Sulfur %	Sulfide Sulfur %	Neutralization Potential (modified) tons $CaCO_3$ eq./kiloton	Acid Generating Potential (AP) tons $CaCO_3$ eq./kiloton	Net Neutralizing Potential (modified) tons $CaCO_3$ eq./kiloton	NP/AP (modified)
1	T-24B	7.1	2480	1.12	0.51	0.61	8	19	-11	0.42
2	T-11	7.5	1410	1.09	0.38	0.71	14	22	-8	0.64
3	BH1-72	7.3	591	0.31	0.01	0.30	10	9	1	1.11
4	BH2-19	7.0	1887	1.19	0.26	0.93	33	29	4	1.14
5	BH3-84	7.2	1064	0.65	0.39	0.26	14	8	6	1.75
6	BH1-176	7.7	662	1.16	0.3	0.86	45	27	18	1.67
7	BH3-111	7.2	757	0.3	0.13	0.17	21	5	16	4.20
8	BH1-123	7.5	702	0.55	0.17	0.38	39	12	27	3.25
9	BH4-75-80	7.2	1315	0.61	0.13	0.48	37	15	22	2.47
Mean*		7.3	1208	0.78	0.25	0.52	25	16	8	1.51
Min		7.0	591.0	0.3	0.0	0.2	8.0	5.0	-11.0	0.4
Max		7.7	2480.0	1.2	0.5	0.9	45.0	29.0	27.0	4.2
All tailings samples				0.92	0.31	0.61				1.12
Mean*		7.5	1149	0.60	0.20	0.41	31	13	18	2.42
Min		7.0	451	0.17	0.01	0.17	8	5	-11	0.42
Max		8.2	2480	1.2	0.70	1.05	45	33	34	5.00

*Statistics for NP-AP and NP/AP were calculated by subtracting and dividing, respectively, the mean and standard deviations for NP and AP.

Table 3.5
Total Metals Concentrations in Humidity Cell Samples

Parameter	Kinetic Test Samples (N=9)			All Tailings Samples Tested (N=26)		
(mg/kg)	mean	minimum	maximum	mean	minimum	maximum
Aluminum	7734	2140	14400	11872	800	32200
Arsenic	2.1	1.3	3.6	3.58	1.3	8
Barium	61.0	6.4	127.0	98.6	6.4	220
Cadmium	1.4	0.5	2.8	1.01	0.5	2.8
Calcium	14724	7030	18800	16851	7030	24300
Chromium	32	<2	67	84.8	2	175
Cobalt	7	<2	19	8.08	1	19
Copper	107	65	163	133.2	65	216
Fluoride	na	na	na	4737.5	2200	5780
Iron	13772	5150	25900	16189	5150	25900
Lead	85	26	131	84.7	26	131
Magnesium	6581	960	12700	8909	960	18400
Manganese	783	581	1130	709.2	490	1130
Molybdenum	226	167	292	223.6	117	352
Nickel	25	2	58	28.0	2	58
Selenium	0.3	<0.2	0.9	0.417	0.2	0.9
Silver	0.8	<1	5.7	1.02	0.2	5.7
Vanadium	26.9	2.0	53.5	41.6	2	84
Zinc	175	88	335	159.2	88	335

na = not analyzed for this element.

Table 3.6
Soluble Metals Concentrations in Humidity Cell Samples

Parameter	Kinetic Test Samples (N=9)			All Tailings Samples Tested (N=23)		
(ppm)	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Aluminum	0.07	0.03	0.13	0.08	0.03	0.13
Antimony	0.002	0.002	0.004	0.002	0.002	0.004
Arsenic	0.001	0.001	0.001	0.003	0.001	0.006
Barium	0.027	0.016	0.046	0.025	0.014	0.046
Cadmium	0.005	0.001	0.016	0.003	0.001	0.016
Calcium	269	87	553	320	57	553
Chromium	0.01	0.01	0.01	0.01	0.01	0.02
Cobalt	0.00	0.00	0.00	0.01	0.01	0.02
Copper	0.01	0.01	0.02	0.01	0.01	0.05
Flouride	1.90	1.90	1.90	2.59	1.20	4.00
Iron	0.01	0.01	0.01	0.01	0.01	0.03
Lead	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium	16.0	4.8	43.4	19.5	4.7	43.4
Manganese	1.31	0.18	4.05	0.84	0.04	4.05
Mercury,	0.0004	0.0004	0.0004	0.0003	0.0002	0.0005
Molybdenum	3.76	0.22	7.66	4.67	0.22	9.12
Nickel	0.03	0.01	0.04	0.01	0.01	0.04
Potassium	23.4	9.6	34.0	28.7	9.6	47.2
Selenium,	0.002	0.001	0.004	0.002	0.001	0.004
Silver	0	0	0	0.0119	0.005	0.041
Sodium	18.3	2.6	44.1	19.6	2.6	48.1
Strontium	5.1	2.2	7.2	5.7	0.8	10.4
Thallium	0.00	0.00	0.00	0.03	0.02	0.04
Vanadium	0.000	0.000	0.000	0.007	0.005	0.010
Zinc				0.03	0.02	0.04
pH	7.43	7.10	7.70	7.32	6.80	7.70
Conductivity	1.4	0.7	2.5	1.7	0.5	2.7
Sulfate	842.2	330.0	1660.0	923.5	200.0	1660.0

1:1 liquid to solids ratio

Table 3.7
Results of the Enhanced H_2O_2 Oxidation Tests
(modified NAG tests)

SAMPLE	SAMPLE WEIGHT (g)	VOLUME 17% H2O2 (mL)	TIME (days)	pH	Redox (mV)	Comments
BH1-72	2.5	250	0.3	3.99		
			1	4.27		
			2	4.37		
			3	4.45		
			4	4.46		
			7	4.57		
			11	5.45		
			15	5.65		
			17	5.61	382	
			24	5.61		
			31	5.6	388	test terminated
BH1-176	2.5	250	0.3	3.4		
			1	3.56		
			2	3.64		
			3	3.67		
			4	3.72		
			7	3.88		
			11	4.02		
			15	4.09		
			17	4.13	458	
			24	4.21		
			31	4.3		
			38	4.26		
			45	4.39		
			52	4.4		
			59	4.43		
			66	4.46		
			73	4.49	457	
BH2-19	2.5	250	0.3	3.17		
			1	3.38		
			2	3.42		
			3	3.42		
			4	3.47		
			7	3.58		
			11	3.69		
			15	3.72		
			17	3.75	476	
			24	3.8		
			31	3.91		
			38	3.93		
			45	4.01		
			52	4.04		
			59	4.05		
			66	4.09		

Table 3.7
Results of the Enhanced H_2O_2 Oxidation Tests
(modified NAG tests)

SAMPLE	SAMPLE WEIGHT (g)	VOLUME 17% H2O2 (mL)	TIME (days)	pH	Redox (mV)	Comments
			73	4.13		
BH2-37	2.5	250	0.3	3.13		
			1	3.28		
			2	3.3		
			3	3.3		
			4	3.34		
			7	3.39		
			11	3.48		
			15	3.48		
			17	3.52	488	
			24	3.54		
			31	3.64		
			38	3.73		
			45	3.78		
			52	3.79		
			59	3.81		
			66	3.83		
			73	3.86		
T-11	2.5	250	0.3	3.84		
			1	4.29		
			2	4.58		
			3	4.78		
			4	4.91		
			7	4.95		
			11	5.45		
			15	5.59		
			17	5.55	390	
			24	5.54		
			31	5.56	399	test terminated

Table 3.8
Humidity Cell Test Set-Up and Samples

Cell No.	Sample No.	Sample Description	Approximate Mass (kg)	Irrigation Volume (mL)	Cell Diameter (cm)	Bed Height (cm)
1	T-24B	aged surface sample, lowest NP/AP encountered	0.25	500	10	2
2	T-11	aged surface sample	0.25	500	10	2
3	BH1-72sp	high S content, NP/AP between 1 and 1.5, aplite	0.25	440	10	2
4	BH2-19	high S content, NP/AP between 1 and 1.5, andesite	0.30	500	10	2
5	BH3-84	high S content, NP/AP between 1.5 and 3, aplite	0.25	425	10	1.5
6	BH1-176	high S content, NP/AP between 1.5 and 3, andesite	0.30	500	10	2
7	BH3-111	potentially non-acid generating, NP/AP>3, aplite	0.30	315	10	1
8	BH1-123	potentially non-acid generating, NP/AP>3, andesite	0.30	500	10	2
9	BH4-75-80	tailings slimes, NP/AP between 1.5 and 3	0.30	500	10	2.5

"--" = Data currently unavailable.

Table 3.9
Summary of Calculated Oxidation Rates

	Oxidation Rate				
Cell	Overall (kgO2/m3/s)	As (mole/m3/s)	Cd (mole/m3/s)	Mo (mole/m3/s)	Zn (mole/m3/s)
1	9.80E-08	3.80E-10	1.40E-10	4.20E-07	8.60E-09
2	8.70E-09	8.60E-10	6.40E-11	1.60E-07	5.80E-09
3	1.60E-08	1.30E-09	4.40E-10	1.80E-07	5.00E-09
4	7.80E-09	9.00E-10	8.60E-11	1.90E-07	3.30E-09
5	6.20E-09	1.30E-09	-	9.70E-08	-
6	7.80E-09	1.10E-09	-	6.50E-08	-
7	5.20E-09	2.30E-09	-	8.00E-08	-
8	7.80E-09	1.10E-09	-	1.20E-07	-
9	1.60E-08	9.60E-10	-	4.70E-08	-

TABLE 3.10
Chemistry of Groundwater Samples Collected from Boreholes

		Sample Number		
		BH-1	BH-3	BH-4
General Chemistry				
Carbonate ($CaCO_3$)	mg/L	< 1	< 1	< 1
Bicarbonate ($CaCO_3$)	mg/L	57	216	482
Hydroxide ($CaCO_3$)	mg/L	< 1	< 1	< 1
Total alkalinity ($CaCO_3$)	mg/L	57	216	482
Chloride	mg/L	11	8	14
Fluoride	mg/L	8.12	3.90	3.20
NO_2/NO_3-N, Total	mg/L	< 0.06	0.96	360
Sulfate	mg/L	1300	890	1200
Total Dissolved Solids	mg/L	2100	1600	2300
Total Metals				
Aluminum	mg/L	< 0.1	< 0.1	< 0.1
Arsenic	mg/L	< 0.005	< 0.005	< 0.005
Barium	mg/L	0.01	0.03	0.05
Cadmium	mg/L	< 0.005	< 0.005	< 0.005
Calcium	mg/L	400	330*	560*
Chromium	mg/L	< 0.01	< 0.01	< 0.01
Copper	mg/L	< 0.01	< 0.01	< 0.01
Iron	mg/L	0.1	< 0.1	0.4
Lead	mg/L	< 0.006+	< 0.003	< 0.006+
Magnesium	mg/L	17	34	36
Manganese	mg/L	2.0	6.3^	4.9
Mercury	mg/L	< 0.0002	< 0.0002	< 0.0002
Molybdenum	mg/L	11*	1.2	3.5
Nickel	mg/L	< 0.02	< 0.02	< 0.02
Potassium	mg/L	31	14	22
Selenium	mg/L	< 0.005	< 0.005	0.007
Silver	mg/L	0.002	< 0.002	< 0.002
Sodium	mg/L	170*	96*	86*
Zinc	mg/L	< 0.02	< 0.02	< 0.02

* Detection limit raised. Dilution required due to analyte concentration.

^ Detection limit raised. Analyte determined at a dilution so that an appropriate post spike concentration could be used.

+ Detection limit raised. Sample diluted to reduce matrix interferences.

Table 4.1
Results of MINTEQA2 Modeling of Leach Extraction Results from Representative Samples

SUPERSATURATED MINERAL PHASES (or minerals close to equilibrium)

MINERAL PHASE	SAMPLE NO.				
	BH1-40	BH1-135	BH4-75-80	T24-B	VC-3,10-20
Al(OH)3	-0.771	-0.637	-0.748	-	-0.358
Al4(OH)10SO4	-0.808	0.380	-0.355	-	1.629
ALUNITE	-0.361	1.453	0.662	-	2.214
ANHYDRITE	-	-0.080	-0.240	-0.034	-0.483
ARAGONITE	-	-0.610	-0.478	-0.670	-0.940
BARITE	0.069	0.877	0.679	0.586	0.464
BOEHMITE	1.017	1.152	1.046	-0.403	1.431
CALCITE	-	-0.456	-0.324	-0.516	-0.786
CELESTITE	-	-0.269	-0.282	-0.646	-0.348
DIASPORE	2.766	2.900	2.794	1.345	3.179
FERRIHYDRITE	1.226	1.196	1.261	0.955	1.063
FLUORITE	0.180	0.686	0.395	1.760	0.219
GIBBSITE (C)	0.892	1.026	0.920	-0.529	1.305
GOETHITE	5.436	5.406	5.471	5.165	5.273
GYPSUM	-	0.180	0.021	0.227	-0.222
K JAROSITE	1.165	2.485	2.206	2.436	2.008
MAGHEMITE	5.849	5.789	5.918	5.306	5.521
RHODOCHROSITE	-	-	-	-0.832	-
OTAVITE	-	-	-	-0.516	-
Ba(AsO4)2	-	4.591	-0.553	2.860	-
Sb(OH)3	-0.887	-0.728	-	-	-
Cu(SbO3)2	-	-0.216	0.560	-	-
MAG-FERRITE	5.894	6.053	6.393	5.048	5.675
LEPIDOCROCITE	4.746	4.716	4.781	4.475	4.583

POSSIBLE MINERAL PHASES PRESENT

MINERAL NAME	MINERAL FORMULA
Al4(OH)10SO4	$Al_4(OH)_{10}SO_4$
ALUNITE	$KAl_3(SO_4)_2(OH)_6$
BARITE	$BaSO_4$
BOEHMITE	ALO(OH)
DIASPORE	ALO(OH)
FERRIHYDRITE	$Fe_5HO_8 \cdot 4H_2O$
FLUORITE	CaF_2
GIBBSITE (C)	$AL(OH)_3$
GYPSUM	$CaSO_4 \cdot 2H_2O$
K JAROSITE	$KFe_3(SO_4)_2(OH)_6$

Table 4.2
Results of MINTEQA2 Modeling of Initial Wash from Humidity Cell Tests

MINERAL PHASE	HUMIDITY CELL NO. 1	HUMIDITY CELL NO. 3	HUMIDITY CELL NO. 4	HUMIDITY CELL NO. 7
Al(OH)3	-0.912	-	-	-0.658
AL4(OH)10SO4	-0.230	-	-	-
ALUNITE	0.855	-	-0.965	-
ANHYDRITE	-0.052	-	-0.015	-
ARAGONITE	-0.450	-0.579	-0.391	-0.598
BARITE	1.210	-0.217	1.298	0.357
BOEHMITE	0.877	0.731	0.471	1.131
CALCITE	-0.296	-0.424	-0.237	-0.444
CELESTITE	-0.644	-	-0.347	-
CHALCEDONY	-0.150	-0.328	-0.398	-0.436
CRISTOBALITE	-0.075	-0.253	-0.323	-0.361
DIASPORE	2.625	2.480	2.219	2.879
FERRIHYDRITE	0.967	1.358	1.216	1.375
FLUORITE	1.928	1.017	0.774	-0.202
GIBBSITE (C)	0.751	0.606	0.345	1.005
GOETHITE	5.178	5.568	5.425	5.585
GYPSUM	0.209	-	0.115	-
K JAROSITE	2.025	0.462	2.169	0.102
QUARTZ	0.353	0.175	0.105	0.067
SiO2 (A, GL)	-0.657	-0.835	-0.906	-0.943
SiO2 (A, PT)	-0.972	-	-	-
MANGANITE		-0.737	-	-
RHODOCHROSITE	-0.177	-0.285	-	-0.837
TENORITE	-0.918	-0.386	-0.728	-0.975
ZNSIO3	2.493	2.237	2.041	2.052
WILLEMITE	-0.714	-	-	-
OTAVITE	0.307	0.719	-0.578	-0.493
ANALCIME	-	-0.530	-	-0.635
HALLOYSITE	2.661	2.013	1.352	2.596
LOW ALBITE	-	-0.244	-	-1.457
ANNITE	-	-	1.235	-
LAUMONITE	1.712	1.127	0.469	1.608
Sb(OH)3 (s)	1.300		0.332	0.319
Cu(SbO3)2	1.359	-0.345	1.314	2.078
BA(ASO4)2	4.481	4.239	5.267	-
Sb2O3 SENARM	0.658	-	-	-
LEUCITE	-0.803	-0.481	-0.993	-0.385
MICOCLINE	1.395	1.540	0.957	1.527
H SANIDINE	0.925	1.070	0.487	1.057
LEPIDOCROCITE	4.488	4.878	4.736	4.897

POSSIBLE MINERAL PHASES PRESENT

MINERAL NAME	MINERAL FORMULA
ARAGONITE	$CaCO_3$
BARITE	$BaSO_4$
BOEHMITE	ALO(OH)
DIASPORE	ALO(OH)
FERRIHYDRITE	$Fe_5OH_8 \cdot 4H_2O$
FLUORITE	CaF_2
GIBBSITE (C)	$AL(OH)_3$
GYPSUM	$CaSO_4 \cdot 2H_2O$
K JAROSITE	$KFe_3(SO_4)_2(OH)_6$
QUARTZ	SiO_2
ZNSIO3	$ZNSIO_3$
HALLOYSITE	$Al_2Si_2O_5(OH)_4 \cdot 2H_2O$
LAUMONITE	$Ca_4(Al_8Si_{16}O_{48}) \cdot 16H_2O$
Sb(OH)3 (s)	$Sb(OH)_{3\,(s)}$
Cu(SbO3)2	$Cu(SbO_3)_2$
MICOLINE	$KAlSi_3O_8$
H SANIDINE	$KAlSi_3O_8$

Table 4.3
Results of MINTEQA2 Modeling of Steady State Solution from Humidity Cell Tests

MINERAL PHASE	HUMIDITY CELL NO. 1	HUMIDITY CELL NO. 3	HUMIDITY CELL NO. 4	HUMIDITY CELL NO. 7
Al(OH)3	-	-0.957	-0.609	-0.529
ARAGONITE	-	-	-	-0.956
BARITE	-0.758	-	-0.453	-
BOEHMITE	0.072	0.832	1.179	1.259
CALCITE	-	-	-	-0.802
CHALCEDONY	-0.651	-0.832	-0.921	-0.795
CRISTOBALITE	-0.576	-0.757	-0.846	-0.720
DIASPORE	1.821	2.581	2.928	3.508
FERRIHYDRITE	1.785	1.860	1.876	1.877
FE3(OH)8	-0.665	-0.478	-	-0.613
FLUORITE	-	-	-0.683	-
GIBBSITE (C)	-0.053	0.706	1.054	1.134
GOETHITE	5.995	6.070	6.085	6.087
K JAROSITE	-0.964	-	-	-
QUARTZ	-0.148	-0.329	-0.418	-0.292
MANGANITE	-	-	-	-0.948
TENORITE	-	-0.974	-	-0.965
ZNSIO3	0.691	1.043	-	-
OTAVITE	-	-0.232	-	-
HALLOYSITE	0.051	1.207	1.723	2.136
KAOLINITE	3.374	-	5.047	5.459
MUSCOVITE	3.784	5.825	6.587	-
PYROPHYLLITE	2.676	3.471	3.809	4.472
LAUMONITE	-	-	-0.615	0.155
Sb(OH)3 (s)	-	-0.858	-0.466	-0.490
Cu(SbO3)2	0.048	0.173	-	1.667
BA(ASO4)2	-	4.163	-	5.632
MICOCLINE	-	-0.736	-0.668	-0.026
H SANIDINE	-	-	-	-0.496
MONTMORILLONITE	2.581	3.856	3.753	4.733
LEPIDOCROCITE	5.305	5.38	5.396	5.397

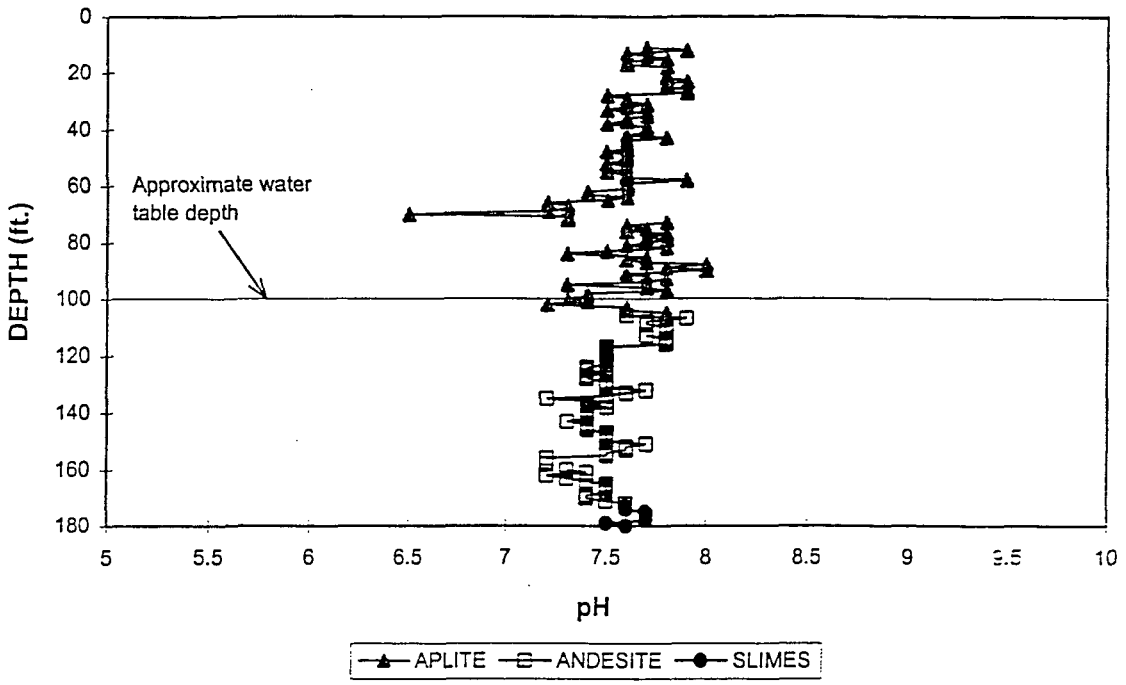
POSSIBLE MINERAL PHASES PRESENT

MINERAL NAME	MINERAL FORMULA
BOEHMITE	ALO(OH)
DIASPORE	ALO(OH)
FERRIHYDRITE	$Fe_5OH_8 \cdot 4H_2O$
GIBBSITE	$AL(OH)_3$
GOETHITE	I-FeO·OH
HALLOYSITE	$Al_2Si_2O_5(OH)_4 \cdot 2H_2O$

FIGURES

Figure 3.1

(a) pH versus Depth for BH1



(b) Conductivity versus Depth for BH1

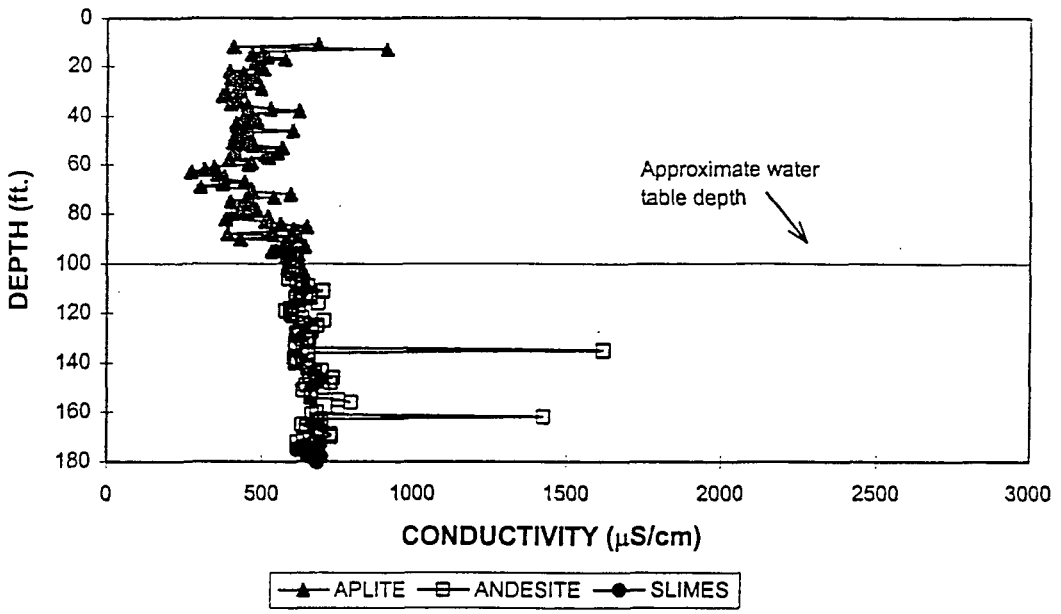
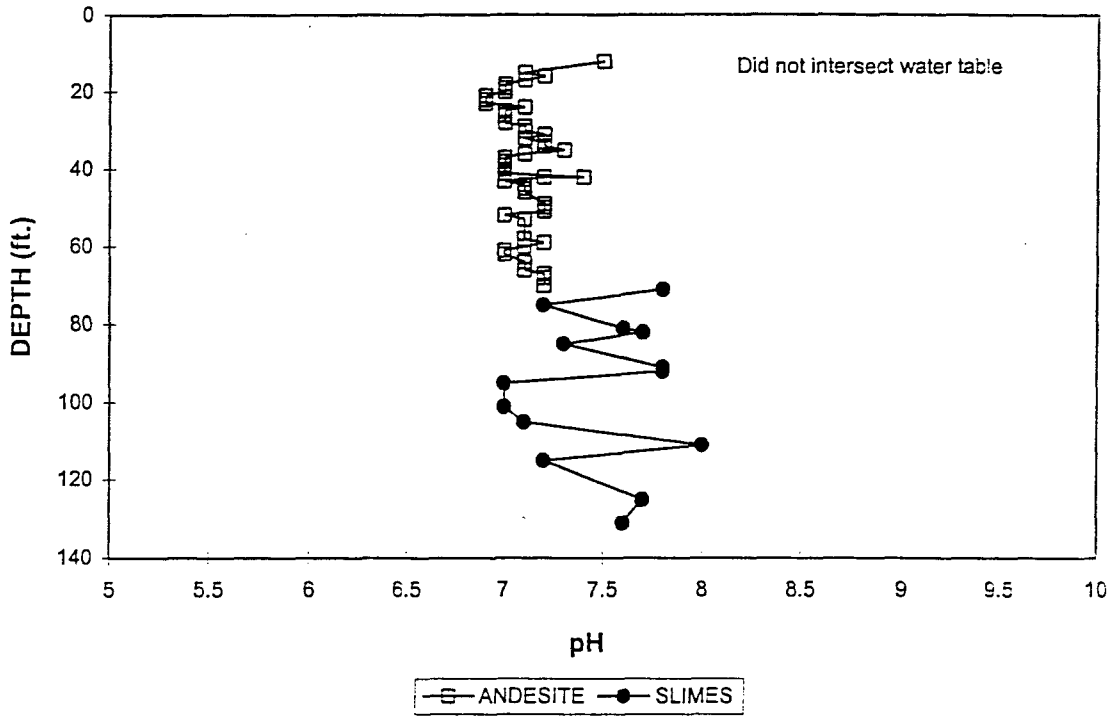


Figure 3.2

(a) pH versus Depth for BH2



(b) Conductivity versus Depth for BH2

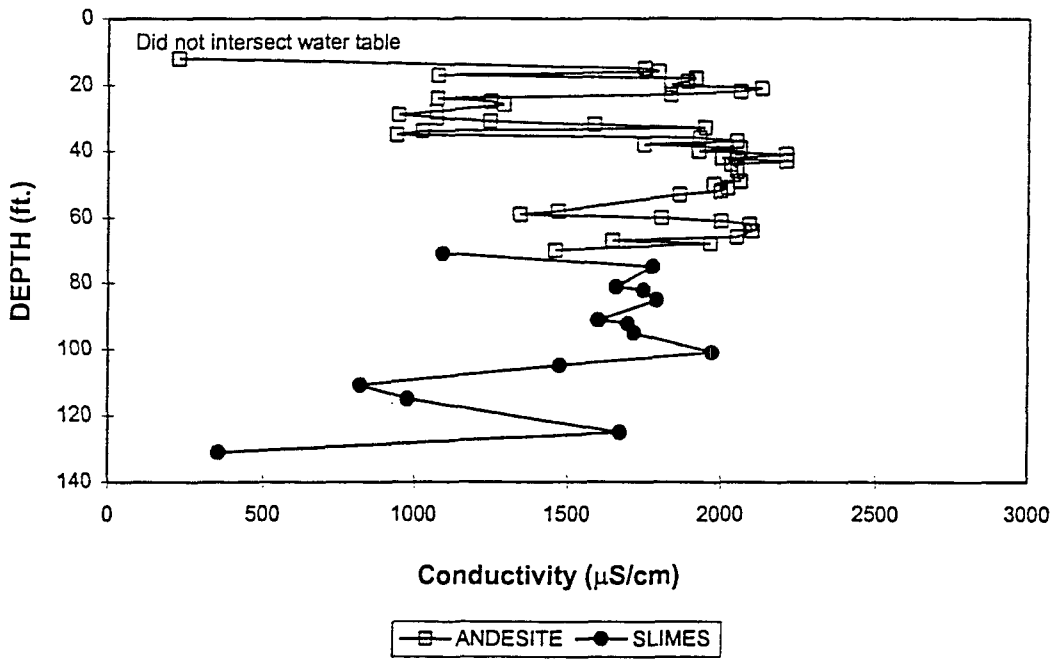
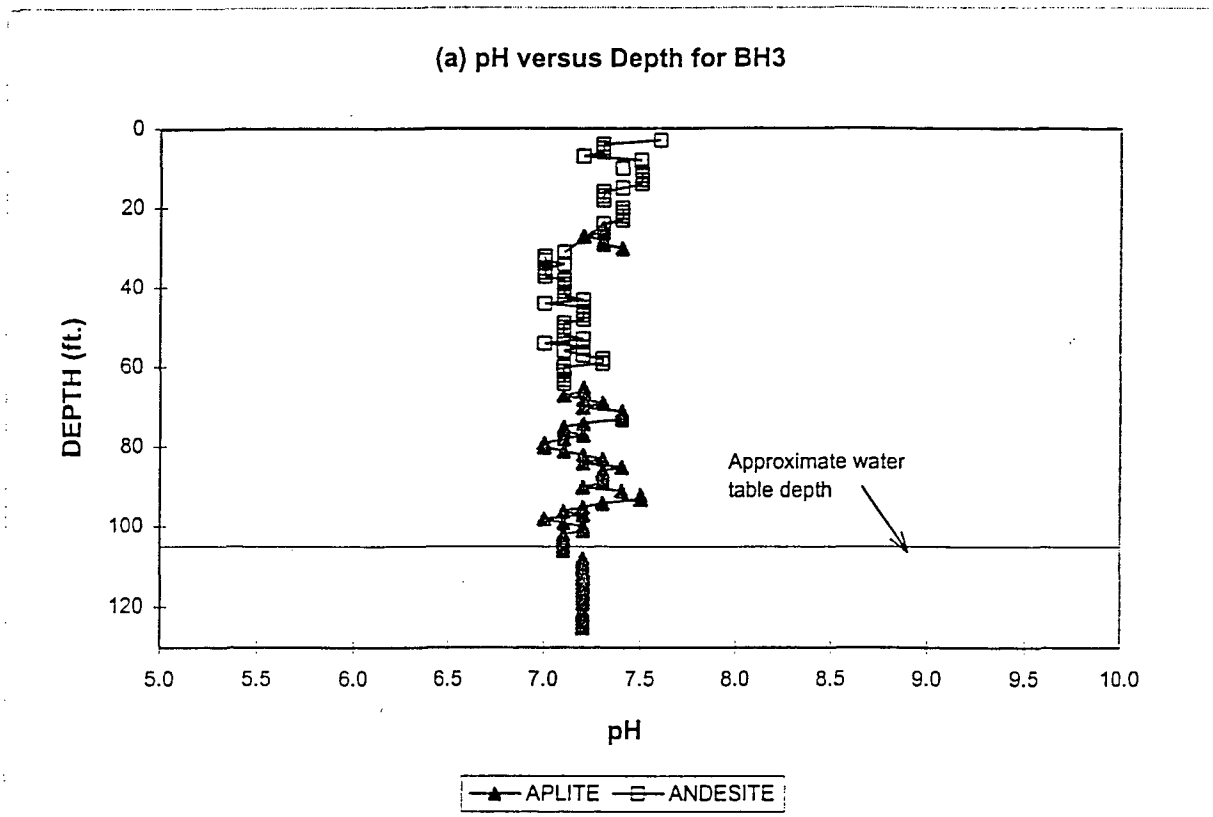


Figure 3.3


(a) pH versus Depth for BH3
DEPTH (ft.)
0
20
40
60
80
100
120
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
pH
Approximate water table depth
APLITE
ANDESITE

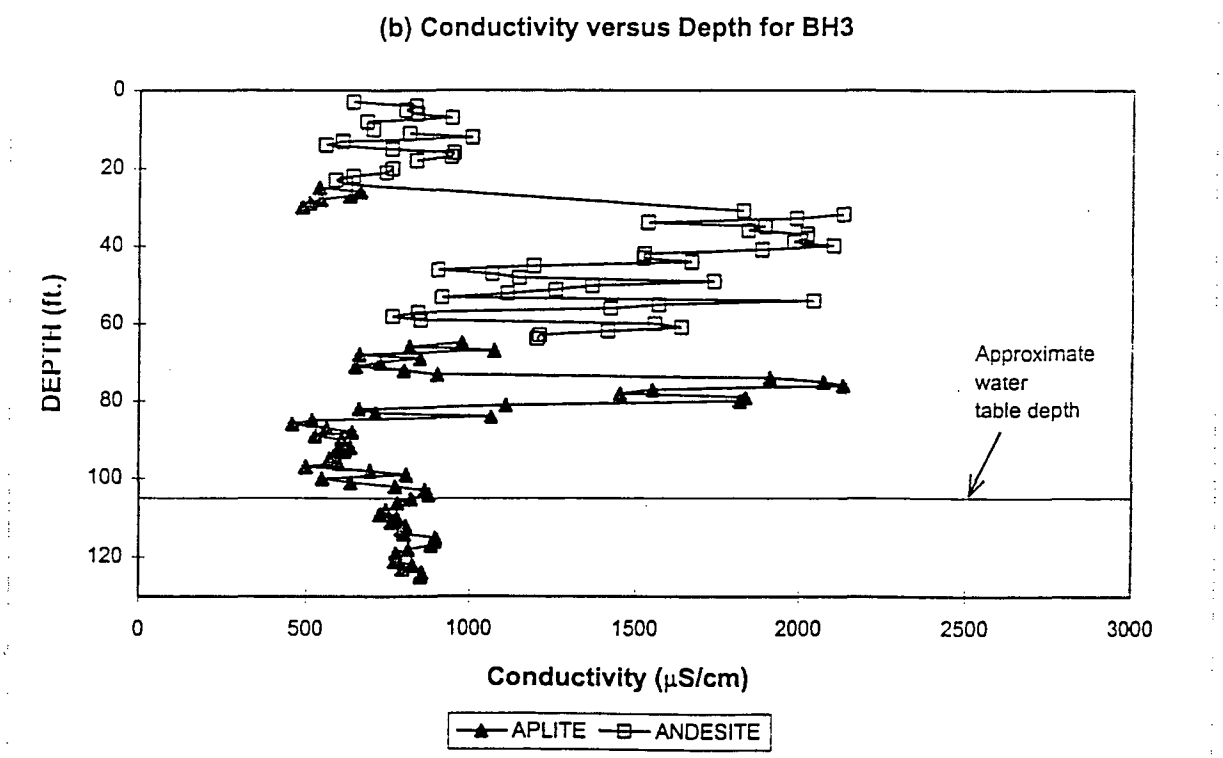
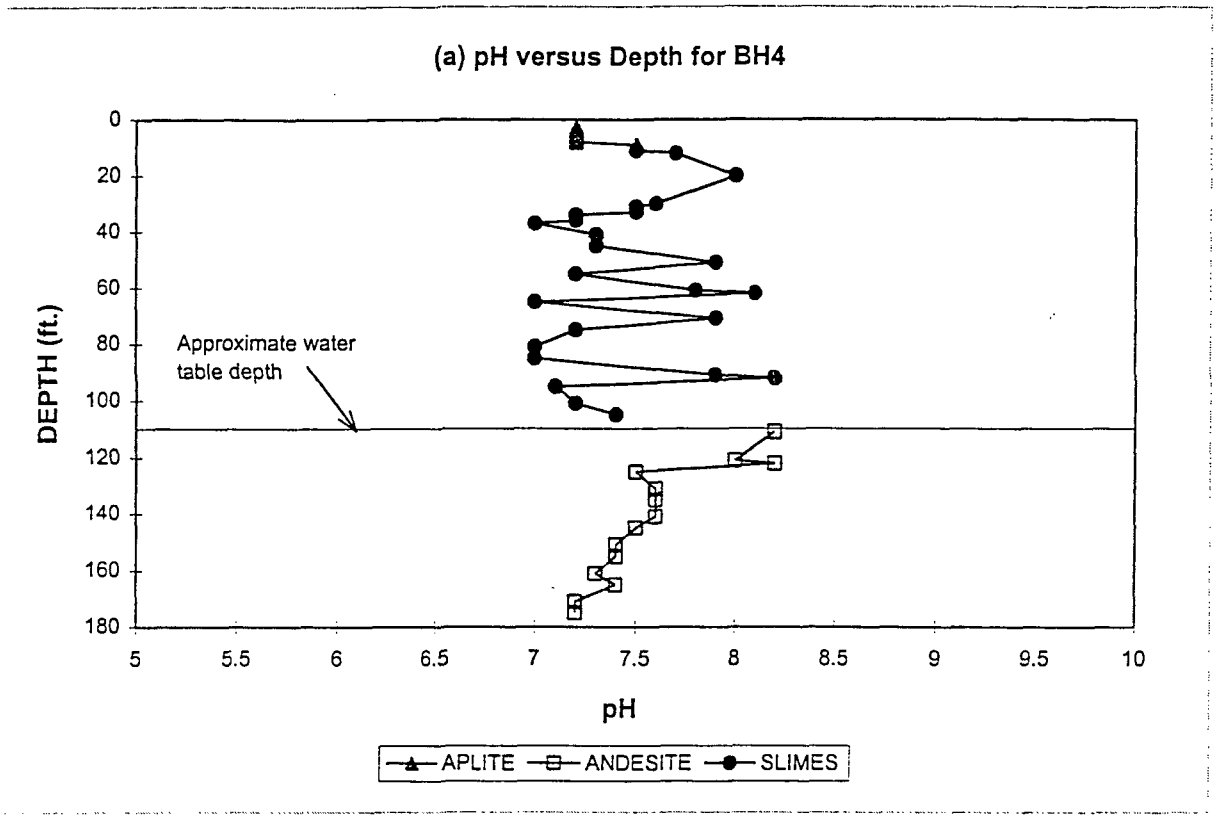

(b) Conductivity versus Depth for BH3
DEPTH (ft.)
0
20
40
60
80
100
120
0
500
1000
1500
2000
2500
3000
Conductivity (µS/cm)
Approximate water table depth
APLITE
ANDESITE

Figure 3.4


(a) pH versus Depth for BH4
DEPTH (ft.)
0
20
40
60
80
100
120
140
160
180
Approximate water table depth
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
pH
APLITE
ANDESITE
SLIMES

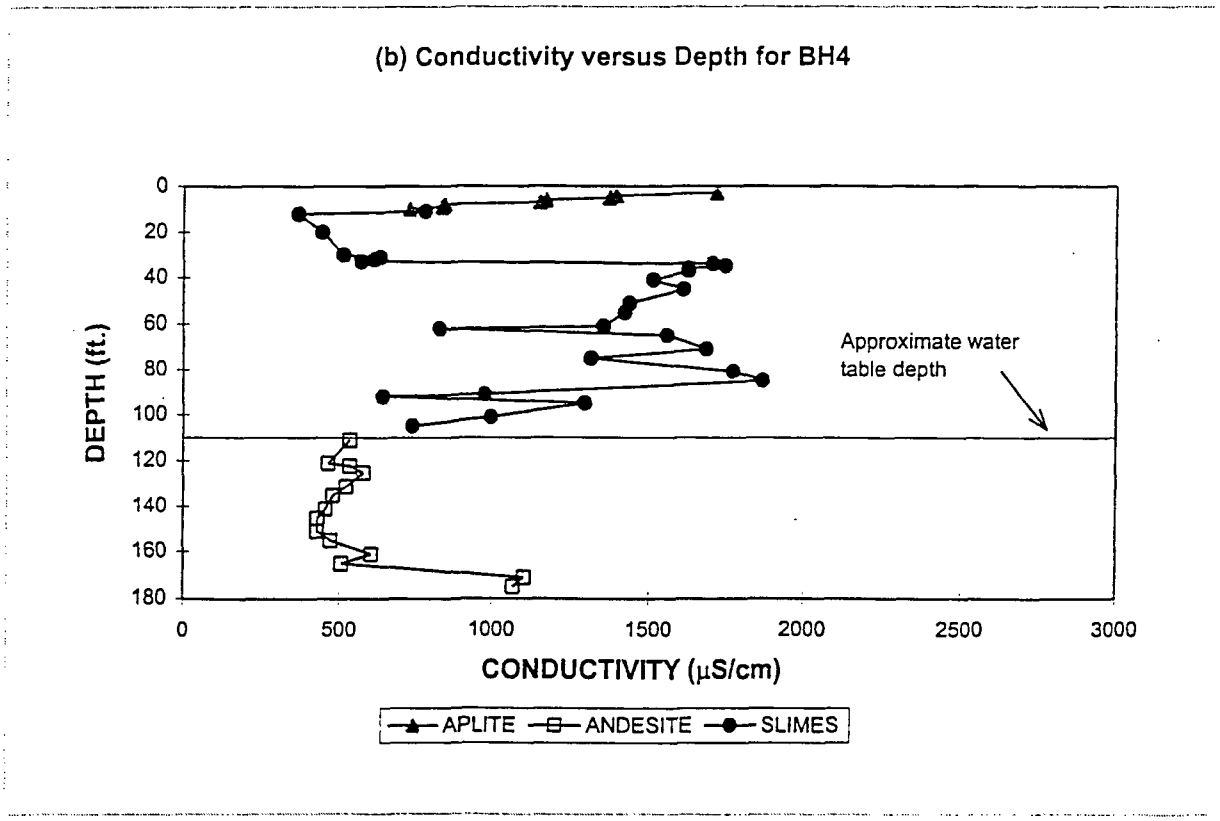

(b) Conductivity versus Depth for BH4
DEPTH (ft.)
0
20
40
60
80
100
120
140
160
180
Approximate water table depth
0
500
1000
1500
2000
2500
3000
CONDUCTIVITY (µS/cm)
APLITE
ANDESITE
SLIMES

Figure 3.5
NP vs AP for Questa Tailings Samples

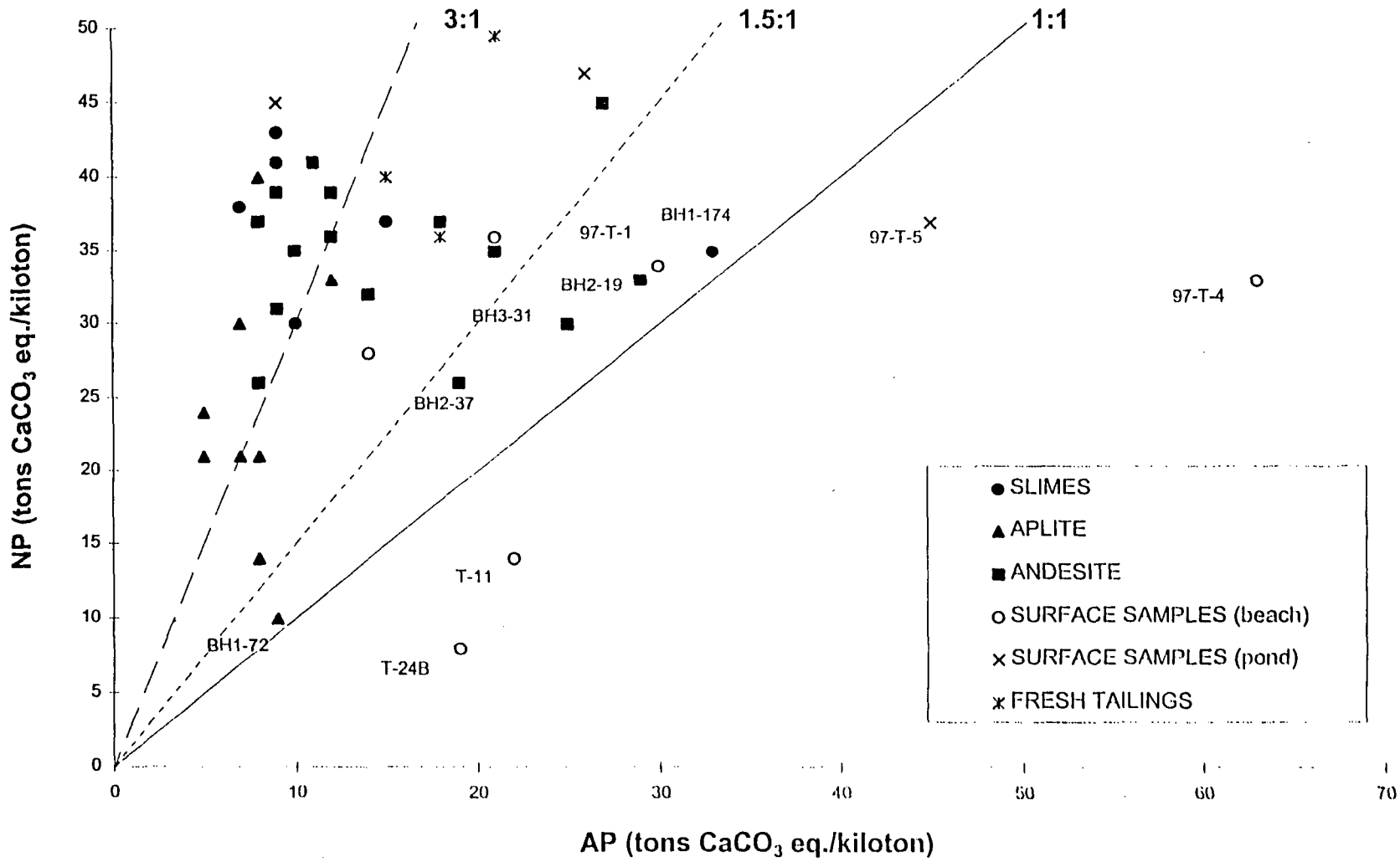
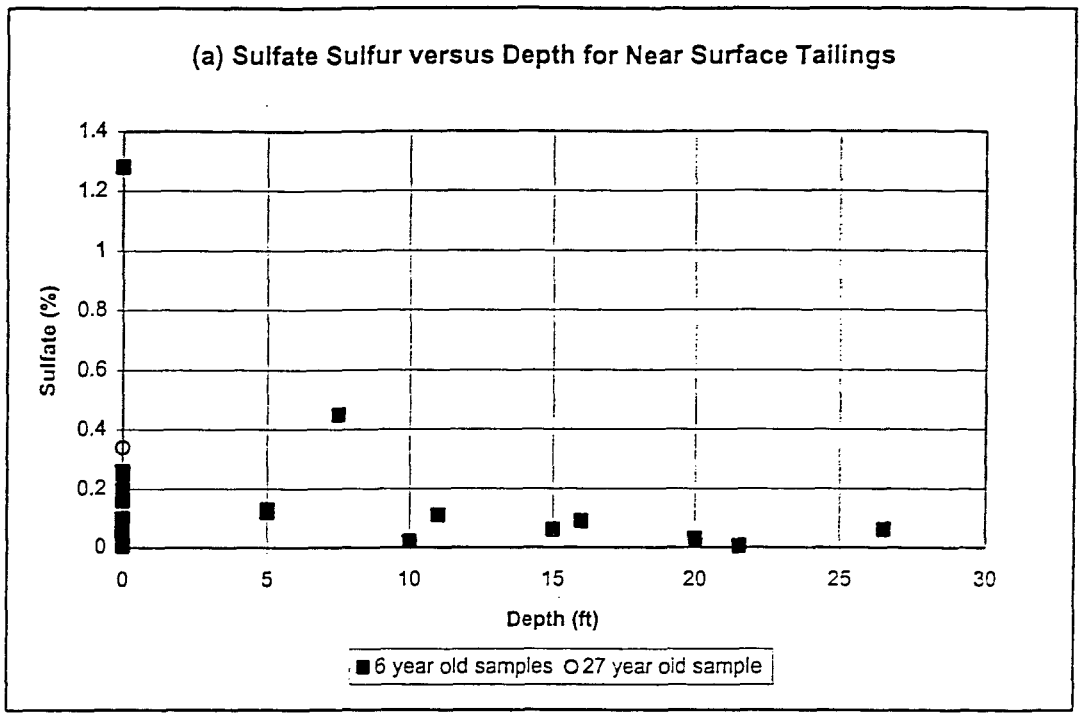


Figure 3.6


(a) Sulfate Sulfur versus Depth for Near Surface Tailings
Sulfate (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Depth (ft)
6 year old samples
27 year old sample

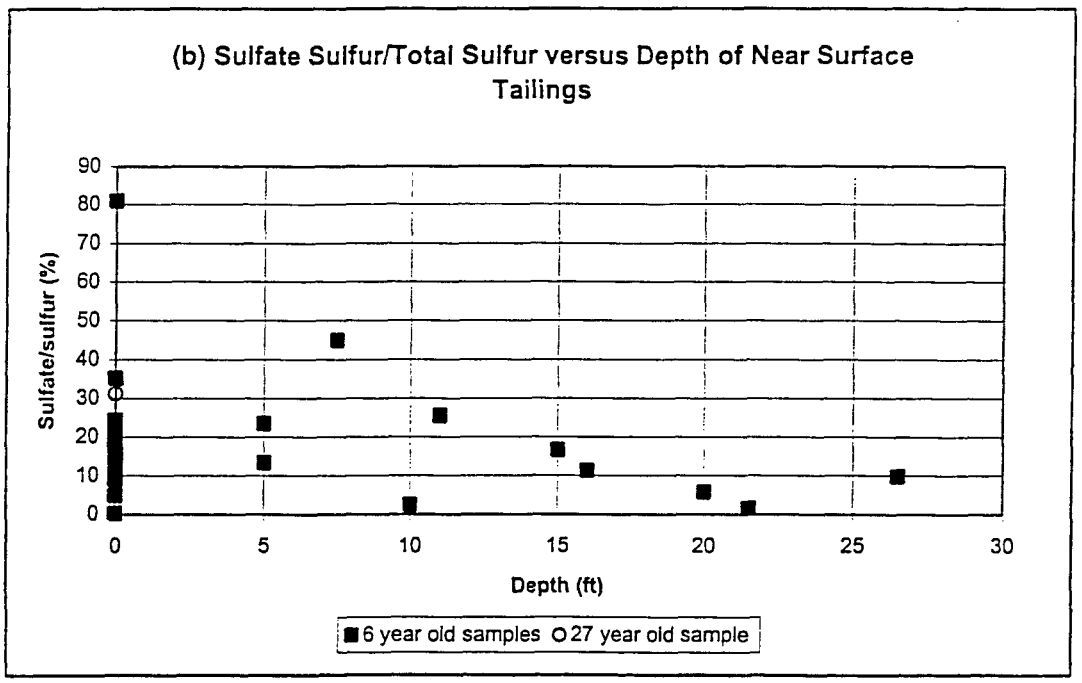
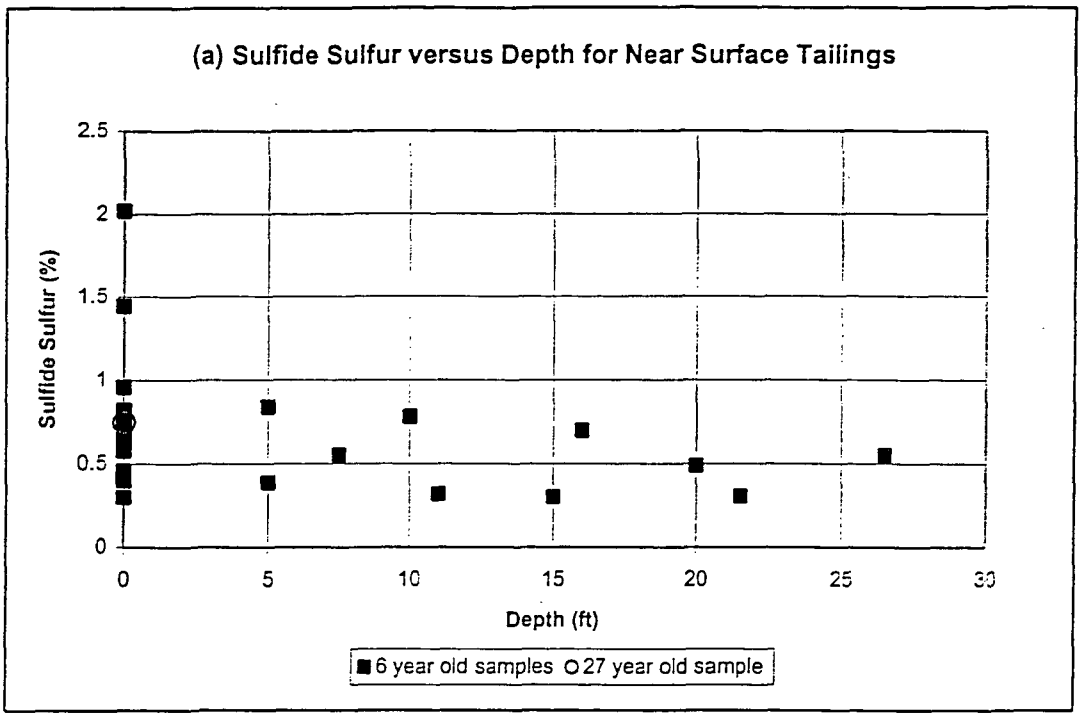

(b) Sulfate Sulfur/Total Sulfur versus Depth of Near Surface Tailings
Sulfate/sulfur (%)
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Depth (ft)
6 year old samples
27 year old sample

Figure 3.7


(a) Sulfide Sulfur versus Depth for Near Surface Tailings
Sulfide Sulfur (%)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
Depth (ft)
6 year old samples
27 year old sample

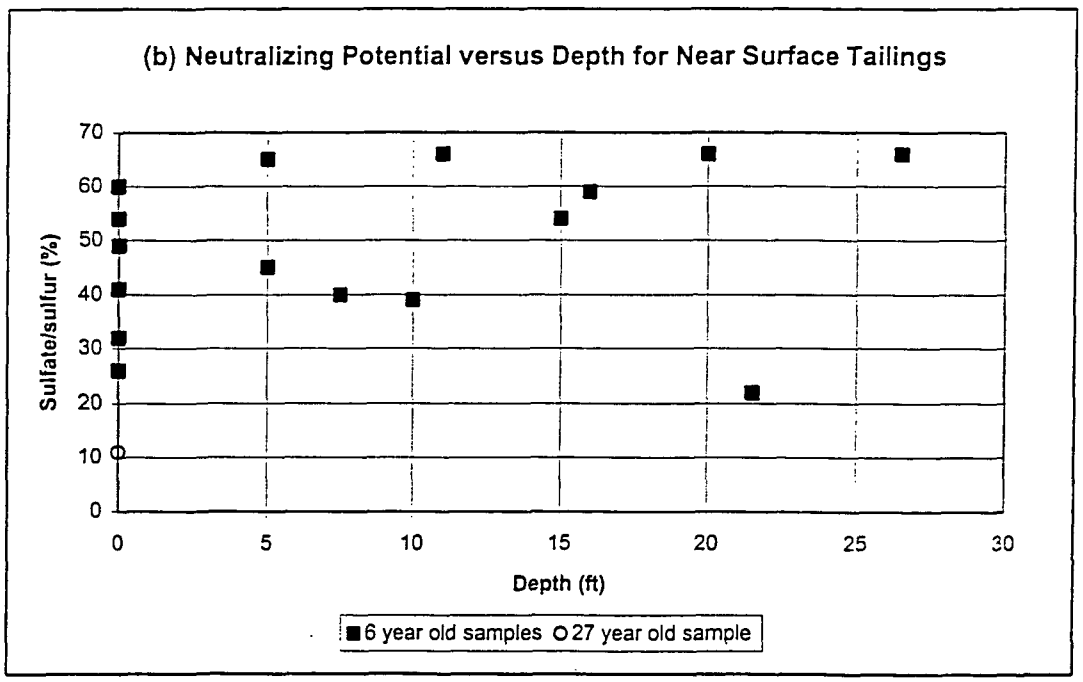

(b) Neutralizing Potential versus Depth for Near Surface Tailings
Sulfate/sulfur (%)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Depth (ft)
6 year old samples
27 year old sample

Figure 3.8
Age Trends in Solids

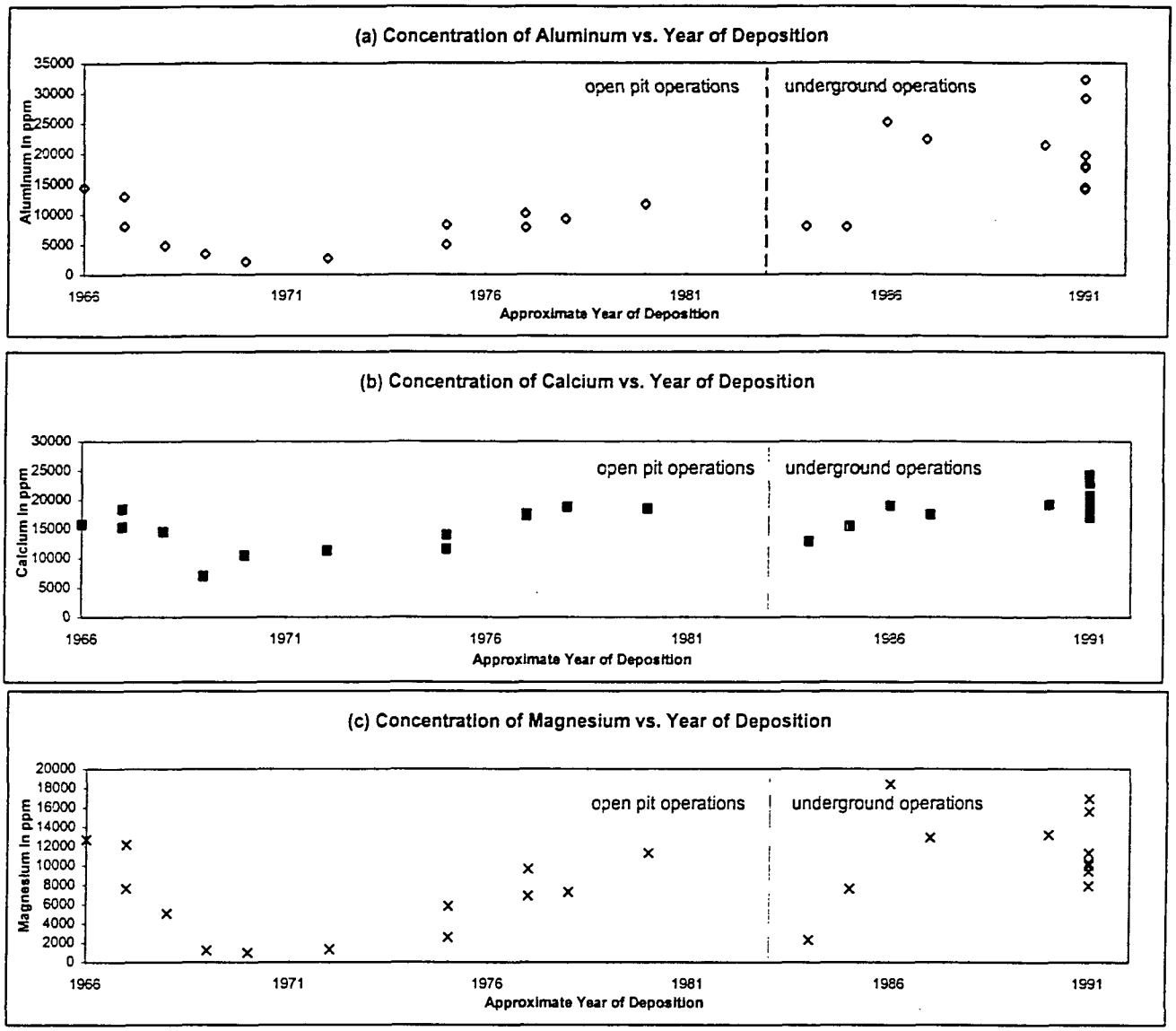
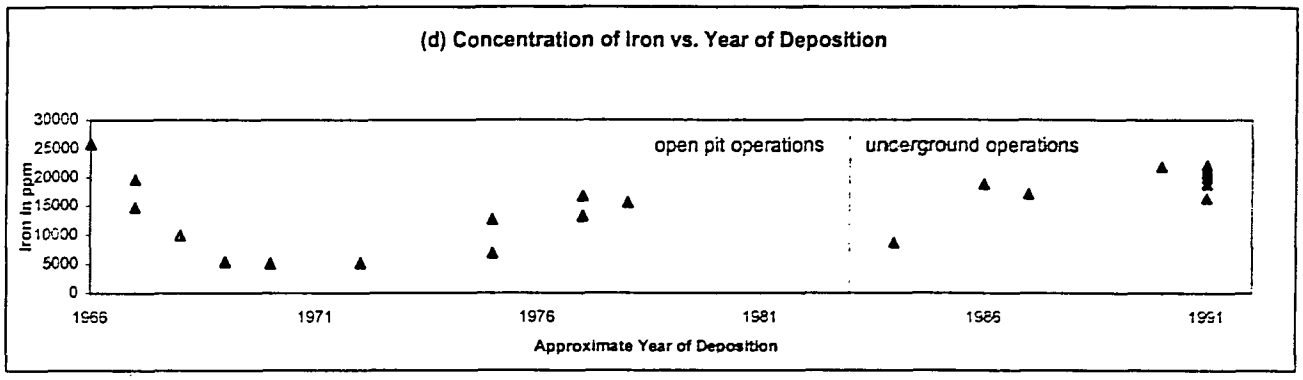
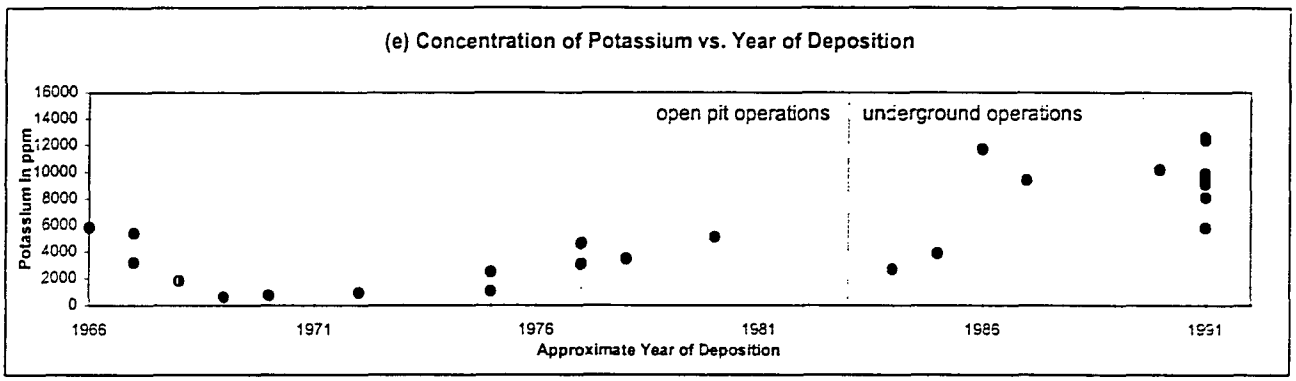


Figure 3.8
Age Trends in Solids





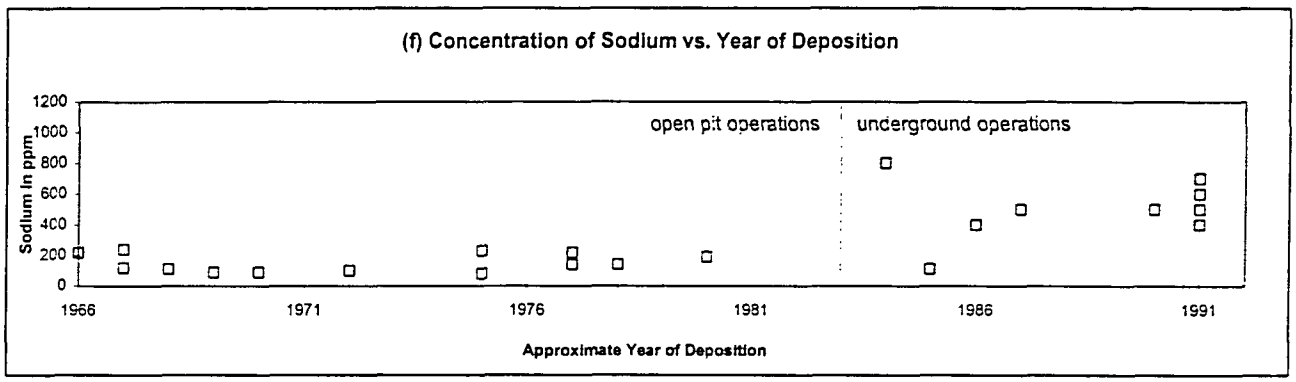
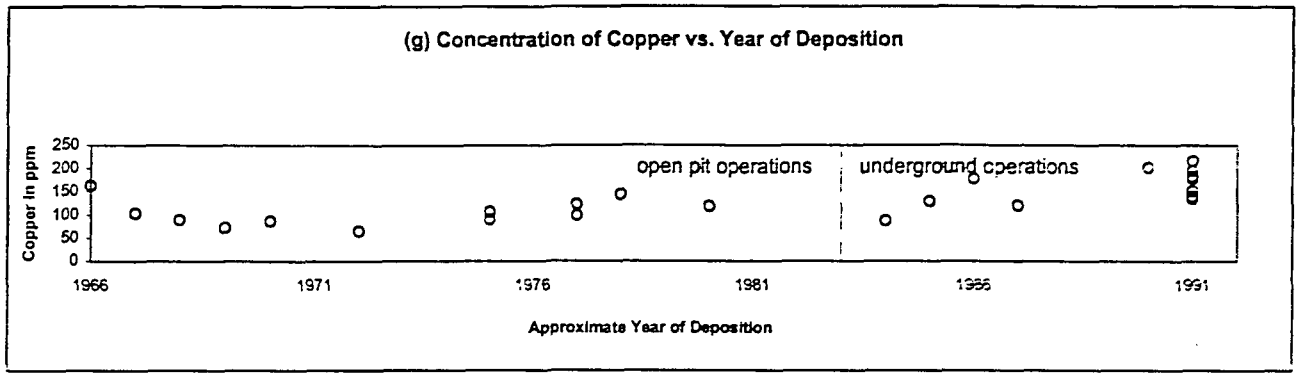
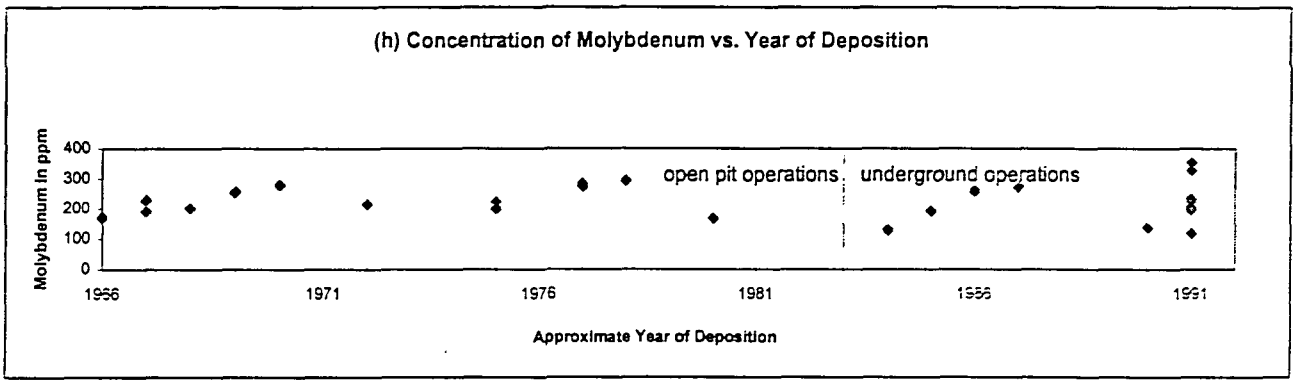


Figure 3.8
Age Trends in Solids





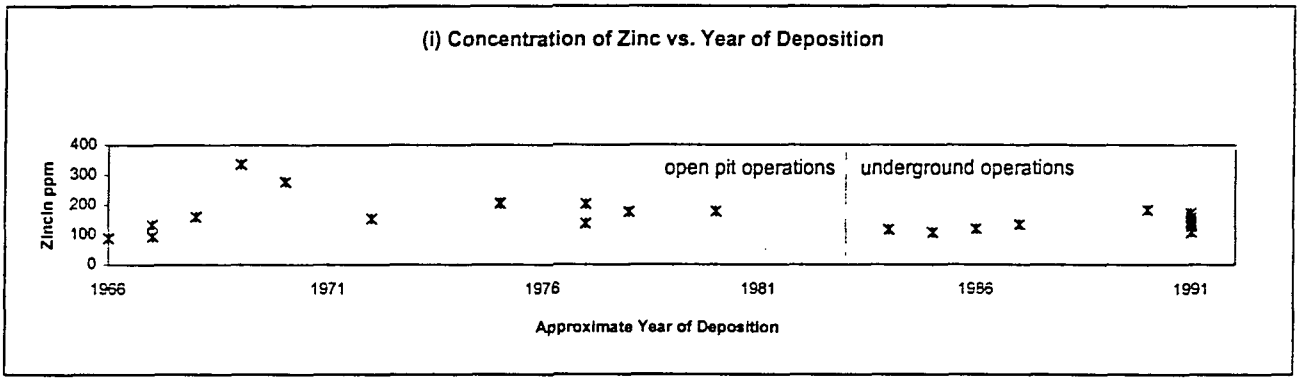


Figure 3.9
Extractable Sulfate versus Depth for the near surface samples

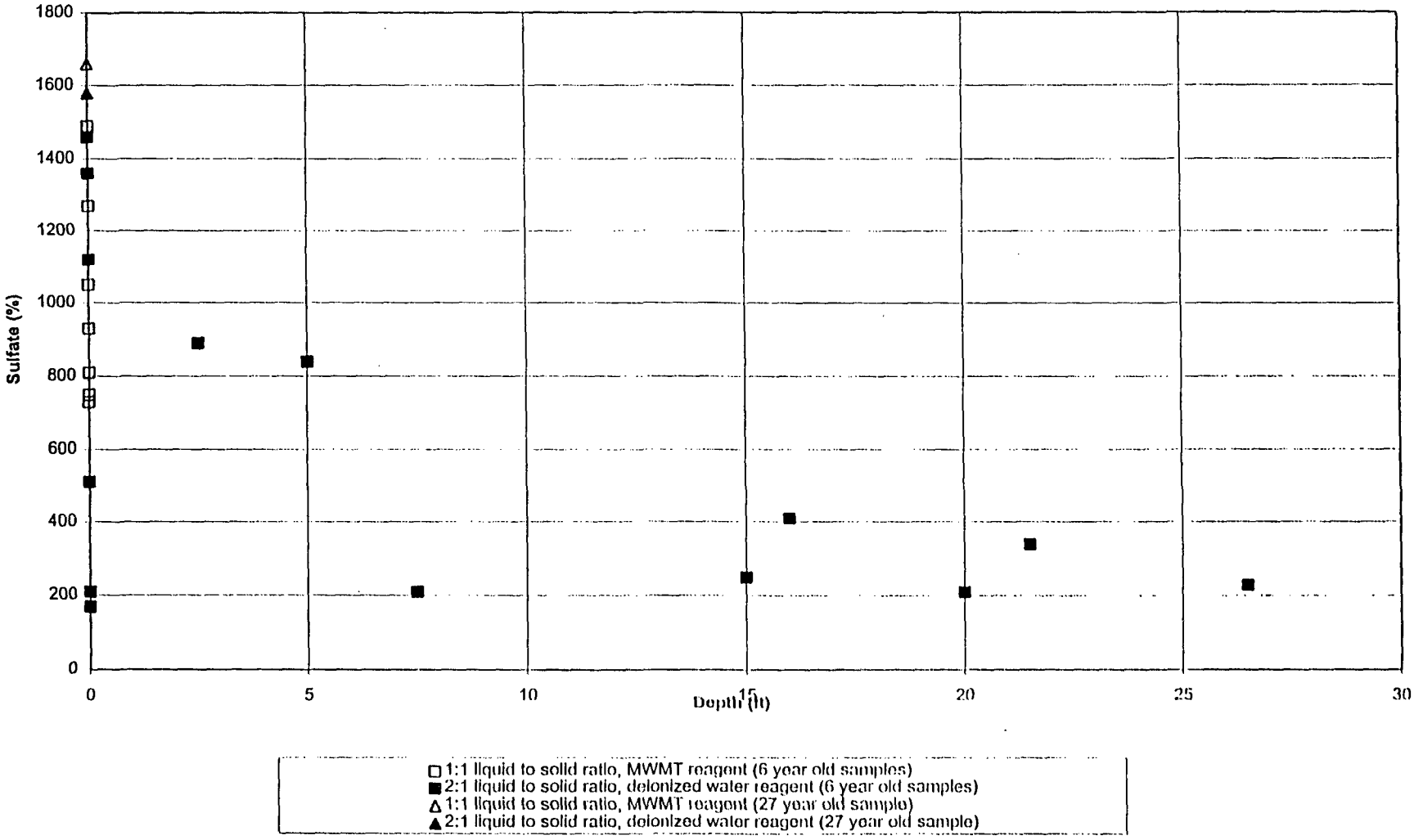


Figure 3.10
Leach Extraction Results versus Deposition Year of Tailings

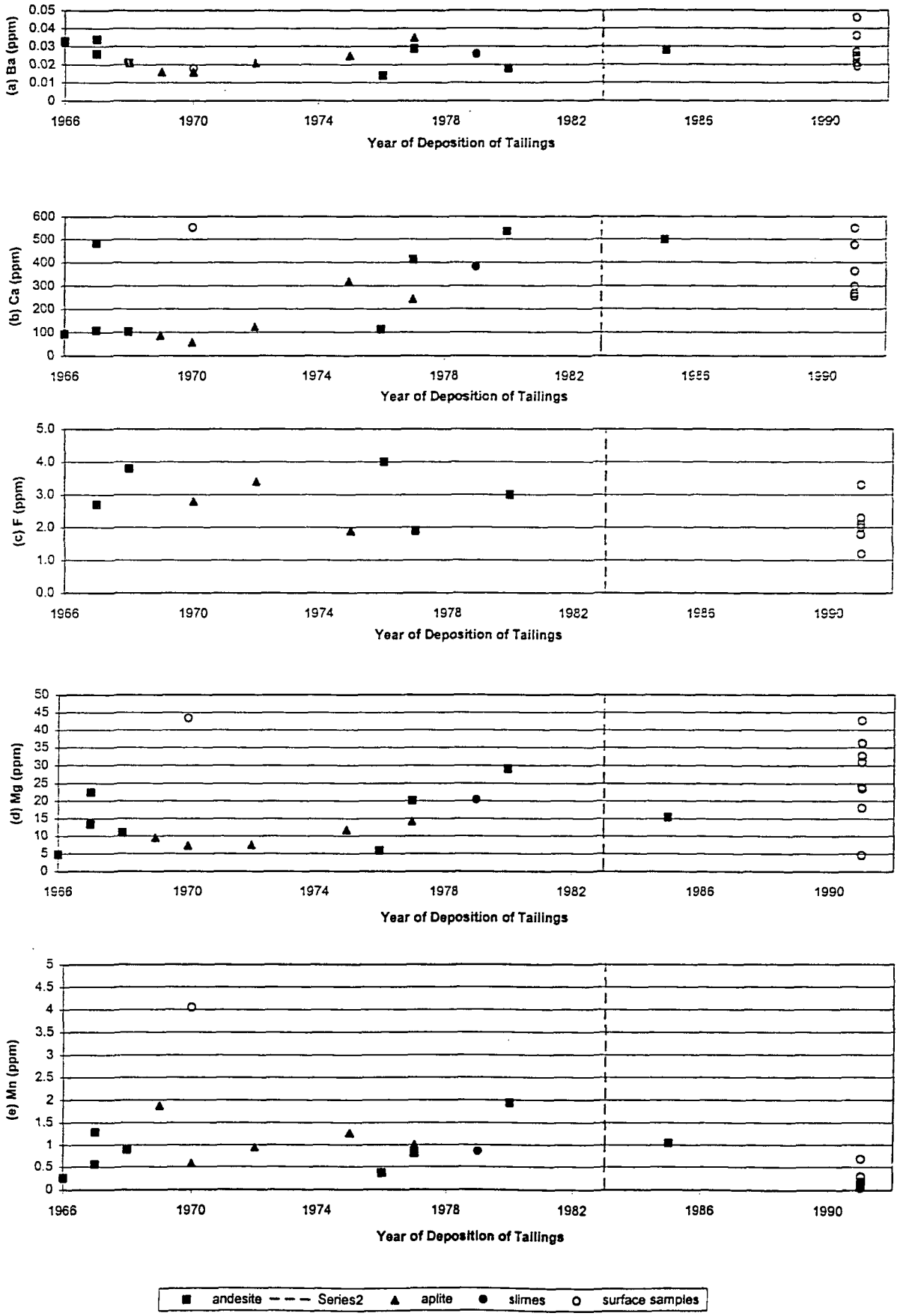


Figure 3.10 (continued)
Leach Extraction Results versus Deposition Year of Tailings

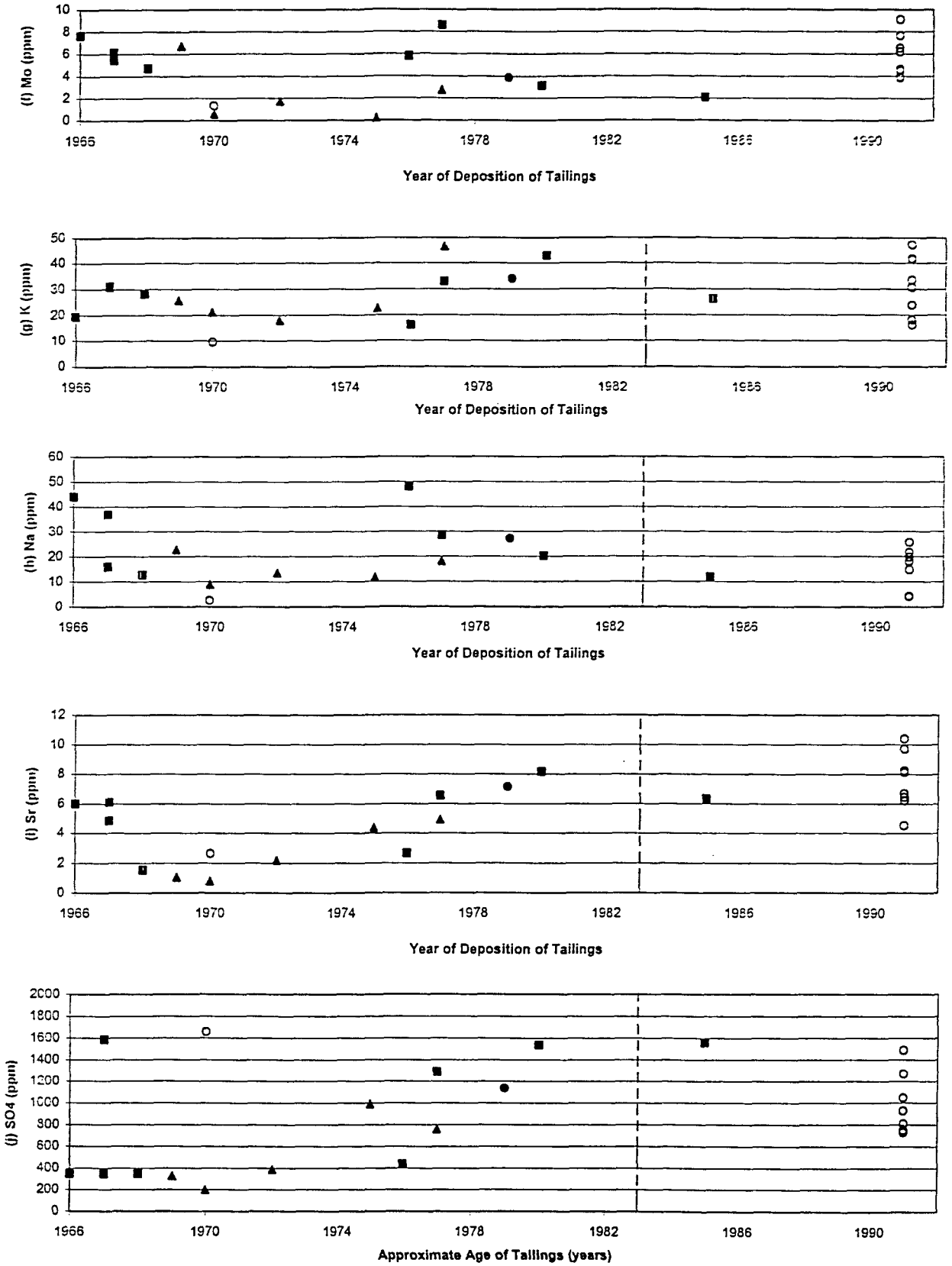


Figure 3.11
Enhanced H_2O_2 Oxidation Tests for the Questa Tailings

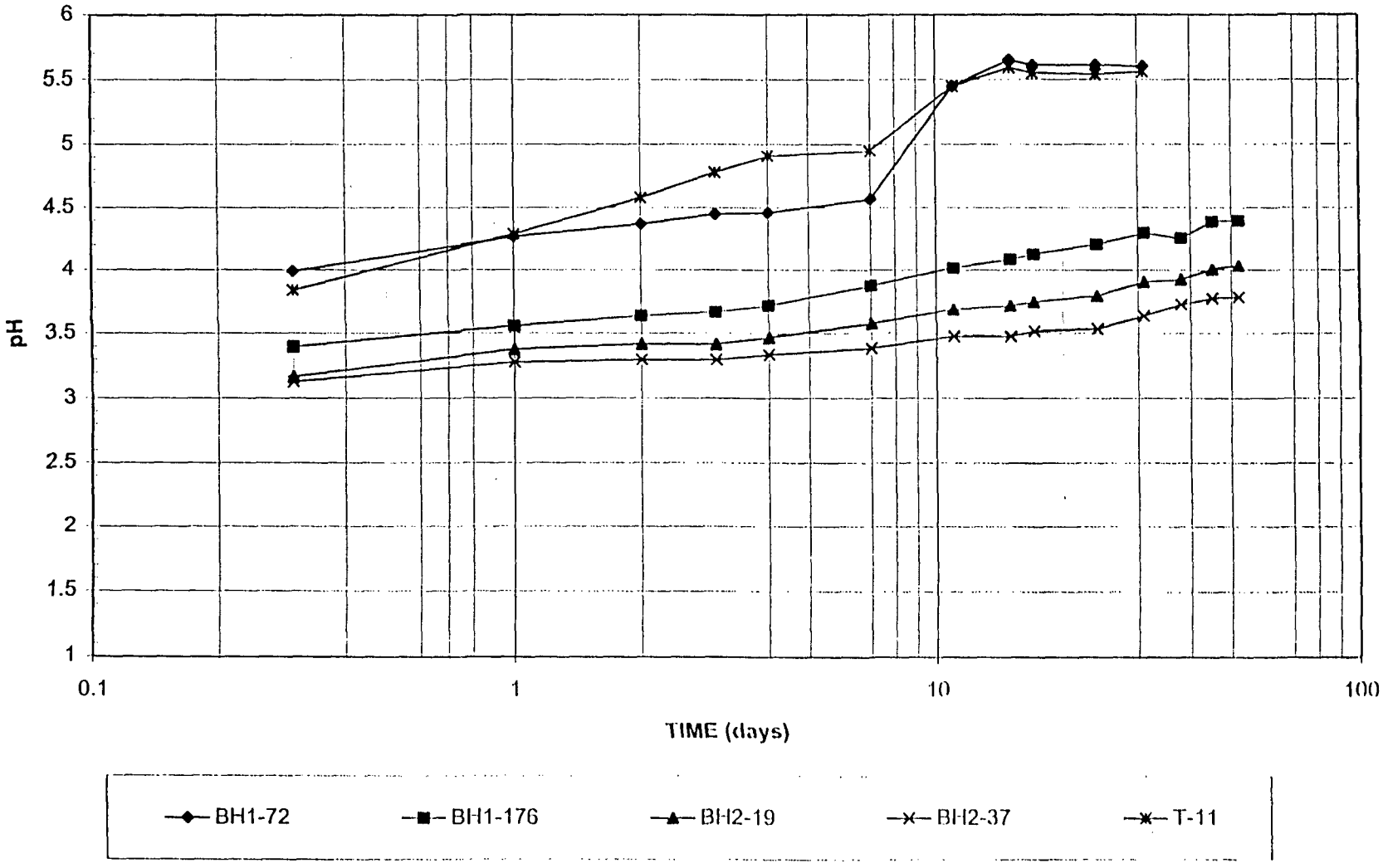


Figure 3.12
QA/QC Results for Total Metal Concentrations

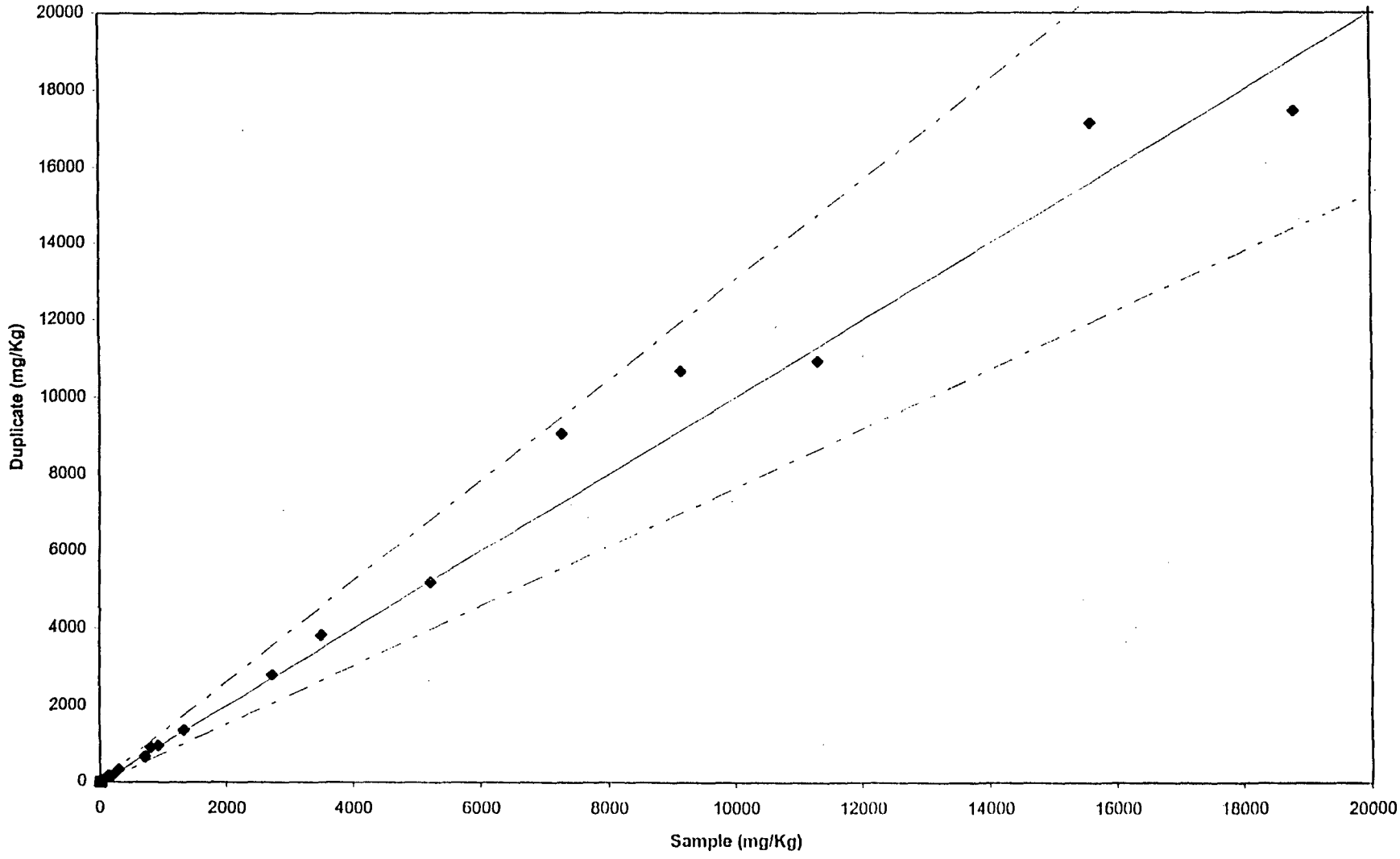


Figure 3.13
QA/QC Results for Soluble Metals Concentrations

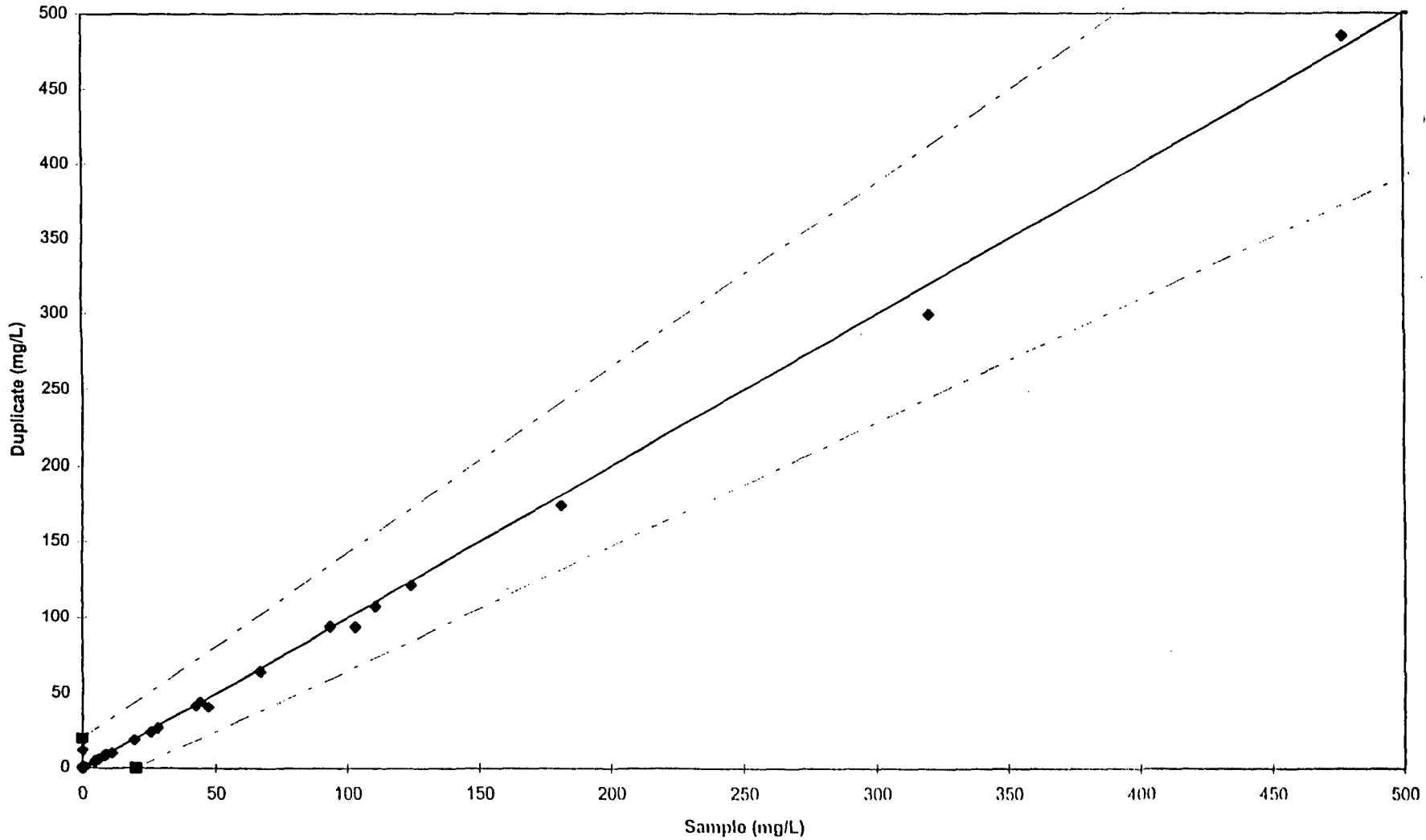
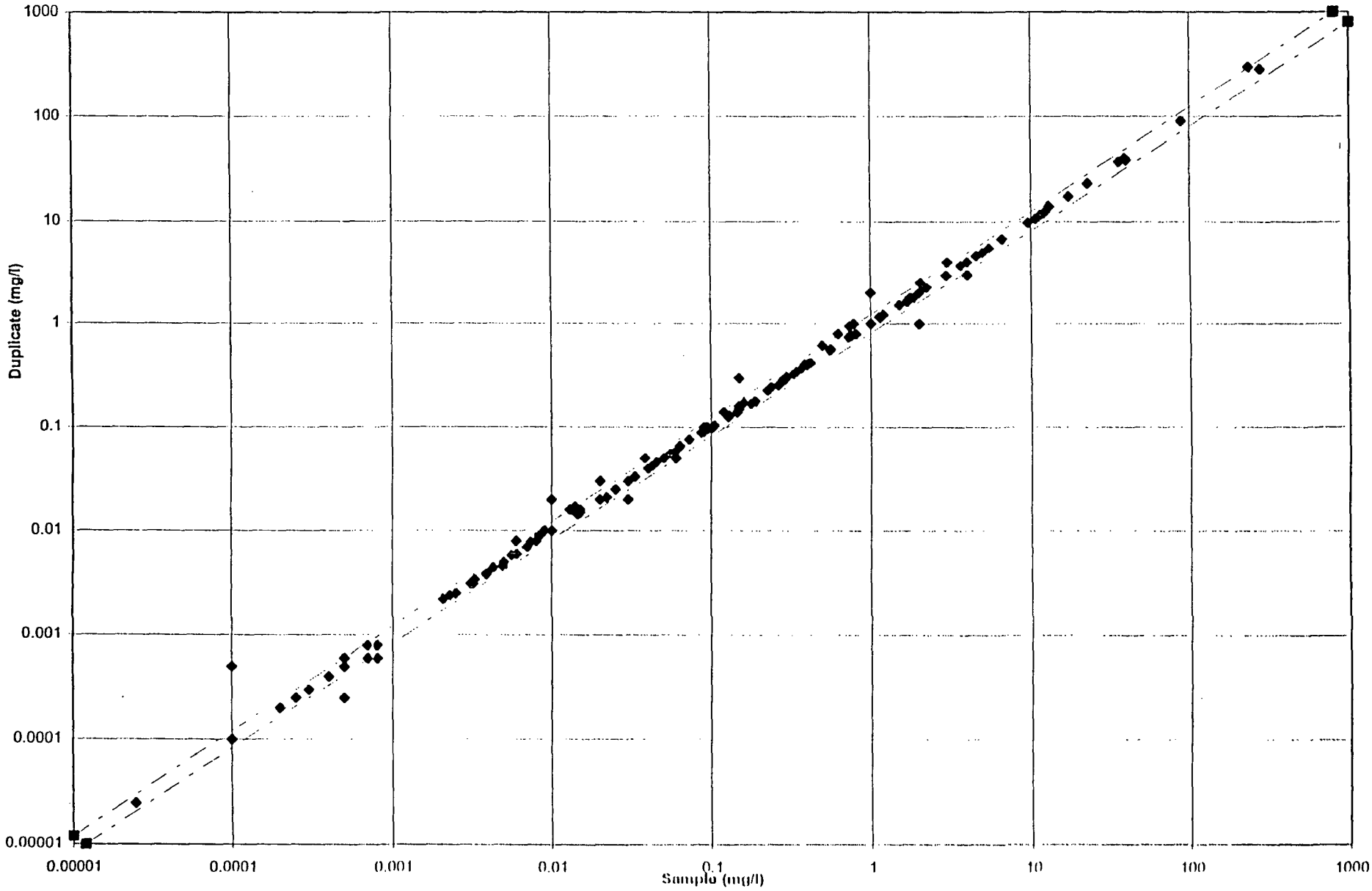


Figure 3.14
Results of Duplicate Analyses for Humidity Cell Leachates
(dashed lines equal ± 20%)



APPENDICES

A

APPENDIX A

TESTING PROTOCOLS

MODIFIED ACID BASE ACCOUNTING (ABA)

Objectives

- To determine the balance between acid producing and acid consuming components of mine waste.

Principles of Test

The fundamental principals of acid base accounting comprise two distinct measurements:

1. Determination of the neutralization potential (NP) of a sample.
2. Calculation of the acid potential (AP) of the sample.

The difference between the two values, the net neutralization potential (Net NP), and the ratio (NP:AP) allow classification of the sample as potentially acid consuming or producing. To facilitate comparison of values, NP, AP, and Net NP are all expressed in units of kg $CaCO_3$ equivalent per tonne.

In the original Sobek method of acid base accounting, the neutralization potential is determined by heating the sample and mixing for two hours. In the modified method, the neutralization potential is determined by treating a sample with excess standardized hydrochloric acid at ambient, or slightly above (25 - 30°C) ambient, temperatures for 24 hours. A fizz test is employed to provide a guide to the amount of acid to be initially added to the test. Acid is added as required during the acid-treatment stage to maintain sufficient acidity for reaction. After treatment, the unconsumed acid is titrated with standardized base to pH 8.3 to allow calculation of the calcium carbonate equivalent for the acid consumed.

For the calculation of the acid potential, the sample is analyzed for total sulphur and sulphate sulphur, and sulphide sulphur is calculated by difference. AP is determined from the calculated sulphide sulphur analysis, assuming: 1) total conversion of sulphide to sulphate; and, 2) production of 4 moles H^+ per mole of sulphide oxidized assuming that all the suphide is present as pyrite. In some cases, difficulties associated with the analytical procedures for sulphide analysis may influence the estimation of the acid generation potential. For example, sulphate associated with the mineral barite is not readily distinguished from sulphide in a typical sulphate analysis, and does not contribute to the acid potential.

Equipment

1. Aluminium foil.
2. 250 mL Erlenmeyer flask.
3. Reciprocating shaking apparatus or other suitable agitation device.

4. Buret, 50 or 100 mL, one for each of the acid and the base solutions.
5. pH meter, equipped with a combination pH electrode.

Reagents

1. Distilled (or deionized) water, preferably CO_2-free (store in container equipped with an ascarite tube)
2. Certified grade, 0.1 N hydrochloric acid, for standardization of bases
3. Approximately 0.1 N sodium hydroxide, standardized.
4. Approximately 0.5 N sodium hydroxide, standardized.
5. Approximately 0.1 N hydrochloric acid, standardized.
6. Approximately 0.5 N hydrochloric acid, standardized.
7. Approximately 25 percent strength hydrochloric acid, for fizz test.
8. Buffer solutions (pH 4.00 and 7.00) for calibration of pH meter.

Procedure

1. Crush and pulverize the sample to a target size of 80 percent minus 60 mesh (Tyler). Tailings samples should be tested at the received particle size.

2. Submit a sample of the test material for total sulphur and sulphate sulphur analyses.

3. Use certified 0.1 N hydrochloric acid to standardize the 0.1 N and 0.5 N sodium hydroxide solutions to standardize the 0.1 N and 0.5 N hydrochloric acid solutions.

4. Place approximately 0.5 g of pulverized sample on a piece of aluminium foil in a small shallow dish. Add one or two drops of 25 percent HCl to the sample. The presence of carbonate will be indicated by a bubbling or an audible "fizz". Rate the "fizz" as indicated in Table 1.

Table 1. Volume and Normality of HCl for Use in NP Determination on Basis of Fizz Rating (2g Sample)

Fizz Rating	HCl (mL)	HCl (Normality)
None	20	0.1
Slight	40	0.1
Moderate	40	0.5
Strong	80	0.5

5. Weigh 2.00 g of the sample (minus 60 mesh) into a 250 mL Erlenmeyer flask and, as a first approximation, add the volume and normality of HCl as indicated by the "fizz" rating in Table 1.

6. Agitate the contents of the flask for 24 hours by placing on a shaking apparatus. At least once in the treatment period, and preferably after approximately 6 hours of reaction, check the pH of the pulp. If the pH is above 2.0, add an appropriate volume of hydrochloric acid of the same strength originally added (generally between 1.5 to 2.0 ml). Record the amount added for back titration.

7. At the end of the shaking period, check the pulp pH. If the total volume and strength of acid was appropriate, the end pH will be in the range 1.5 - 2.0. If the pH is above this range, the amount of acid added is judged to be insufficient for reaction. If the pH is below the range, the amount of acid added is judged to be too high, causing over reaction. In either case, repeat the test using the next higher or lower volume or strength of HCl as appropriate.

8 Titrate the contents of the flask using 0.1 N or 0.5 N NaOH (corresponding to the normality of HCl used in step 4) to pH 8.3. Titrate with NaOH until a constant reading of 8.3 remains for at least 30 seconds.

Calculations

1. The neutralization potential, NP, of the sample is given by:

$$NP = \frac{50\,a\,[x - (b/a)\,y]}{c}$$

where NP = neutralization potential in tonnes $CaCO_3$ equivalent per 1000 tonnes of material

a = normality of HCl
b = normality of NaOH
c = sample weight in grams
x = volume of HCl added in mL
y = volume of NaOH added to pH 7.0 in mL

2. The acid potential, AP, of the sample in kg $CaCO_3$ equivalent per ton, is given by:

AP = Percent sulphide sulphur x 31.25

where, sulphide sulphur = total sulphur - sulphate sulphur

3. The net neutralization potential, Net NP, in kg $CaCO_3$ equivalent per ton of material is given by:

$$\text{Net NP} = \text{NP} - \text{AP}$$

Reporting of Results

The results of the test should be tabulated to provide the following information:

Sample description, paste pH, total sulphur analysis (% S_T), sulphate sulphur analysis (% $S(SO_4)$), NP (kg $CaC0_3$ equivalent per ton), AP (kg $CaC0_3$ equivalent per ton), Net NP (kg $CaC0_3$ equivalent per ton).

References

Lawrence, R.W., Poling, G.P. and Marchant, P.B., 1989. Investigation of predictive techniques for acid mine drainage. Report on DSS Contract No. 23440-7-9178/01-SQ, Energy Mines and Resources, Canada, MEND Report 1.16.1 (a).

Sobek, A.A., Schuller, W.A. Freeman, J.R. and Smith, R.M., 1978, Field and Laboratory Methods Applicable to Overburden and Minesoils, EPA 600/2-78-054, 203pp.

EPA 1312 LEACH EXTRACTION TEST WITH NMWM REAGENT

Objectives

- To characterise and quantify the soluble contaminant content of waste rock samples.

Principles of Test

The sample is mixed with distilled water, and is agitated in a flask to allow dissolution of the contained, soluble secondary mineral phases. The solution is collected at the end of the test, filtered, and analysed for immediate parameters (pH, alkalinity, acididity, sulphate, and conductivity) and for contained metals.

Procedure

1. Split a representative sample of approximately 200 to 500 g from the field sample, and determine exact weight. Place in Erlenmeyer Flask. The amount of sample is at the discretion of the technician, but should be increased if the particle size is large or the variation between the different particles is high.

2. Add distilled (or de-ionized) water acidified to a pH of between 5.0 and 5.5 using HCl to the sample to obtain a water to solids ratio of exactly 2:1 by weight. Cap the Erlenmeyer flask and place in agitation device.

3. Agitate the slurry for a total period of 23 hours. Terminate the agitation process and allow suspended solids to settle for one hour prior to termination of the test.

4. Remove the clear decant and filter the solution immediately, using a standard 0.45 μm millepore filter. Remove a small portion of the filtrate and determine the conductivity and pH.

5. Solution samples are submitted for analysis of immediate parameters (pH, alkalinity, acidity, Eh, and conductivity) and for constituent concentrations (ICP metal scan and sulphate).

Interpretation

Soluble salt and radionuclide contents are calculated from the eluate constituent concentration and volume, and are reported per unit mass of waste rock.

Solubility controls on the solution concentrations should be checked by assessing saturation indices for the contaminants of concern. This may be done rapidly by using a geochemical equilibrium model such as MINTEQA2 or equivalent. Where saturation

conditions are indicated, consecutive extraction tests should be performed to determine the total soluble component loading from the cumulative constituent release by the waste rock sample.

References

The field extraction test is modified from a number of different sources, including the EPA series of extraction tests.

STATIC NET ACID GENERATION (NAG) TEST PROCEDURE

Objectives: to determine the net acid remaining, if any, after complete oxidation of the materials with hydrogen peroxide and allowing complete reaction of the acid formed with the neutralizing components of the material. The NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure and weathering and is used to refine the results of the theoretical ABA predictions.

Principles of the Tests: after neutraliziation is completed, by reaction with hydrogen peroxide, the remaining H_2SO_4, if any, is titrated with sodium hydroxide. The amount of NaOH needed is equivalent to the NAG of the material (expressed in kg H_2SO_4/tonne material).

Sample Preparation: tailings samples can be tested 'as received'.

Reagents:

1. H_2O_2 - BDH 'Analar' Analytical Reagent 30% w/v (100 V), or equivalent, diluted 1:1 with deionized H2O to 15% [a].
2. NaOH - 0.50M Standardized Solution.
3. NaOH - 0.10M Standardized Solution.

Procedure:

Add 250 mL of reagent 1 (15% H_2O_2) to 2.5 g of tailings (pulverized sample if testing waste rock) sample in a 500 mL wide mouth conical flask, or equivalent. Cover with a watch glass, and place in a fumehood or well ventilated area [b]. The H_2O_2 should be at room temperature before commencing test.

Allow sample to react until 'boiling' or effervescing ceases. Heat sample on hot plate and gently boil until effervescence stops or for a minimum of 2 hours. Do not allow sample to boil dry - add deionized water if necessary.

Allow solution to cool to room temperature then record final pH (NAGpH).

Rinse the sample that has adhered to the sides of the flask down into the solution with deionized water. Add deionized water to give a final volume of 250 mL.

Titrate solution to pH 4.5 while stirring with appropriate NaOH concentration based on final NAG solution pH as follows:

NAG Solution pH	Reagent	NaOH Concentration
>2	3	0.10 M
≤2	2	0.50 M

[a] The pH of the H_2O_2 used in the NAG test should be checked to ensure it is between pH 4 and 7. If the pH is less than 4 then add dilute NaOH (use a solution made up by adding 1 g NaOH to 100 mL deionized H_2O) until the pH is greater than 4 (aim for a pH between 4 and 6). The pH is adjusted to greater than pH 4 to ensure that the phosphoric acid, used to stabilize H_2O_2 in some brands, is neutralized. The pH of the 15% H_2O_2 should always be checked to ensure that any stabilizing acid is neutralized, otherwise, false positive results may be obtained.

[b] The NAG reaction can be vigorous and sample solutions can 'boil' at temperatures of up to 120°C. Great care must be taken to place samples in a well ventilated area or fume cupboard.

Calculations

The NAG capacity is determined by titration of the sample to determine the net amount of acid generated by peroxide oxidation.

Net Acid Generation

$$NAG = \frac{49 \times V \times M}{W}$$

Where:

NAG = net acid generation (kg H_2SO_4/tonne)

V = volume of base NaOH titrated (mL)

M = molarity of base NaOH (moles/L)

W = weight of sample reacted (g)

NOTE: If NAG value exceeds 25 kg H_2SO_4 per tonne, repeat using a 1.00 g sample.

Interpretations

The NAG capacity is an independent measure of the acid generating potential of a sample. Materials should be classified based on the table given below.

SAMPLE CATEGORY	FINAL NAGpH	NAG VALUE (kg H_2SO_4/t)	NNP
POTENTIALLY ACID FORMING			
Higher capacity	<4	>10	positive
Lower capacity	<4	≤10	-
UNCERTAIN[□]	≥4	0	positive
NON-ACID FORMING[J]	≥4	0	negative

[□] Further evaluation including sulfur forms and mineralogy

[J] Acid consuming materials are identified by NNP values less than approximately -100

References

Miller, S., Robertson, A., and Donohue, T. (1997). Advances in Acid Drainage Prediction Using The Net Acid Generation (NAG) Test. In: *Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, B.C., Canada, 1997*, vol II, pp. 535-547.

Lewis, H.S., Susteyo, W., Miller, S.D., and Jeffery, J.J. (1997). Waste Rock Management Planning and Implementation at P.T. Freeport Indonesia Company's Mining Operations in Irian Jaya. In: *Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, B.C., Canada, 1997*, vol III, pp. 1361-1376.

HUMIDITY CELL TEST PROCEDURE

Objectives

The primary objectives of the humidity cell tests are to:

- establish the overall rate of oxidation;
- ascertain the relative rates of oxidation of the different sulfide minerals present in the tailings;
- establish the rate of acid neutralization by the naturally contained neutralization potential; and,
- identify potentially controlling secondary mineral phase that may limit constituent release under oxidizing conditions.

Setup and Procedures

The humidity cell tests will be conducted in short columns as shown in Figure 1. The short columns will have an internal diameter of 3 inches, a height of about 5 inches, and will be equipped with a perforated baseplate on which the sample will be suspended. Nylon mesh will be placed on top of the baseplate to retain the tailings. The tailings will be placed to a depth of about 0.75 inches, representing approximately 150g of tailings. The chamber beneath the perforated baseplate will be equipped with a drainage tube to allow extraction of the leachate. The top of the column will be sealed to prevent dust contamination. The chamber above the tailings will be equipped with and inlet and outlet through which a continuous stream of humidified air will be passed in between water flushes.

At start-up, the tailings sample will be flushed with approximately 500 mL of distilled water to remove as much of the readily soluble phases as possible. The leachate from this initial flush will be analyzed.

Subsequently, the cells will be operated on a weekly cycle. Each cell will be flushed with 500 mL distilled water every 7 days of operation. The leachate will be introduced over a period of four hours. Leachate recovery will be maximized by placing a small pressure differential over the tailings bed using a vacuum pump. The pressure difference will not exceed 2" of water pressure. Immediate parameters, including pH, conductivity, redox potential, sulphate and acidity/alkalinity, will be obtained immediately after the leachate has been recovered. Once the immediate parameters have been obtained, the leachate will be filtered through a 0.45 μm medium. The filtered leachate will be split and preserved as required for laboratory analysis of pH, conductivity, sulfate and dissolved constituents (metals). The reanalysis of samples for pH, conductivity, and sulfate will provide a check on these analysis.

The leachates will be analyzed on a weekly basis for all parameters for the first five weeks of testing. Thereafter, the immediate parameters will be continued to be determined on a weekly basis. Detailed constituent analyses will be performed only on every third leachate generated. It is anticipated that the humidity cells will be continued for a total of twenty weeks of testing.

At the end of testing, the final residue will be air dried, weighed, and representative samples taken for mineralogical examination, acid base accounting and bulk chemical analysis.

Interpretation

The leachate water quality will be assessed using the USGS MINTEQA2 geochemical speciation model (Alison, 1990) to determine if any secondary mineral phases are controlling the solubility of dissolved constituents. Depending on the outcome of this modeling the following may be the approach that will be used to interpret the results.

Total sulphide oxidation rates will be calculated from the rate of sulphate released from the humidity cell tests. This will used to estimate the rate of acid generation.

Relative rates of oxidation for the primary sulphide minerals will be determined based on the metal constituent release rates.

Rates of acid neutralization and alkalinity release will be determined from the alkalinity in the leachates, and the rate at which acidity is being generated from sulphide oxidation.

B

APPENDIX B

SUMMARY OF SAMPLES ANALYZED VIA VARIOUS TEST METHODS

	GEOCHEMICAL TESTING											GEOTECHNICAL TESTING				
SAMPLE NO.	MIN. EXAM	SOBEK ABA	ICP	LEACH EXT. (MOD. 1312)	GRADATION TESTING	MIN. EXAM [b]	MODIFIED SOBEK ABA	ICP	LEACH EXT. (MOD. NMWM)	HUMIDITY CELL (column no.)	MODIFIED NAG TESTING	Grain Size Analysis	Soil Moisure Retention Curve	Standard Proctor Compact.Test	Flex. Wall Falling Head	Rigid Wall Constant Head
BH1-22							X									
BH1-40							X	X	X							
BH1-72							X	X			X					
BH1-72sp									X	X(3)						
BH1-92							X									
BH1-107						X	X	X	X							
BH1-123							X	X	X	X(8)						
BH1-135						X	X	X	X							
BH1-174							X									
BH1-176						X	X	X	X	X(6)	X					
BH2-19							X	X	X	X(4)	X					
BH2-37							X				X					
BH2-42SP							X									
BH2-58						X	X									
BH2-70-75							X	X	X							
BH2-80-85							X									
BH2-90-95							X									
BH2-100-105							X									
BH2-125-130							X									
BH3-16							X									
BH3-31							X									
BH3-37						X	X	X	X							
BH3-51							X									
BH3-69							X	X	X							
BH3-84							X	X	X	X(5)						
BH3-111						X	X	X	X	X(7)						
BH3-121							X									
BH3-125							X									
BH4-30							X									
BH4-75-80							X	X	X	X(9)						
BH4-95-100							X									
BH4-110-120							X	X	X							
BH4-120-125							X									
BH4-135-140							X									
BH4-170-175							X									
T-1	X	X	X	X												
T-2	X															
T-4					X											
T-5																
T-6																
T-7																
T-8																
T-9																
T-10																
T-11		X	X	X			X		X	X(2)	X					
T-12																
T-13		X	X	X												
T-14					X											
T-15																
T-16																
T-17		X	X	X												
T-18																
T-19		X		X												
T-20		X	X	X												

	GEOCHEMICAL TESTING											GEOTECHNICAL TESTING				
SAMPLE NO.	Min. Exam	Sobek ABA	ICP	Leach Extn (MOD. 1312)	GRADATION TESTING	MIN. EXAM [b]	MODIFIED ABA	ICP	LEACH EXT. (MOD. NMWM)	HUMIDITY CELL (column no.)	NAG TESTING	Grain Size Analysis	Soil Moisure Retention Curve	Standard Proctor Compact.Test	Flex. Wall Falling Head	Rigid Wall Constant Head
T-22		X														
T-24	X															
T-24B		X		X			X		X	X(1)						
T-25					X											
T-26					X											
T-27					X											
T-28					X											
T-32					X											
VC-1 0-2.5			X	X												
VC-1 2.5-5					X											
VC-1 5-10																
VC-1 10-20		X	X	X												
VC-1 20-21.5		X	X	X												
VC-2 1-9																
VC-3 5-7.5		X	X	X												
VC-3 7.5-10																
VC-3 10-15		X	X	X												
VC-3 15-20																
VC-3 20-20.8																
VC-4 2.5-5		X	X	X												
VC-4 5-13																
VC-4 15-16		X		X												
VC-4 16-25	X															
VC-4 25-26.5		X	X	X												
VC-5 0-2.5																
VC-5 2.5-5		X		X												
VC-5 5-12.5																
VC-6 0-10		X		X												
VC-6 10-11		X		X												
Additional Samples																
(taken by GM in 1996)																
T-3 (comp. cover, dam 1C)												X	X		X	X
T-21 (uncomp. cover, dam 5A)												X	X		X	X
T-23 (bulk alluv., borrow area												X				
T-2 (fine tailings)												X	X		X	
T-24 (coarse tailings)												X	X			X
(taken by AMR in 1997)																
97-AL-1 (uncomp. cover, dam 1C)												X	X	X	X	
97-AL-2 (silty alluvium)												X	X	X	X	
97-T-1 (coarse tails)							X									
97-T-2 (fine tails)							X									
97-T-3 (fine tails)							X					X			X	
97-T-4 (coarse tails)							X									
97-T-5 (fine tails)							X									
97-T-6 (coarse tails)							X									
97-T-7 (coarse tails)							X					X	X		X	
1st quarter tailings - 97							X									
2nd quarter tailings - 97							X									
3rd quarter tailings - 97							X									
NUMBER OF TESTS	4	18	12	18	8	6	47	14	16	9	5	10	7	2	7	3

C

APPENDIX C

MINERALOGICAL REPORT

RGI Report No. 036008/1

MINERALOGICAL ANALYSES OF THE QUESTA TAILINGS

1.0 Introduction

1.1 Scope of work

Six samples of the Questa mine tailings, labeled BH1-107, BH1-135, BH1-176, BH2-58, BH3-37, and BH3-111, were received from Steffen Robertson and Kirsten (U.S.). Inc. for mineralogical examination on April 9, 1997 as part of the geochemical and physical testing of the Questa tailings in accordance with Molycorp's Discharge Plan 933 (SRK, 1997). Sample locations can be seen in Figure 1 (sample notation includes borehole number followed by the sample depth from surface in feet). The mineralogical characterization consisted of mineral identification, with emphasis on the alteration, oxidation and/or dissolution of any potentially acid-generating and/or potentially acid-neutralizing minerals in the tailings. In the context of this report, the term alteration is used to describe any changes in the chemical or mineralogical composition of the certain minerals, either within the tailings environment or prior to disposal. Both oxidation and dissolution are specific types of alteration. Oxidation is used to describe the alteration of certain sulfides in the presence of oxygen. The oxidation of some, but not all, sulfides can produce acid. Dissolution describes the alteration of minerals due to the chemical process that turns minerals into solution. Dissolution reactions are oftentimes pH dependent and can reflect pH conditions or buffering reactions that may be occurring.

The samples were dried at room temperature and characterized macroscopically using a hand lens. Splits of the samples were then taken; half was used for powder x-ray diffraction analysis and the other half was used to prepare polished thin sections for petrographic examination in both transmitted and reflected light. The results of these analyses are presented in this report.

1.2 Background information

Meyer and Leonardson (1990) present a comprehensive interpretation of the geology, mineralogy and paragenetic relationships of the different rock types in the Questa mining district. In general, the Questa mining area consists of aplite and andesite rocks. Aplites are fine grained, light colored intrusive igneous rocks consisting predominantly of quartz and alkali feldspar minerals. Andesites are fine grained, dark colored, extrusive igneous rocks that often contain phenocrysts composed of sodic plagioclase and one or more of the mafic minerals (e.g. biotite, hornblende, pyroxene), in a groundmass composed generally of the sample minerals. The mineralization and alteration of these rocks were interpreted by Meyer and Leonardson to have occurred as a series of events. These are summarized here in chronological order as they relate to the ore zone.

1. A pervasive pre-mineralization of biotite-quartz-magnetite alteration of the andesite within 200 to 500 meters of the andesite-aplite intrusion occurred first. Outside this region, a chlorite-epidote-calcite±pyrite±magnetite alteration of the andesite predominates.

2. This was followed by the main-stage magmatic hydrothermal breccia and related alteration which is responsible for the majority of the molybdenite mineralization in the central and western portions of the deposit. The breccia fragments are centimeter or less sized andesite fragments in a vertically zoned pegmatitic aplite matrix of quartz±orthoclase±biotite±molybdenite±rutile.
3. Quartz-molybdenite-pyrite veining cross-cuts the magmatic hydrothermal breccia unit described above. The mineralization associated with this veining episode makes up a significant part of the ore body beyond the boundaries of the magmatic hydrothermal breccia unit.
4. Molybdenite "paint", or thin fracture fillings of pure molybdenite, cross-cuts most of the previously described geological units and is the final stage of molybdenum mineralization at Questa.
5. Quartz-sericite-pyrite alteration associated with rhyolite porphyry dikes cross-cuts all but the latest phases of molybdenum mineralization.
6. Late stage quartz-fluorite-sericite-base metal sulfide veining is located distally to the ore deposit and cross-cuts the rhyolite porphyry dikes. It is this event that is responsible for the fluorite and base metal haloes above the deposit.
7. Calcite/gypsum veining is the youngest molybdenum-related event to effect the region. Most of the region is significantly veined by calcite and gypsum veining substitutes for calcite in the region up-dip of the molybdenum ore-body. It is believed that this event represents meteoric influx into the deposit coinciding with the diminishing hydrothermal system.
8. Deuteric alteration associated with post-mineral latite porphyry and lamprophyre porphyry dikes is also present in the area. This alteration is largely restricted to the dikes and consists of the minerals epidote, chlorite, calcite and local magnetite.

Based on the review of this report, the minerals that are likely to report to the Questa tailings include the primary components of aplites and andesites, as well as the ore minerals and coexisting alteration minerals. These minerals would include quartz, feldspars, biotite and/or amphibole and pyroxene, molybdenite, pyrite, magnetite, chlorite, calcite, epidote, rutile, sericite, fluorite, base metal sulfides such as chalcopyrite and sphalerite, and gypsum.

1.3 Previous mineralogical work on the Questa tailings

Mineralogical characterization of four tailings samples from the Questa tailings facility had been done previously and is reported in SRK (1996). The samples examined in that study consisted of 3 surface samples, one of which had been exposed to the atmosphere for approximately 25 years, and one sample from a vibracore drill at a depth of 16 to 25 inches below the surface. In making conclusions from the mineralogical characterization done in this study the results of these four, previously examined samples were also taken into consideration.

2.0 Macroscopic Characterization

Macroscopic characterization of the Questa tailings involved color classification, grain size approximation, identification of visible sulfides, and description of mineral formation

as a result of processes occurring after mill processing (i.e. secondary or tertiary minerals). The results of this characterization are given in Table 1.

Table 1 summarizes the macroscopic characteristics of each of these samples.

Sample number	Color of dried sample	Grain size	Approximate % visible sulfides	Comments
BH1-107	grey	~90% sand, ~10% fines [a]	<1%	All the tailings samples were extremely homogeneous, no secondary or tertiary [b] mineral formation was visible, no cemented portions were identifiable macroscopically.
BH1-135	light grey	<50% sand, >50% fines	none	
BH1-176	grey	<50% sand, >50% fines	<1%	
BH2-58	light grey	~50% sand, ~50% fines	<1%	
BH3-37	grey	~70% sand, ~30% fines	<1%	
BH3-111	predominantly light grey with ~15% dark mineral content	~80% sand, ~20% fines	<1%	

[a] fines include silt and clay size fractions
[b] secondary minerals are those minerals that have formed after tailings deposition as a result of oxidation reactions and/or precipitation from pore water; tertiary minerals are those that have formed after samples are removed from the tailings area (Jambor, 1994)

3.0 X-ray Diffraction Analyses

Powder x-ray diffraction analyses (XRD) were completed on a Siemens D5000 powder x-ray diffractometer at the University of British Columbia. The diffractometer was equipped with a graphite monochromator; data were obtained using Cu KI radiation, a voltage of 40 kV and a current of 30 mA. The samples were scanned from 3 ° and 60 ° 2Π in steps of 0.02 ° per 0.8 seconds. Peak identification was done with the help of the JCPDS search program.

The X-ray diffractograms for each of the 6 samples submitted are given in Figure 1. The mineral content was similar in all 6 samples and consists of:

quartz (SiO_2),
plagioclase feldspar ($(Na,Ca)Al(Si,Al)_3O_8$),
potassium feldspar ($KAlSi_3O_8$),
biotite ($KMg_3(Si_3Al)O_{10}(OH)_2$),
muscovite ($KAl_2Si_3AlO_{10}(OH)_2$),
chlorite ($(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$),
trace amphibole ($Ca_2(Fe,Mg)_4Al(Si_7Al)O_{22}(OH,F)_2$),
trace calcite ($CaCO_3$),
trace gypsum ($CaSO_4 \cdot 2H_2O$),
+/- clay.

The presence of gypsum was verified by washing sample BH3-37 with distilled water and analyzing the washed sample. The gypsum peak disappeared when the washed sample was reanalyzed by XRD as a result of gypsum dissolution.

The clay content was verified via glycolation (i.e. treatment by glycol) of sample BH3-37. Glycolation is a treatment used for clay identification whereby glycol replaces the interlayer water present in clay minerals. This results in expansion of these layers and produces shifts in the XRD peaks. After glycolation for 16 hours, a small peak was seen at a d-spacing of approximately 14 Angstroms (a shift from ~ 10 Angstroms), a characteristic shift for some clay minerals. Further analyses to determine the specific type of clay mineralogy present in these samples were not done in this study.

Approximations of the relative abundance of the major minerals for each of the samples are summarized in Table 2. These approximations were made based on the relative peak heights of the 100 peak (or largest peak) for each of the minerals identified and are only qualitative.

Table 2: Approximate percentages of major minerals in the tailings.

Sample	quartz	potassium feldspar	plagioclase feldspar	biotite	muscovite	chlorite	others
BH1-107	55 %	8 %	25 %	5 %	5 %	2 %	+/- calcite
BH1-135	50 %	10 %	12.5 %	12.5 %	10 %	5 %	trace gypsum, +/- calcite
BH1-176	50 %	12 %	18 %	12 %	3 %	4 %	trace amphibole, +/- calcite
BH2-58	48 %	9 %	30 %	5 %	4 %	4 %	trace gypsum, +/- calcite
BH3-37	40 %	11 %	26 %	11 %	4 %	4 %	~ 4% calcite, ~1% gypsum
BH3-111	43 %	5 %	43 %	4 %	4 %	1 %	+/- calcite

No secondary or tertiary minerals besides gypsum were detected via x-ray diffractometry, suggesting that these minerals are either in concentrations below the detection limit of the diffractometer or are poorly crystalline to amorphous in character.

4.0 Petrographic Analysis

Polished thin sections were prepared by Vancouver Petrographics. Non-aqueous media were used in the section preparation so as not to dissolve any soluble phases that may be present in the tailings. The sections were examined petrographically using a Nikon SMZ-1 OPTIPHOT2-POL stereoscopic microscope at the University of British Columbia. Photomicrographs were taken using the microflex AFX-DX attachment and a Nikon FX-35DX camera. The results of the petrographic characterization are presented on the following sample log sheets, and the approximate mineralogical modal abundances are presented graphically in Figure 2.

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH1-1079
[andesite, deposited in 1968]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	50	pristine anhedral grains, colorless.
Plagioclase	20	exhibited alteration typical of sericite replacement, appears to have occurred prior to tailings deposition because alteration is not confined to edges or cracks but is seen sporadically throughout the grains.
Potassium feldspar	10	predominantly in the sand-size fraction, no signs of alteration.
Biotite	5	pleochroic from light to dark brown, no indications of alteration along edges or cleavage planes.
Muscovite	3	very small shreds of muscovite throughout the section.
Chlorite	4	pleochroic from light to dark green, bluish-grey interference colors.
Calcite	5	colorless to pale yellow, rhombohedral cleavage and striations easily seen on some grains, no dissolution textures evident.
Fluorite	2	very high relief, isotropic, cleavage.
OPAQUE	1	
Pyrite	(60)*	predominantly euhedral, many containing inclusions of sphalerite, a few grains exhibited weak dissolution textures, one iron-oxyhydroxide oxidation rim present (photomicrograph 1).
Sphalerite	(25)	red internal reflections sometimes seen; some grains contain abundant chalcopyrite inclusions; typically anhedral.
Chalcopyrite	(10)	present as inclusions in sphalerite and as isolated grains; very slight dissolution around grain edges sometimes seen, as well as one iron-oxyhydroxide rim (photomicrograph 2).
Molybdenite	(5)	usually very fine grained plates seen as inclusions in both silicates and other sulfides; no apparent alteration, grey with a blue tint.
Magnetite	(<2)	minor, anhedral grains, no exsolution lamellae evident.

* numbers in brackets are approximate percentages of opaque mineral fraction

COMMENTS:

- predominantly sand-size grains,
- slight "iron-staining" present in an aggregate of predominantly feldspar (photomicrograph 3).

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH1-135
[andesite, deposited in 1967]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	35	typical quartz
Plagioclase	25	slightly altered (sericitization).
Potassium feldspar	20	predominantly in the sand-size fraction; no signs of alteration.
Biotite	8	pleochroic from light to dark brown, no alteration.
Chlorite	4	pleochroic from light to dark green, predominantly fine grained.
Hornblende	2	weakly pleochroic in green; diagnostic amphibole cleavage apparent.
Calcite	3	no dissolution textures evident; usually in sand-size fraction.
Fluorite	1	isotropic, high relief.
Apatite	<1	trace amount.
OPAQUE	2	
Pyrite	(80)*	predominantly euhedral, many containing inclusions of other sulfides; minor dissolution evident, and one grain exhibited a very thin oxidation rim around its edge (most likely an iron-oxyhydroxide, possibly with some native sulfur) (photomicrograph 4).
Sphalerite	(10)	typically isolated, anhedral grains with many inclusions.
Chalcopyrite	(<5)	present as inclusions in sphalerite and as isolated grains.
Molybdenite	(5)	very fine grained plates or inclusions in both silicates and other sulfides; some dissolution evident but unclear whether it occurred before or after tailings deposition.
Magnetite	(<1)	minor, anhedral grains, no exsolution lamellae evident.
Galena	(<1)	inclusions in pyrite and sphalerite.
Covellite	(<1)	seen in association with pyrite (photomicrograph 5).
* numbers in brackets are approximate percentages of opaque mineral fraction		

COMMENTS:

- predominantly fine grained, approximately 20% sand-size particles.
- traces of iron-oxyhydroxide precipitation around a few silicate grains.
- "iron staining" also seen in a void within a silicate; the void appears to have been created from molybdenite dissolution. It is not clear whether this dissolution is a result of processes occurring after tailings deposition (photomicrograph 6).

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH1-176
[slimes, deposited in 1966]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	40	typical quartz, no alteration.
Plagioclase	20	slightly sericitized, predominantly fine grained.
Potassium feldspar	12	unaltered.
Biotite	10	pleochroic from light to dark brown, no indication of alteration, predominantly fine grained.
Muscovite	2	very small shreds of muscovite throughout the section.
Chlorite	5	pleochroic from light to dark green, bluish-gray interference colors, fine grained.
Hornblende	2	green, pleochroic.
Calcite	5	rhombohedral cleavage, no dissolution textures evident.
Fluorite	1	isotropic, unaltered.
OPAQUE	3	
Pyrite	(80)*	euhedral, many containing inclusions of other sulfides; a few grains exhibit weak alteration to marcasite around edges (photomicrograph 7).
Sphalerite	(10)	red internal reflections; unaltered.
Chalcopyrite	(5)	present as inclusions in sphalerite and as isolated grains.
Molybdenite	(5)	very fine grained plates predominantly as inclusions (photomicrograph 8).
Magnetite	(1)	exsolution lamellae of ilmenite exhibited.
Galena	(<1)	trace inclusions in pyrite
Pyrrhotite	(<1)	trace amounts as inclusions in pyrite, no oxidation evident.
* numbers in brackets are approximate percentages of opaque mineral fraction		

COMMENTS:
- very fine grained
- distinctly greater sulfide component relative to previous section

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH2-58
[andesite, deposited in 1978]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	30	anhedral.
Plagioclase	25	slightly sericitized throughout section.
Potassium feldspar	15	predominantly in the sand-size fraction.
Biotite	8	pleochroic from moderate to dark brown, bird's eye extinction.
Muscovite	2	very fine grained.
Chlorite	8	pleochroic from light to moderate green, first order interference colors.
Hornblende	3	weak pleochroism from green to brownish green, amphibole cleavage.
Calcite	3	colorless, rhombohedral cleavage.
Fluorite	2	high relief, isotropic.
Apatite	<1	trace apatite
OPAQUE	3	
Pyrite	(60)*	euhedral, one grain exhibited an oxidation rim that appeared to be predominantly native sulfur with residual iron in it, other grains showed alteration to marcasite on their edges (photomicrograph 9).
Sphalerite	(15)	occurs as inclusions in pyrite and as isolated grains.
Chalcopyrite	(10)	very slight dissolution around edges.
Molybdenite	(10)	platy, grey with a blue tint, no apparent alteration.
Magnetite	(2)	minor, anhedral grains, no exsolution lamellae evident.
Galena	(1)	usually as inclusions in sphalerite, light grey, isotropic.
Covellite	(<1)	present in the void of a pyrite grain, possibly secondary.
* numbers in brackets are approximate percentages of opaque mineral fraction		

COMMENTS:
- predominantly sand-size grains,
- no noticeable "iron staining" in the section.

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH3-37
[aplite, deposited in 1980]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	40	colorless to slightly yellow (section a bit thick).
Plagioclase	30	strongly sericitized.
Potassium feldspar	10	typical kspar.
Biotite	8	pleochroic from light to dark brown.
Muscovite	2	minor.
Chlorite	5	dark green, pleochroic.
Fluorite	2	pleochroic from light pink to light green.
Calcite	3	colorless to pale yellow, no dissolution textures evident.
OPAQUE	2	
Pyrite	(45)*	predominantly euhedral, many containing inclusions of sphalerite; all grains appear fresh, no alteration (photomicrograph 10).
Sphalerite	(30)	some grains contain chalcopyrite inclusions.
Chalcopyrite	(10)	very slight dissolution seen in a few grains, very minor.
Molybdenite	(10)	very fine grained, platy, no apparent alteration.
Magnetite	(<5)	minor, anhedral grains.
* numbers in brackets are approximate percentages of opaque mineral fraction		

COMMENTS:

- this thin section was a bit thick,
- extremely fine grained,
- not as many dark colored minerals than the previous sections,
- sulfides show extremely little evidence of post-deposition alteration.

PETROGRAPHIC ANALYSIS, SAMPLE LOG SHEET

PROJECT NO: 09211 (SRK)
SAMPLE NO: BH3-111
[aplite, deposited in 1972]

Mineral	Approx. %	Description
NON-OPAQUE		
Quartz	30	typical.
Plagioclase	25	sericitized quite strongly.
Potassium feldspar	22	sand-size.
Biotite	8	pleochroic, slight green color present, but predominantly brown.
Chlorite	5	pleochroic from light to dark green.
Fluorite	3	isotropic.
Calcite	5	no dissolution apparent (photomicrograph 11).
OPAQUE	1 to 2	
Pyrite	(80)*	predominantly euhedral cubes, no alteration or dissolution textures.
Sphalerite	(10)	some grains contain chalcopyrite inclusions, others have no inclusions (photomicrograph 12).
Chalcopyrite	(5)	present as inclusions and as isolated grains.
Molybdenite	(5)	predominantly in the fine grained fraction.
Galena	(<1)	triangular cleavage pits, euhedral.
Magnetite	(<1)	trace magnetite.
* numbers in brackets are approximate percentages of opaque mineral fraction		

COMMENTS:
- predominantly sand-size grains,
- all the sulfide surfaces are pristine, no signs of dissolution or oxidation.

5.0 Conclusions

Based on the macroscopic characterization, x-ray diffraction analysis and petrographic examination of the Questa tailings, it was determined that the major minerals, in order of decreasing abundance, consist of quartz (SiO_2), plagioclase feldspar ($(Na,Ca)Al(Si,Al)_3O_8$), potassium feldspar ($KAlSi_3O_8$), biotite ($KMg_3(Si_3Al)O_{10}(OH)_2$), chlorite ($(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$), with lesser amounts of muscovite ($KAl_2Si_3AlO_{10}(OH)_2$), amphibole ($Ca_2(Fe,Mg)_4Al(Si_7Al)O_{22}(OH,F)_2$), fluorite ($CaF_2$), and calcite ($CaCO_3$), minor amounts of pyrite (FeS_2), sphalerite ($(ZnFe)S$), chalcopyrite ($CuFeS_2$), molybdenite (MoS_2), magnetite (Fe_3O_4), and trace amounts of apatite ($Ca_5(PO_4)_3(OH,F,Cl)$), galena (PbS), covellite (CuS), pyrrhotite ($Fe_{(1-x)}S$), gypsum ($CaSO_4 \cdot 2H_2O$), iron-oxyhydroxides ($FeO(OH)$) and possibly native sulfur (S^o).

The primary minerals identified that, in the presence of oxygen and water, are potential sources of acidity are pyrite, chalcopyrite and molybdenite. The sulfides that pose possible minor sources of metals are chalcopyrite, sphalerite, molybdenite and minor galena. The minerals that likely contribute to laboratory neutralization potential include calcite, biotite, plagioclase feldspar, and minor clay. Of these minerals, calcite is presumably the only mineral to contribute significant neutralization potential in the field at the pH conditions exhibited throughout the Questa tailings. There was no barite identified in the tailings examined and therefore little concern for the potential contribution from barite to the analytical sulfate-sulfur determination.

Minor alteration due to localized sulfide oxidation occurring after deposition was seen in samples BH1-107, BH1-135, BH1-176, and BH2-58. These samples also contained between 3% and 5% calcite suggesting that, in all likelihood, neutralization of present acid production is taking place. Samples BH3-37 and BH3-111 exhibited no signs of oxidation. The degree of alteration of the sulfides in all six samples is between 1 and 0 on the Sulfide Alteration Index given by Blowes and Jambor (1990), a relativity scale ranging from 0 to 10. This category is defined by only a few grains of sulfides (pyrite and chalcopyrite in this case) that are weakly altered along the rims and fractures; >95% of the grains have sharp, fresh margins.

Some evidence of molybdenite dissolution was identified in sample BH1-135. It is not clear whether this dissolution is a result of processes occurring within the tailings facility, or is due to conditions prior to tailings deposition (i.e. pre-mining conditions or milling processes). This phenomenon is believed to be of minor consideration as only one grain exhibited significant signs of dissolution; most of the molybdenite that has reported to the tailings fraction occurs either as inclusions in other minerals whereby the encapsulation serves to protect the molybdenite from dissolution, or as very fine grained laths.

The soluble mineral constituents identified include iron-oxyhydroxides, gypsum and possibly native sulfur. Based on the mineralogical examination these minerals do not show signs of dissolution in the Questa tailings, but rather are interpreted to serve as sinks for calcium, sulfate, iron, sulfur and possibly for metals such as copper which are commonly attenuated in iron-oxyhydroxides.

6.0 References

Blowes, D.W., and Jambor, J.L. (1990). The Pore-water Geochemistry and the Mineralogy of the Vadose Zone of Sulfide Tailings, Waite Amulet, Quebec, Canada. *Applied Geochemistry*, **5**, pp. 327-346.

Jambor, J.L. (1994). Mineralogy of Sulfide-rich Tailings and Their Oxidation Products. In: *Environmental Geochemistry of Sulfide Mine-Wastes* (J.L.Jambor and D.W. Blowes, eds.), Mineralogical Association of Canada, pp. 59-102.

Meyer, J. and Leonardson, R. (1990). Geology of the Questa Mining District: Volcanic, Plutonic, Tectonic and Hydrothermal History. New Mexico Geological Society, 41st Field Conference, 1990.

Steffen, Robertson and Kirsten (U.S.), Inc. (1996). Questa Tailings Disposal Facility; Assessment of Acid Generating Potential. Report prepared for Molycorp, Inc., March, 1996.

Steffen, Robertson and Kirsten (U.S.), Inc. (1997). Proposal for Teochemical and Physical Testing; Questa Tailings Facility. Report prepared for Molycorp, Inc., March 17, 1997.

FIGURES

Figure 1: X-ray Diffractograms of the Questa Tailings

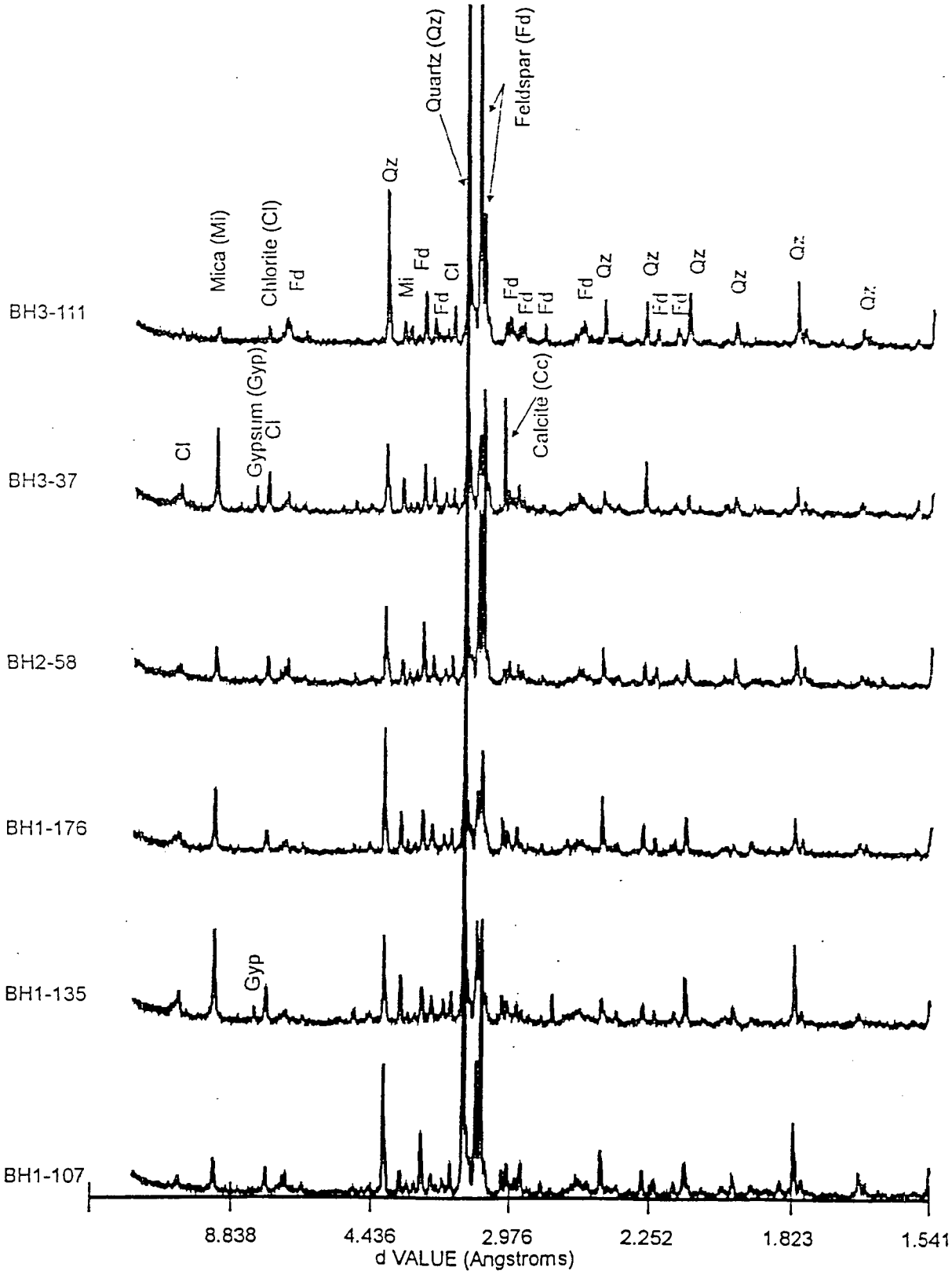
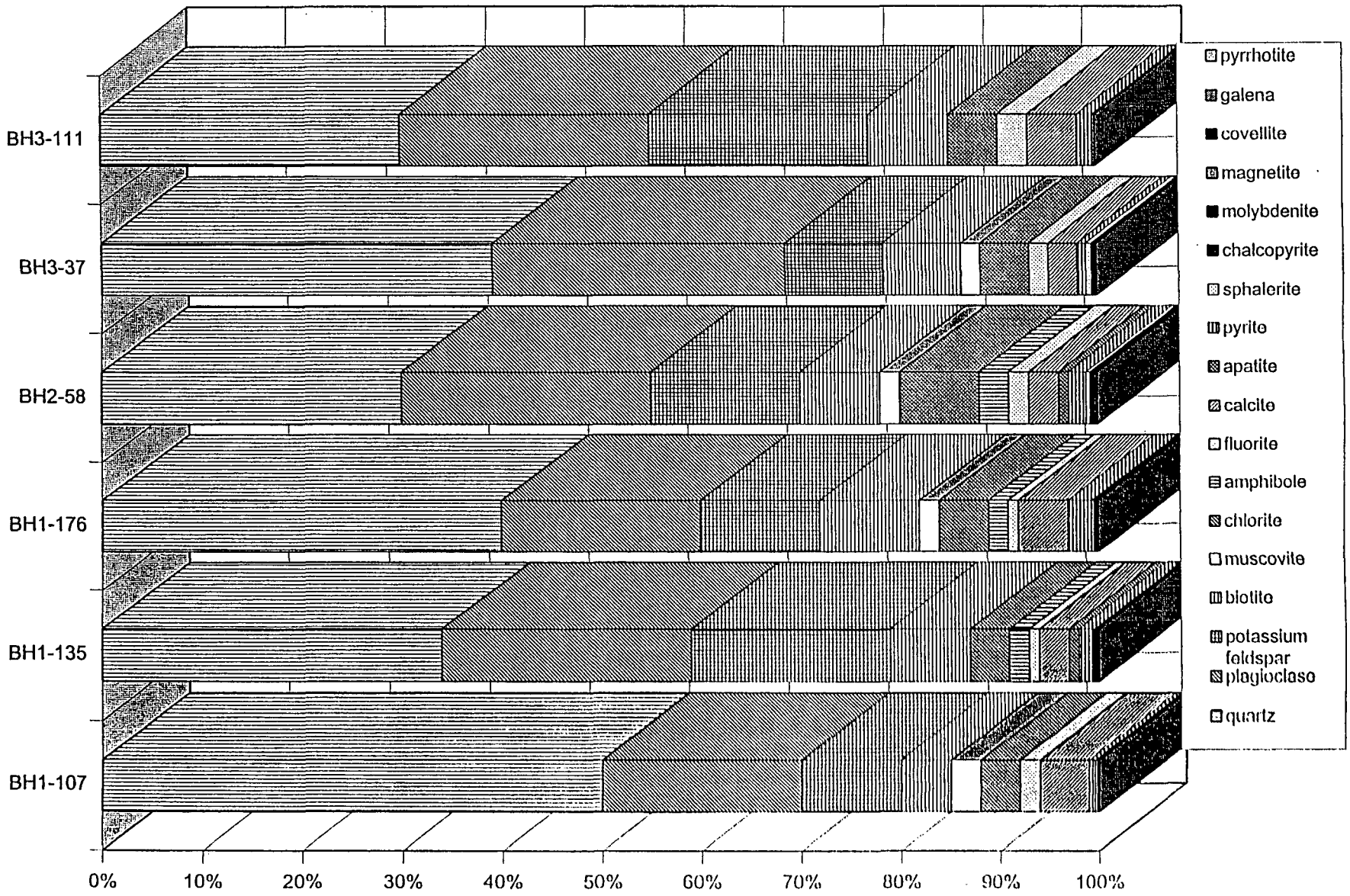


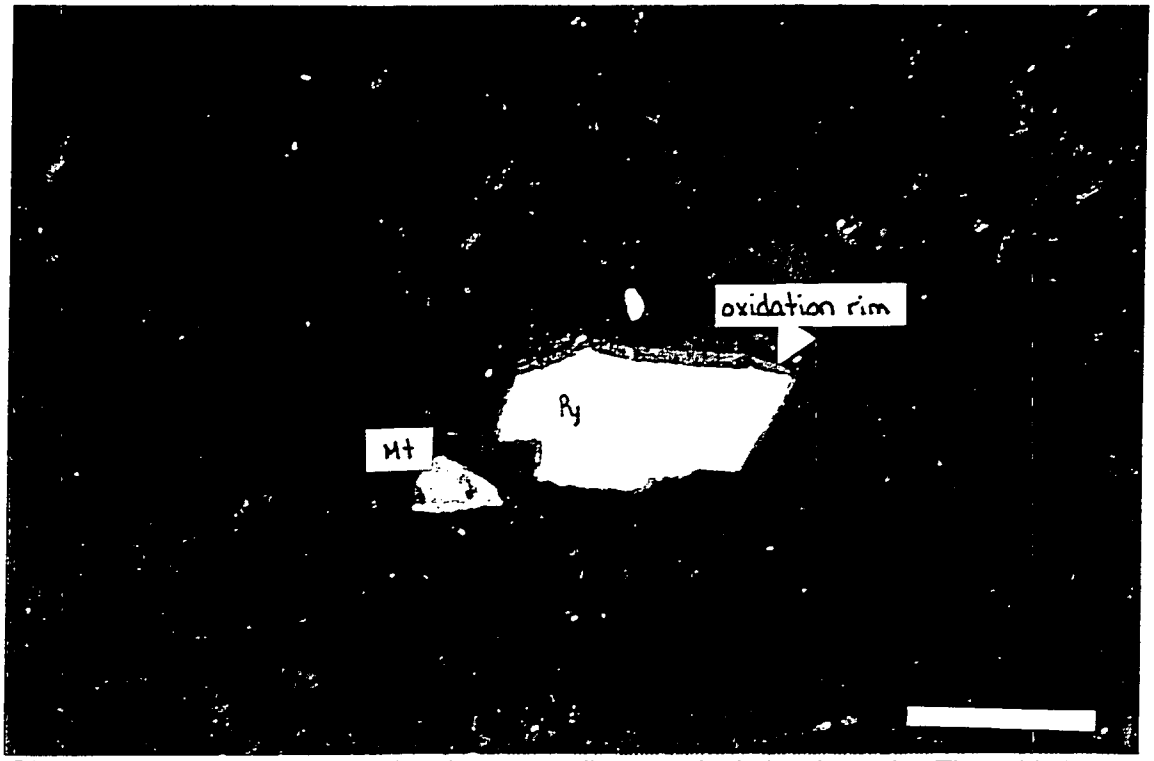
Figure 2: Approximate Mineralogical Modal Abundance Based on Petrographic Analysis.



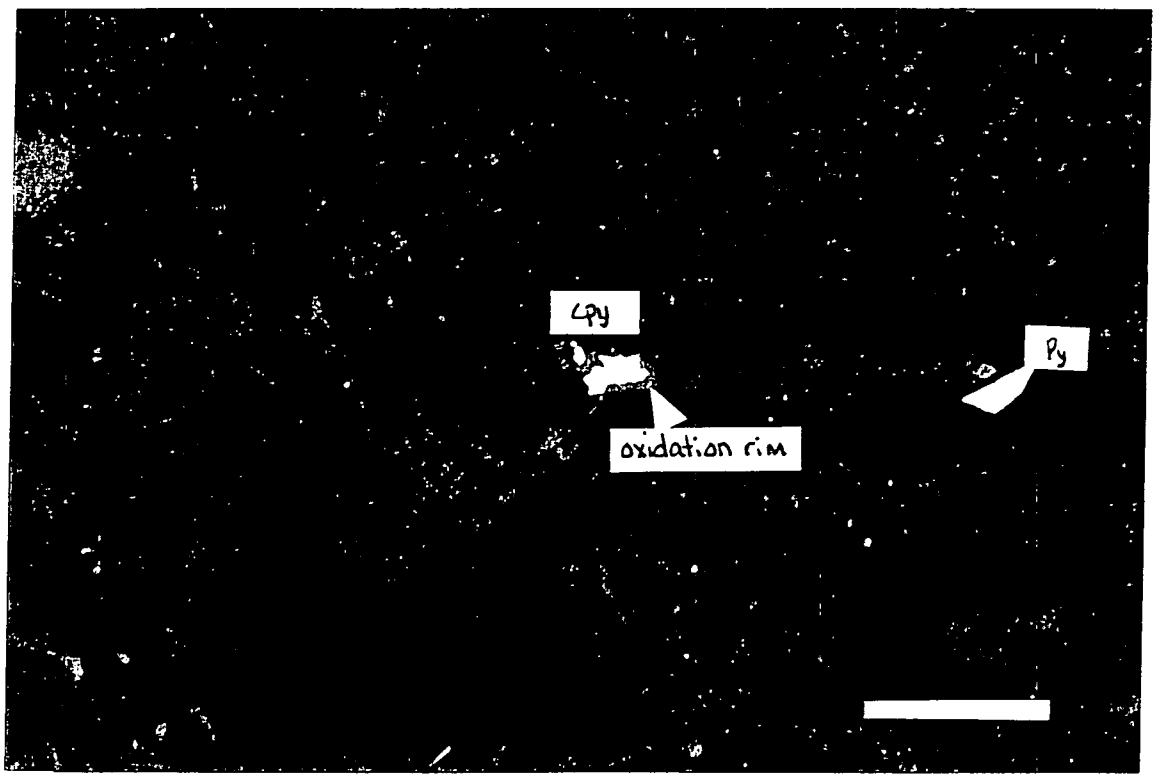
RGC Project No. 036008

Robertson GeoConsultants Inc.
May, 1997.

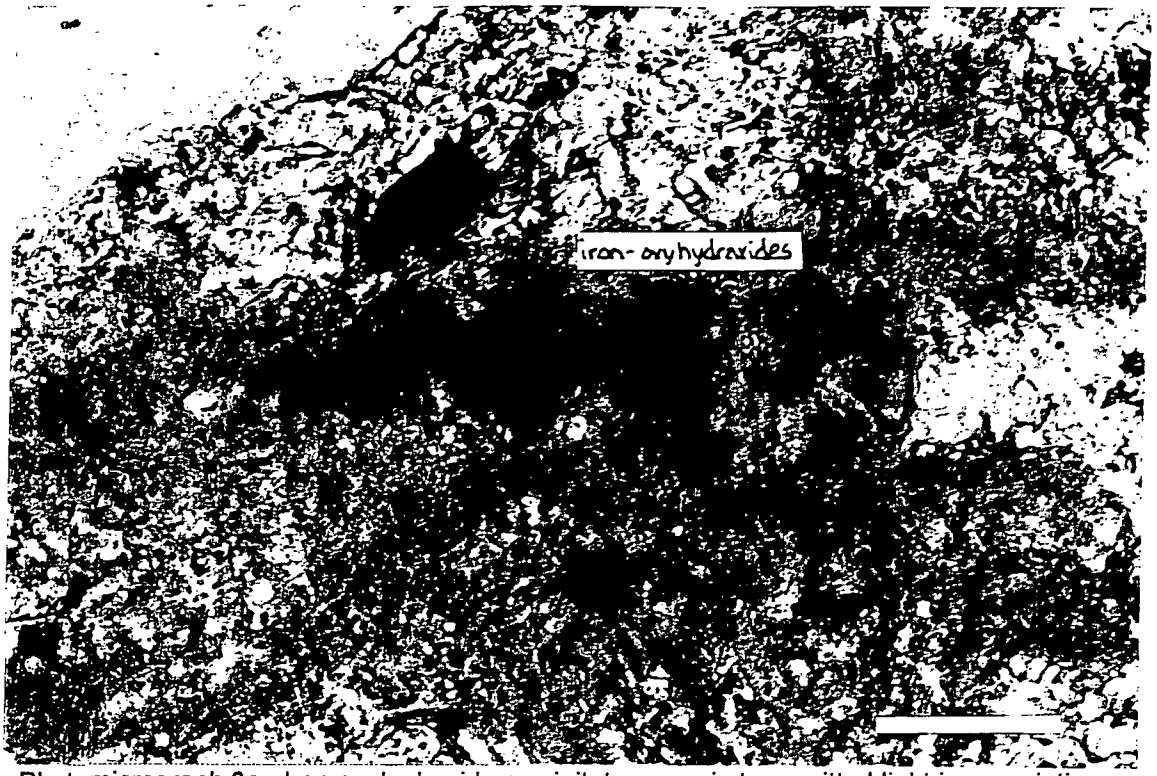
PHOTOMICROGRAPHS



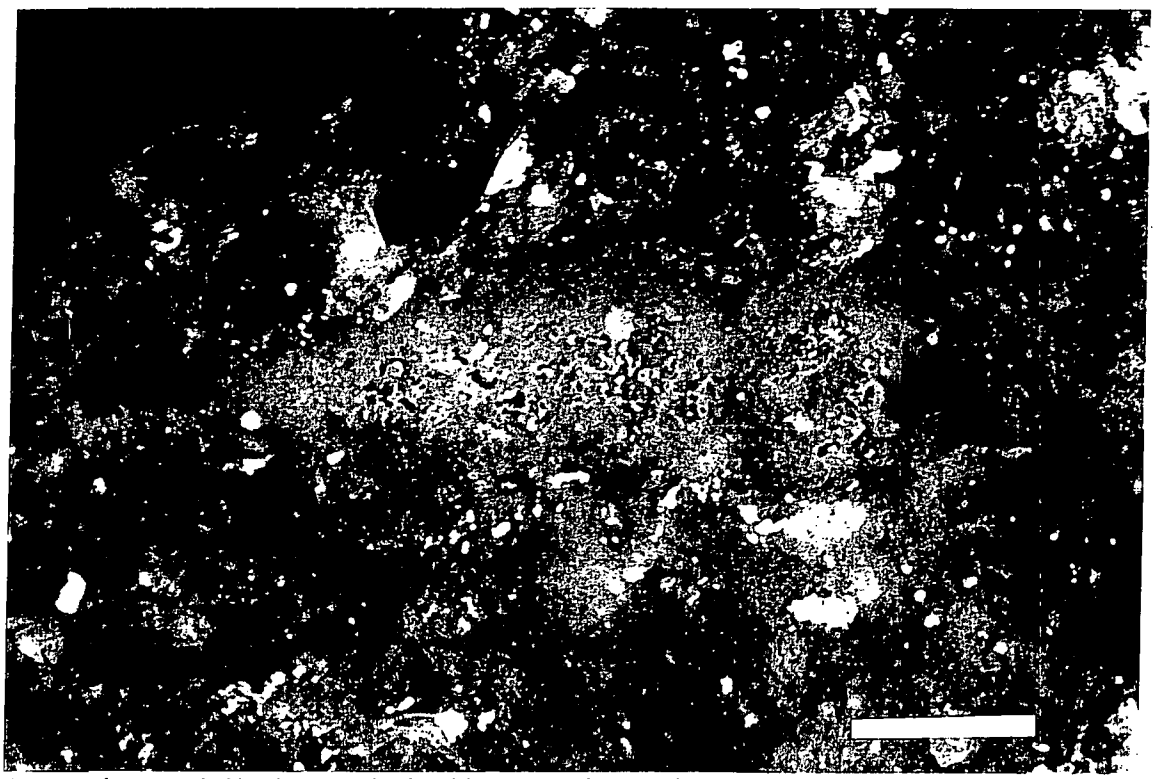
Photomicrograph 1: Thin oxidation rim surrounding an euhedral pyrite grain. The oxidation product is most likely a mixture of an iron-oxyhydroxide and native sulfur. The gray mineral left of the pyrite is magnetite. Sample BH1-107, reflected light, scale bar equals 50 micrometers.



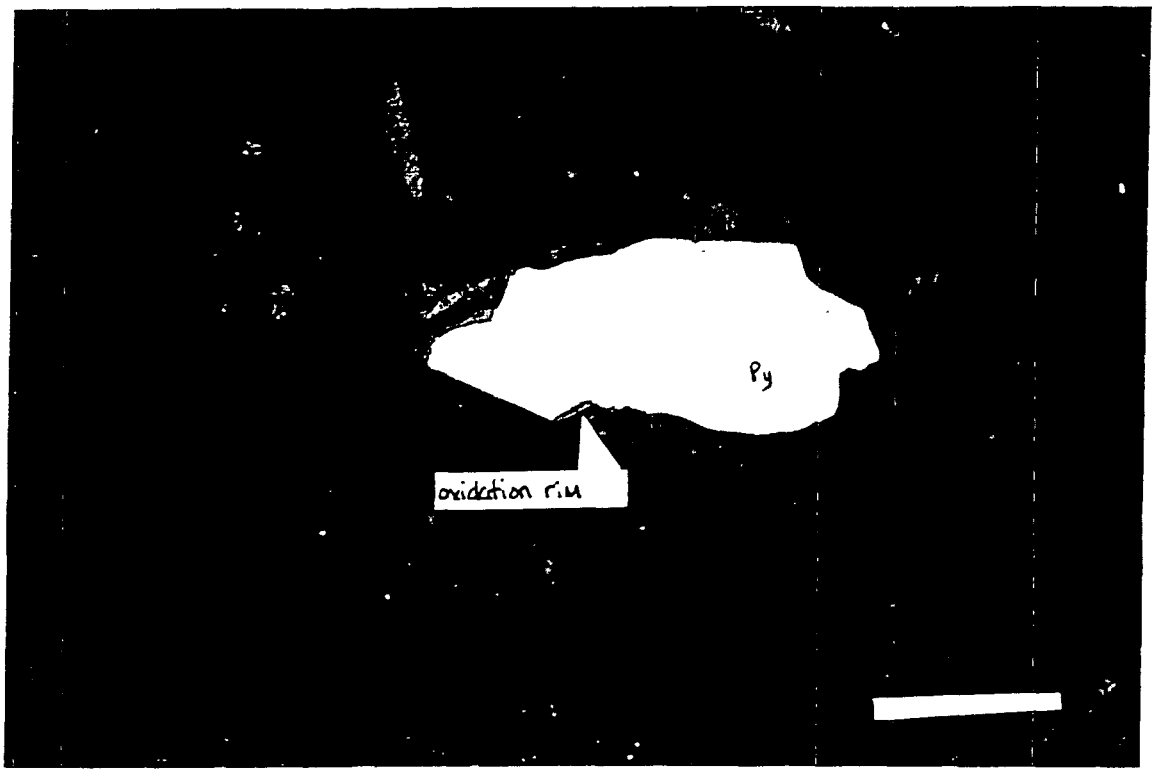
Photomicrograph 2: Oxidation rim surrounding a small chalcopyrite grain. The oxidation product is predominantly iron-oxyhydroxide. The bright triangular grain on the right side of the photomicrograph is pyrite. Sample BH1-107, reflected light, scale bar equals 50 micrometers.



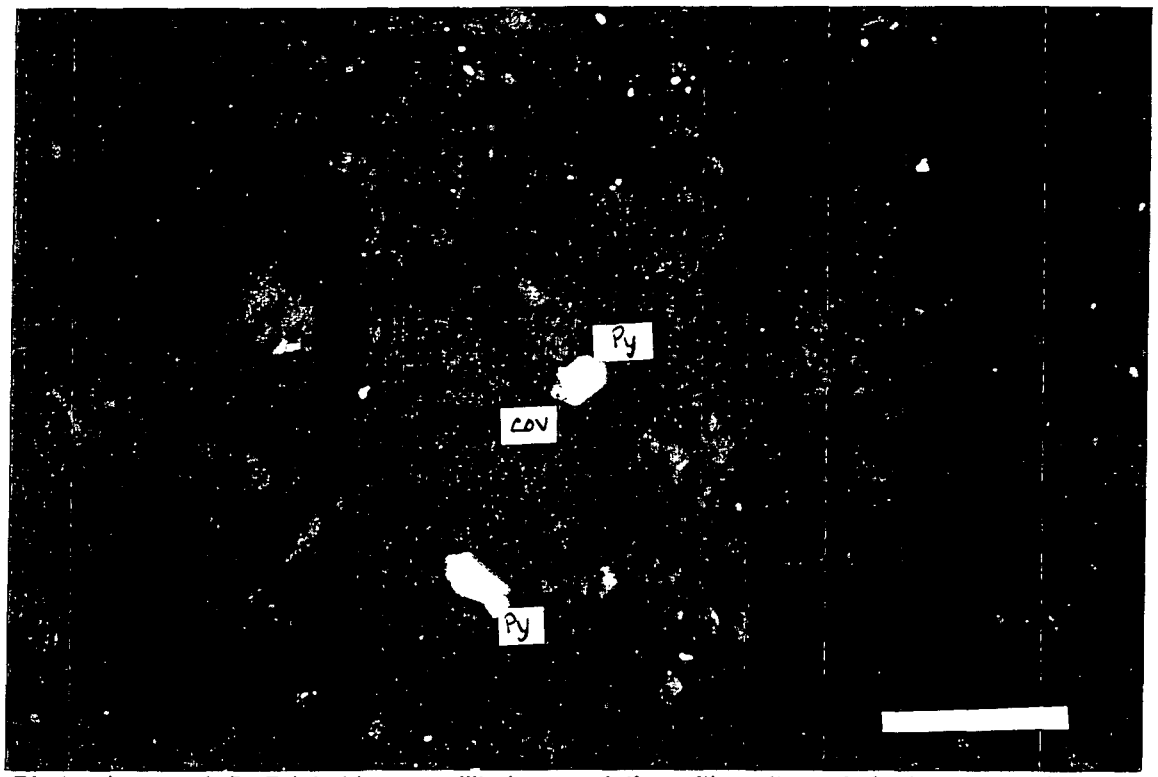
Photomicrograph 3a: Iron-oxyhydroxide precipitates seen in transmitted light in association predominantly with feldspar, scale bar equals 100 micrometers, sample BH1-107.



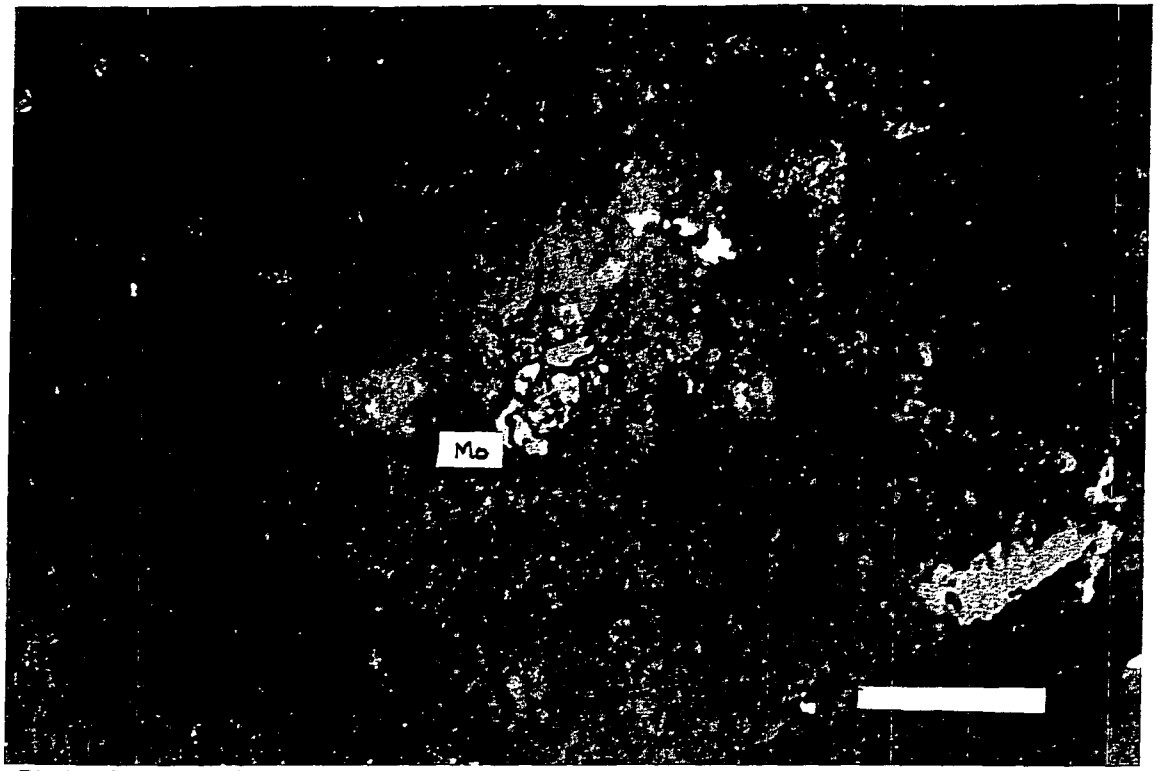
Photomicrograph 3b: Iron-oxyhydroxides seen above taken under crossed polars showing characteristic red color, scale bar equals 100 micrometers, sample BH1-107.



Photomicrograph 4: Preliminary formation of oxidation rim on a pyrite grain from sample BH1-135, scale bar equals 50 micrometers.

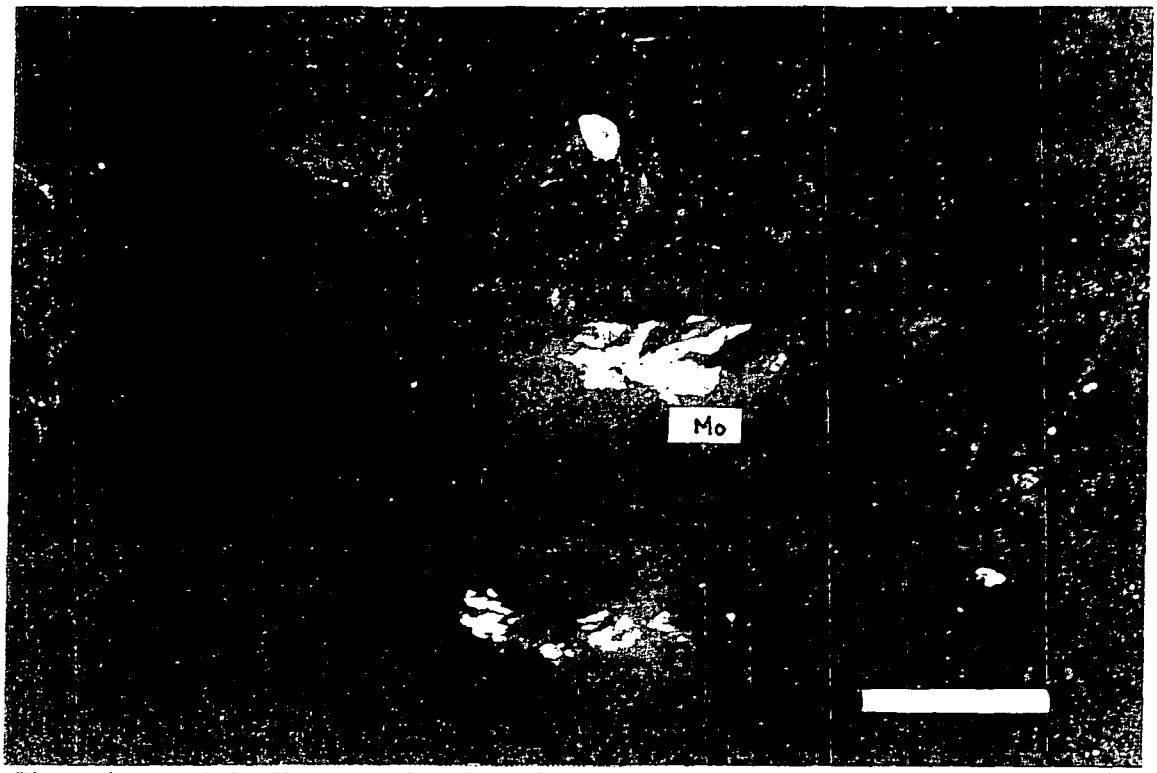


Photomicrograph 5: Bright blue covellite in association with pyrite grain in the center of the photomicrograph, another pyrite grain seen nearer the bottom. It is not clear if the covellite is secondary. Sample BH1-135, reflected light, scale bar equals 50 micrometers.

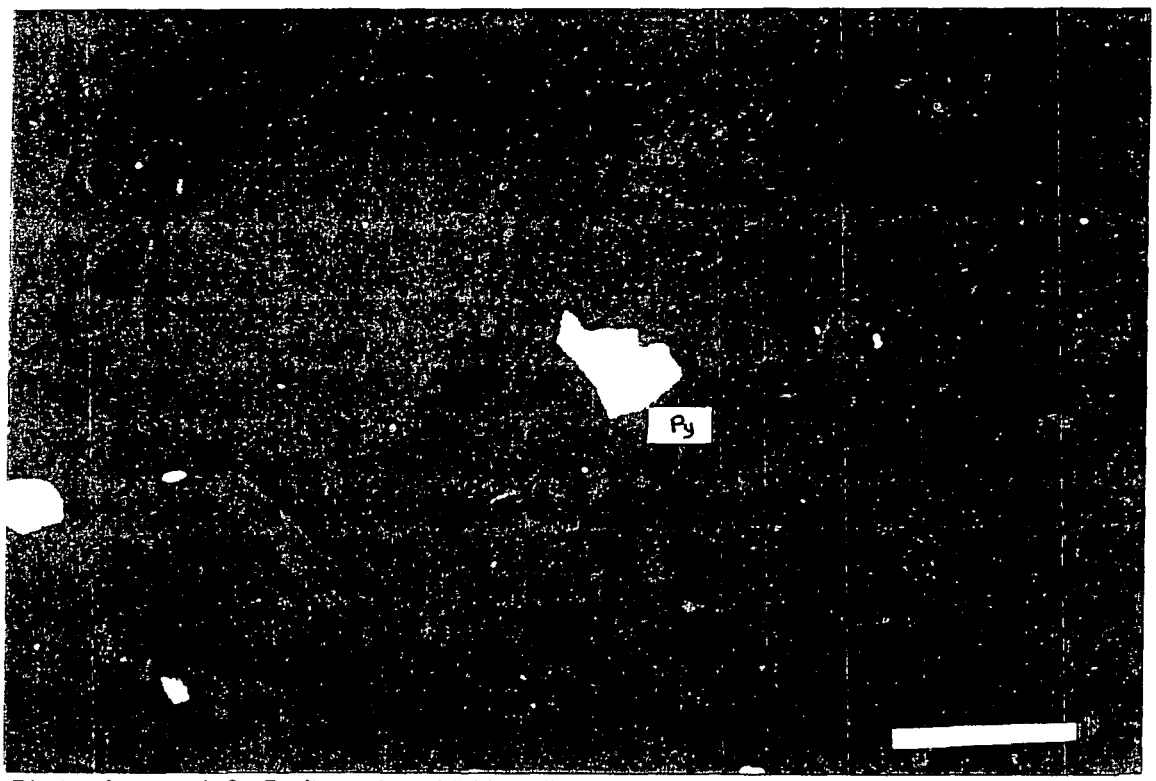


Photomicrograph 6: "Iron staining" within void spaces in a silicate. The void appears to be created by molybdenite dissolution, not clear whether dissolution occurred post deposition. Sample BH1-135, reflected light, scale bar equals 50 micrometers.

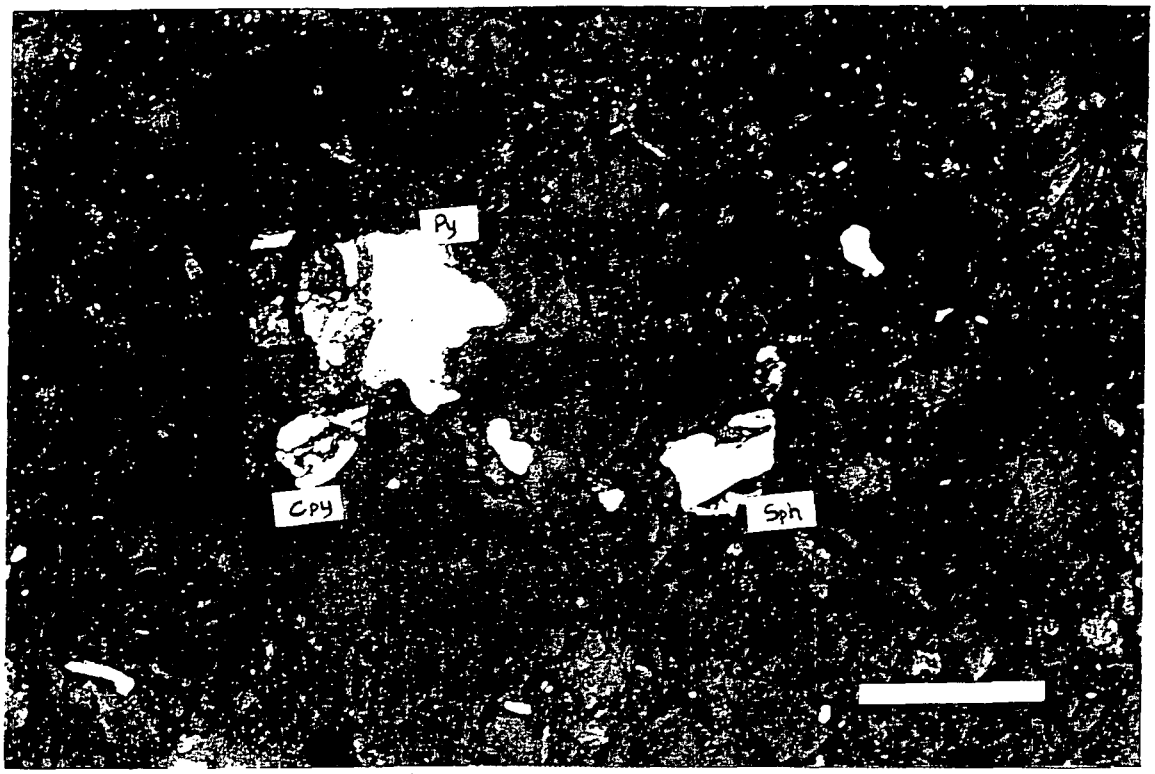
Photomicrograph 7: Very slight dissolution and possible alteration to marcasite around the euhedral pyrite grain in the center of the photomicrograph. Sample BH1-176, reflected light, scale bar equals 50 micrometers.



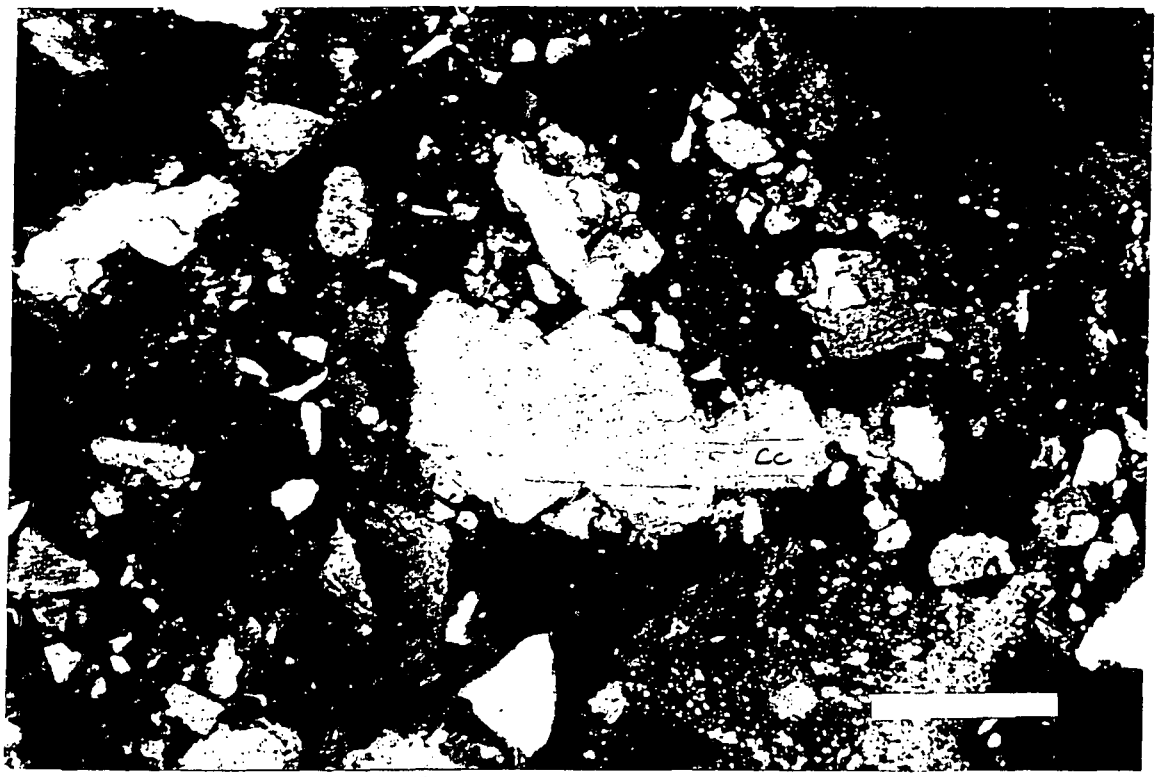
Photomicrograph 8: Platey molybdenite typical of the Questa tailings. Sample BH1-176, reflected light, scale bar equals 50 micrometers.



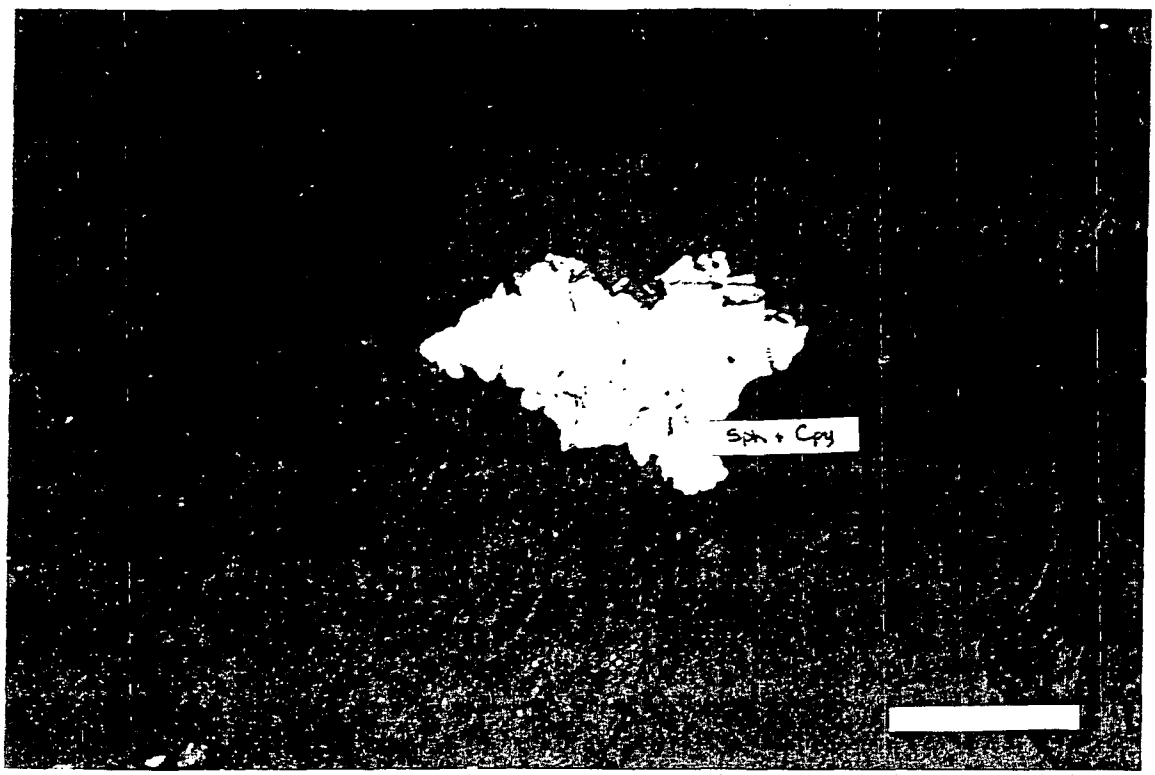
Photomicrograph 9: Pyrite grain exhibiting slight dissolution and alteration to marcasite around its edges. Sample BH2-58, reflected light, scale bar equals 50 micrometers.



Photomicrograph 10: Pristine pyrite, chalcopyrite and sphalerite typical of this sample, no signs of oxidation seen. Sample BH3-37, reflected light, scale bar equals 50 micrometers.



Photomicrograph 11: Typical calcite grain as seen under transmitted light with crossed polars, no dissolution or alteration apparent. Sample BH3-111, scale bar equals 100 micrometers.



Photomicrograph 12: Typical sphalerite with abundant chalcopyrite inclusions, no oxidation textures seen. Sample BH3-111, reflected light, scale bar equals 50 micrometers.

HUMIDITY CELL #1

Sample T-24B
Aged Surface Sample - potentially acid generating

pH = 7.1,
Conductivity = 2480 µS,
NP/AP = 0.42,
Deposition year ~ 1970

CELL 1
SAMPLE T-24B

Dry sample weight: 0.250 kg

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.420	7.24	333	1701	37.3	0.0	9.0	15.1	1595	2679.6
1	Jun.	3	0.500	5.55	0.480	7.27	371	1411	46.8	0.0	8.5	31.4	1097	4785.8
2		10	0.500	5.99	0.500	7.45	389	1074	44.0	0.0	4.5	40.4	631	6047.8
3		17	0.500	5.70	0.500	7.50	330	900	37.5	0.0	3.5	47.4	490	7027.8
4		24	0.500	5.61	0.490	7.55	365	1084	32.0	0.0	3.0	53.3	728	8454.7
5	Jul.	1	0.500	5.58	0.505	7.69	354	736	38.0	0.0	2.8	58.9	344	9149.6
6		8	0.500	5.53	0.475	7.82	357	548	35.5	0.0	1.8	62.2	204	9537.2
7		15	0.500	5.89	0.510	7.76	348	469	34.0	0.0	1.5	65.3	185	9914.6
8		22	0.500	5.60	0.495	7.81	353	576	39.5	0.0	1.8	68.7	215	10340.3
9		29	0.500	5.66	0.500	7.90	338	399	37.0	0.0	1.3	71.2	118	10576.3
10	Aug.	6	0.500	5.58	0.495	7.90	326	294	35.5	0.0	1.3	73.7	71	10716.9
11		12	0.500	5.71	0.500	7.85	330	232	34.5	0.0	1.3	76.2	50	10816.9
12		19	0.500	5.64	0.500	7.82	332	209	35.0	0.0	1.5	79.2	37	10890.9
13		26	0.500	5.81	0.505	7.76	295	169	35.5	0.0	1.8	82.7	23	10937.3
14	Sept.	3	0.500	5.77	0.500	7.89	306	156	35.0	0.0	1.5	85.7	16	10969.3
15		9	0.500	5.86	0.505	7.86	330	114	36.0	0.0	1.5	88.8	11	10991.6
16		16	0.500	5.70	0.510	7.86	315	104	33.0	0.0	1.5	91.8	11	11014.0
17		23	0.500	5.65	0.500	7.78	335	95	30.0	0.0	1.8	95.3	10	11034.0
18		30	0.500	5.85	0.505	7.71	309	106	34.0	0.0	2.3	99.9	11	11056.2
19	Oct.	7	0.500	5.82	0.505	7.66	332	89	30.0	0.0	2.0	103.9	8	11072.4
20		14	0.5	6.05	0.500	7.61	350	93	30.5	0.0	2.3	108.4	10	11092.4

CELL 1
SAMPLE T-24B

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.4	0.3	0.0005	0.08	<0.005	<0.1	<0.1	0.04	550	<0.01	0.05	0.02	11.7	<0.01	<0.05	0.05	55.1
1	0.10	0.0363	0.0004	0.04	<0.005	<0.1	<0.1	0.0048	413	<0.01	<0.01	<0.01	9.61	<0.03	<0.05	<0.01	7.22
2	0.10	0.0172	0.0003	0.04	<0.005	<0.1	<0.1	0.0032	293	<0.01	<0.01	<0.01	9.61	<0.03	<0.05	<0.01	2.21
3	0.018	0.0094	0.0003	0.03	<0.005	<0.1	<0.1	0.0021	224	<0.01	<0.01	<0.01	9.24	<0.03	<0.05	<0.01	0.67
4	0.006	0.0033	0.0001	0.02	<0.005	<0.1	<0.1	0.0021	234	<0.01	<0.01	<0.01	7.30	<0.03	<0.05	<0.01	0.50
5	<0.01	0.0048	<0.0001	0.03	<0.005	<0.1	<0.1	0.0011	162	<0.01	<0.01	<0.01	8.21	<0.03	<0.05	<0.01	0.23
6																	
7																	
8	0.008	0.0040	0.0001	0.03	<0.005	<0.1	<0.1	0.0008	118	<0.01	<0.01	<0.01	6.53	<0.03	<0.05	<0.01	0.14
9																	
10																	
11	0.009	0.0043	0.0023	0.03	<0.005	<0.1	<0.1	0.0005	39.9	<0.01	<0.01	<0.01	5.15	<0.03	<0.05	<0.01	0.06
12																	
13																	
14	0.006	0.0036	0.002	0.03	<0.005	<0.1	<0.1	0.0006	25.4	<0.01	<0.01	<0.01	4.58	<0.03	<0.05	<0.01	0.05
15																	
16																	
17	0.011	0.0019	<0.0001	0.03	<0.005	<0.1	<0.1	<0.0002	20.1	<0.01	<0.01	<0.01	3.95	<0.03	<0.05	<0.01	<0.05
18																	
19																	
20	0.006	0.0024	0.0019	0.03	<0.005	<0.1	<0.1	0.0003	20.0	<0.01	<0.01	<0.01	3.70	<0.03	<0.05	<0.01	<0.05

CELL 1
SAMPLE T-24B

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	11.0	<0.00005	0.29	0.22	<0.3	10	0.0036	5.15	0.0001	2	2.81	<0.1	<0.03	<0.01	<0.03	1.90
1	1.54	<0.00005	0.55	<0.02	<0.3	5	0.0025	3.29	0.0001	<2	1.49	<0.1	<0.03	<0.01	<0.03	0.185
2	1.05	<0.00005	0.62	<0.02	<0.3	4	0.0010	3.23	0.0003	<2	1.10	<0.1	<0.03	<0.01	<0.03	0.098
3	0.722	<0.00005	0.68	<0.02	<0.3	3	0.0006	2.62	<0.0001	<2	0.761	<0.1	<0.03	<0.01	<0.03	0.062
4	0.629	<0.00005	0.74	<0.02	<0.3	3	<0.0005	2.04	0.0001	<2	0.780	<0.1	<0.03	<0.01	<0.03	0.038
5	0.318	<0.00005	1.04	<0.02	<0.3	3	<0.0005	2.38	<0.0001	<2	0.562	<0.1	<0.03	<0.01	<0.03	0.024
6																
7																
8	0.295	<0.00005	1.69	<0.02	<0.3	2	<0.0005	2.39	<0.0001	<2	0.525	<0.1	<0.03	<0.01	<0.03	0.040
9																
10																
11	0.145	<0.00005	1.69	<0.02	<0.3	<2	<0.0005	1.85	<0.0001	<2	0.265	<0.1	<0.03	<0.01	<0.03	0.007
12																
13																
14	0.118	<0.00005	1.62	<0.02	<0.3	<2	<0.0005	1.81	<0.0001	<2	0.231	<0.1	<0.03	<0.01	<0.03	0.005
15																
16																
17	0.098	<0.00005	1.39	<0.02	<0.3	<2	<0.0005	1.54	<0.0001	<2	0.179	<0.1	<0.03	<0.01	<0.03	0.005
18																
19																
20	0.147	<0.00005	1.23	<0.02	<0.3	<2	<0.0005	1.65	<0.0001	<2	0.170	<0.1	<0.03	<0.01	<0.03	0.006

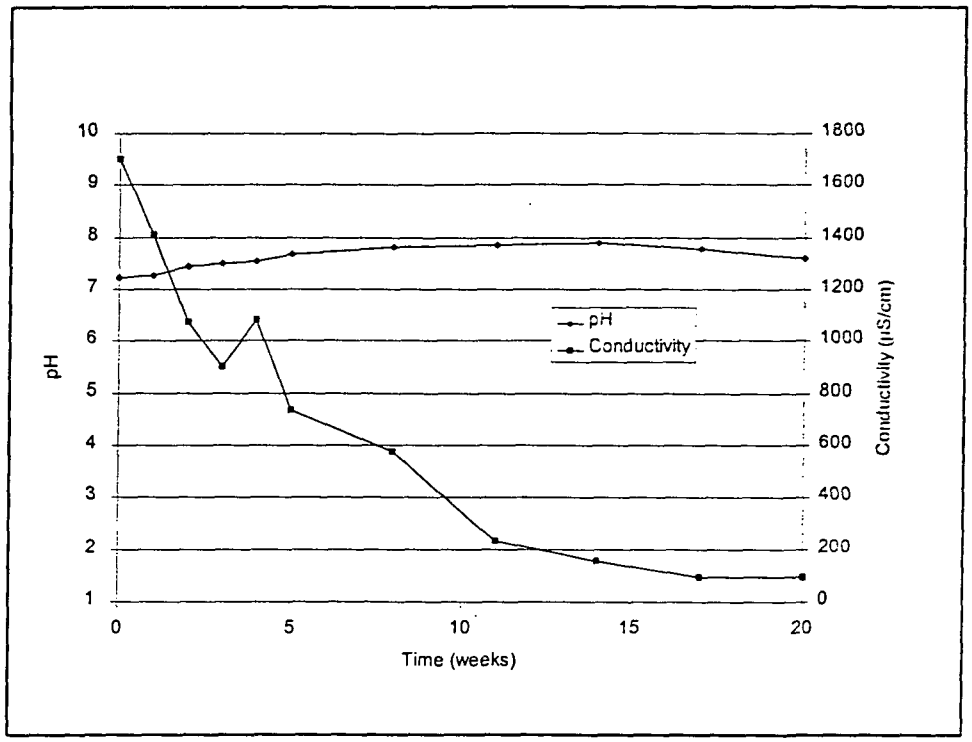
CELL 1
SAMPLE T-24B

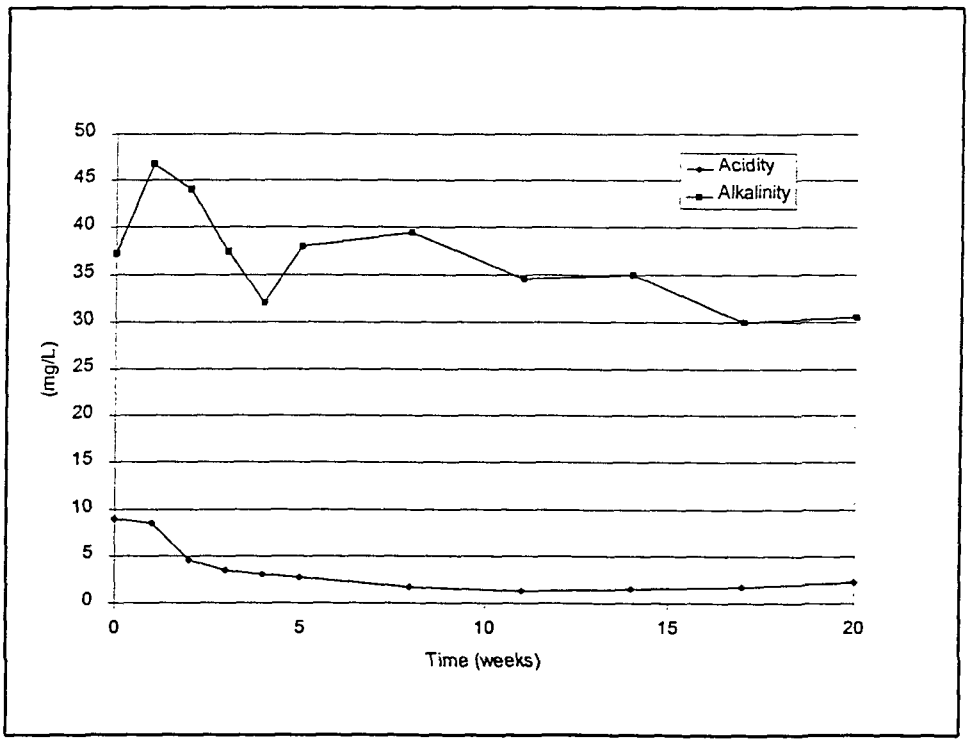
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly Acidity (pH=8.3) (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.04	2680	15.1	62.6	62.6	924.00	92.6	2696	2696	19.66	92.57	0.49	0.37	3.19
1	1.08	2106	16.3	89.8	152.3	792.96	13.9	2040	4736	18.45	13.86	1.06	0.02	0.36
2	0.89	1262	9.0	88.0	240.3	586.00	4.4	1483	6219	19.22	4.42	1.24	0.02	0.20
3	0.91	980	7.0	75.0	315.3	448.00	1.3	1126	7345	18.48	1.34	1.36	0.02	0.12
4	1.29	1427	5.9	62.7	378.1	458.64	1.0	1151	8496	14.31	0.98	1.45	0.02	0.07
5	0.88	695	5.6	76.8	454.8	327.24	0.5	820	9316	16.58	0.46	2.10	0.02	0.05
6		388	3.3	67.5	522.3				9316					
7		377	3.1	69.4	591.6				9316					
8	3.52	426	3.5	78.2	669.8	233.64	0.3	585	9901	12.93	0.28	3.35	0.02	0.08
9		236	2.5	74.0	743.8				9901					
10		141	2.5	70.3	814.1				9901					
11	0.52	100	2.5	69.0	883.1	79.80	0.1	200	10101	10.30	0.12	3.38	0.02	0.01
12		74	3.0	70.0	953.1				10101					
13		46	3.5	71.7	1024.8				10101					
14	0.26	32	3.0	70.0	1094.8	50.80	0.1	127	10228	9.16	0.10	3.24	0.02	0.01
15		22	3.0	72.7	1167.6				10228					
16		22	3.1	67.3	1234.9				10228					
17	0.21	20	3.5	60.0	1294.9	40.20	0.1	101	10329	7.90	0.05	2.78	0.02	0.01
18		22	4.5	68.7	1363.6				10329					
19		16	4.0	60.6	1424.2				10329					
20	0.21	20	4.6	61.0	1485.2	40.00	0.1	100	10429	0.00	0.05	2.46	0.02	0.01

CELL 1
SAMPLE T-24B

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	1500	478	450	23	252	33600	1.31	19.37	0.11	1.61	1.27	8
1							2.54	22.27	0.34	1.69	1.41	14
2							3.82	23.19	0.62	1.78	1.49	18
3							5.05	23.47	0.92	1.86	1.53	21
4							6.01	23.68	1.24	1.95	1.56	25
5							7.11	23.77	1.71	2.04	1.58	27
6							7.11	23.77	1.71	2.04	1.58	28
7							7.11	23.77	1.71	2.04	1.58	30
8							7.98	23.83	2.45	2.12	1.61	31
9							7.98	23.83	2.45	2.12	1.61	31
10							7.98	23.83	2.45	2.12	1.61	32
11							8.66	23.86	3.20	2.21	1.62	32
12							8.66	23.86	3.20	2.21	1.62	32
13							8.66	23.86	3.20	2.21	1.62	33
14							9.27	23.88	3.92	2.30	1.62	33
15							9.27	23.88	3.92	2.30	1.62	33
16							9.27	23.88	3.92	2.30	1.62	33
17							9.80	23.89	4.54	2.38	1.63	33
18							9.80	23.89	4.54	2.38	1.63	33
19							9.80	23.89	4.54	2.38	1.63	33
20							9.80	23.90	5.09	2.47	1.63	33

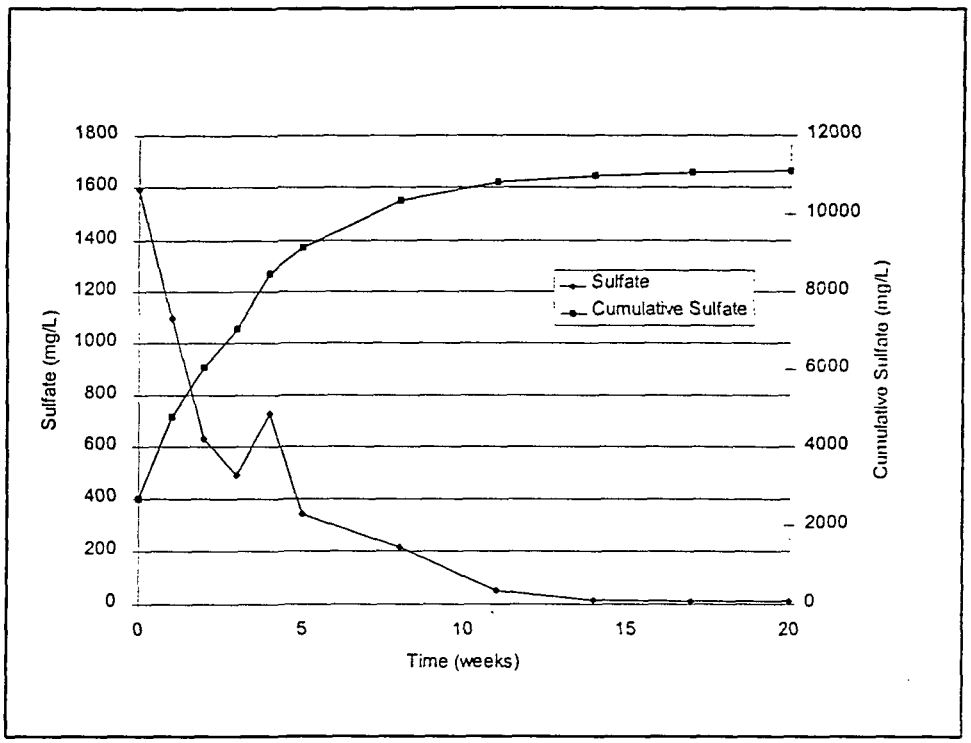
CELL 1 - Sample T-24B

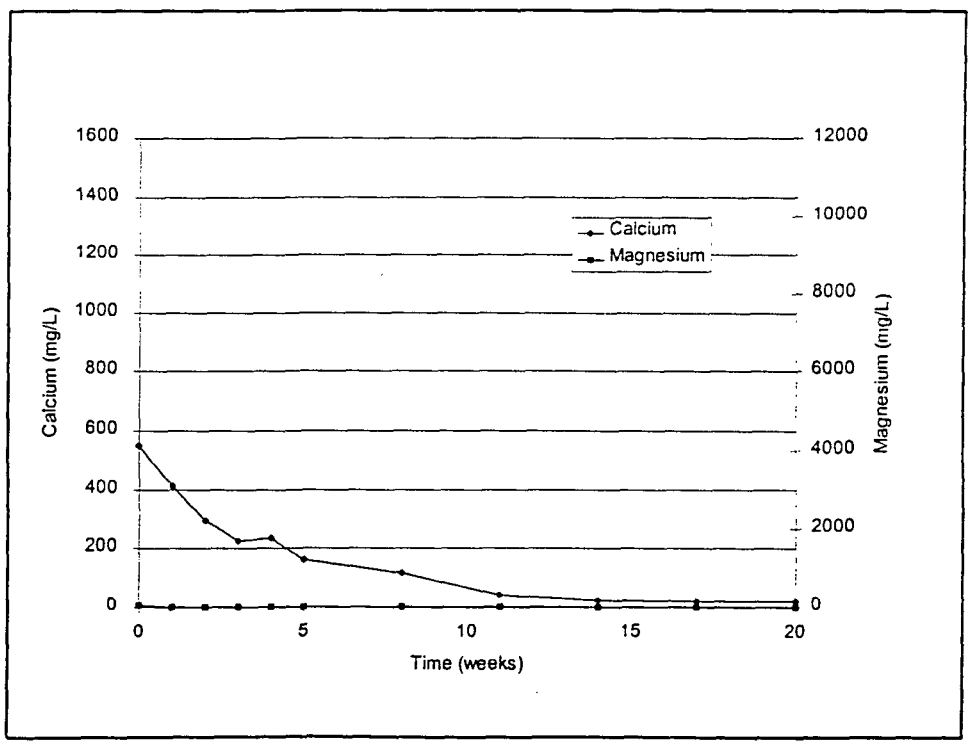




>Aged surface sample, lowest NP/AP encountered

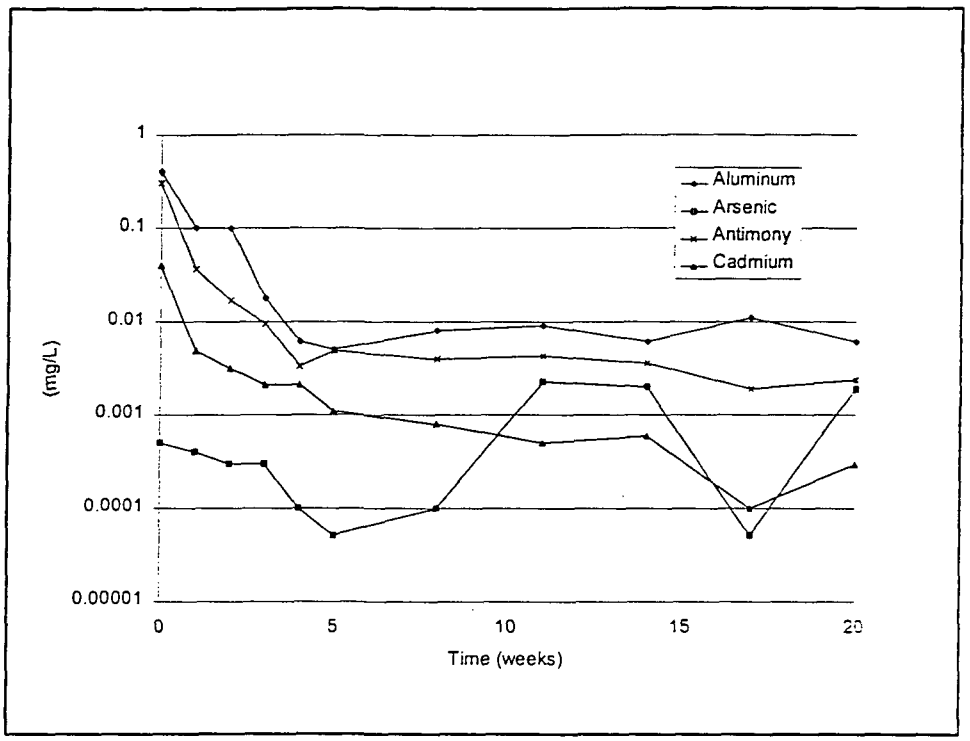
CELL 1 - Sample T-24B

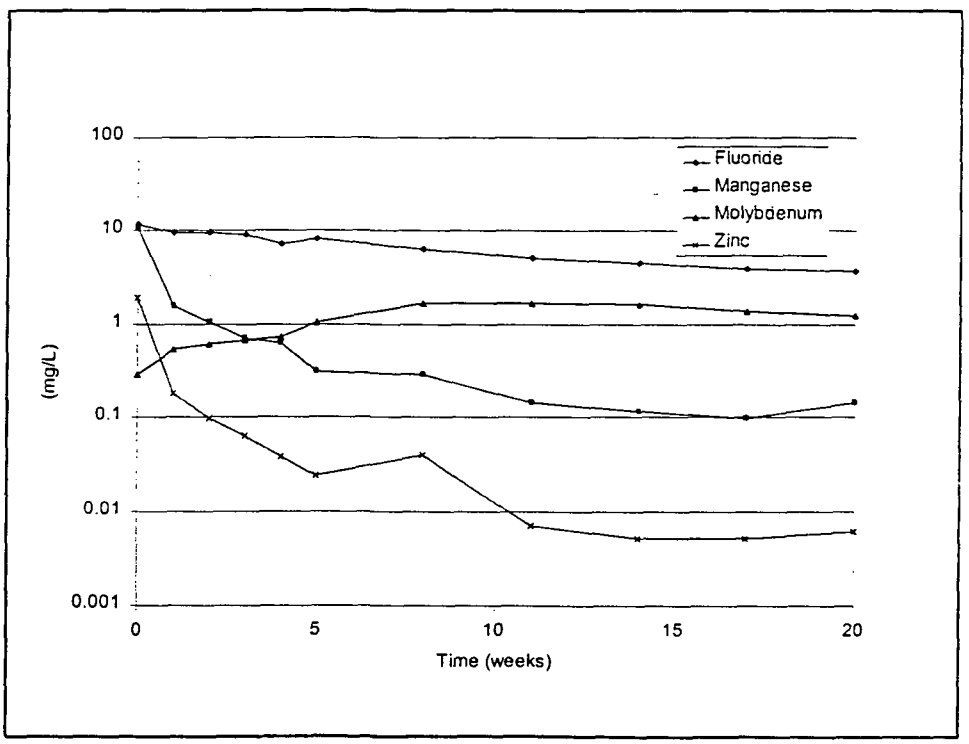




>Aged surface sample, lowest NP/AP encountered

CELL 1 - Sample T-24B





>Aged surface sample, lowest NP/AP encountered

HUMIDITY CELL #2

Sample T-11
Aged Surface Sample - potentially acid generating

pH = 7.5,
Conductivity = 1410 µS,
NP/AP = 0.64,
Deposition Year ~ 1991

CELL 2
SAMPLE T-11

Dry sample weight: **0.250 kg**

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	WATER ADDED pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.420	7.74	346	858	27.0	0.0	2.0	3.4	436	732.5
1	Jun.	3	0.500	5.55	0.490	7.90	367	272	34.5	0.0	1.5	6.3	72	873.6
2		10	0.500	5.99	0.500	8.08	359	150	36.5	0.0	1.0	8.3	20	913.6
3		17	0.500	5.70	0.495	8.06	353	125	35.0	0.0	1.0	10.3	11	935.4
4		24	0.500	5.61	0.500	7.90	357	106	31.5	0.0	1.3	12.8	8	951.4
5	Jul.	1	0.500	5.58	0.485	7.92	345	107	35.0	0.0	1.3	15.2	6	963.0
6		8	0.500	5.53	0.495	8.07	345	95	32.0	0.0	0.5	16.2	6	974.9
7		15	0.500	5.89	0.510	8.15	338	83	28.5	0.0	0.3	16.7	6	987.1
8		22	0.500	5.60	0.495	8.15	346	90	32.0	0.0	0.5	17.7	5	997.0
9		29	0.500	5.66	0.500	8.14	335	80	29.5	0.0	0.5	18.7	4	1005.0
10	Aug.	6	0.500	5.58	0.495	8.18	319	83	29.5	0.0	0.3	19.2	6	1016.9
11		12	0.500	5.71	0.500	8.08	329	76	28.0	0.0	1.0	21.2	4	1024.9
12		19	0.500	5.64	0.495	8.16	331	80	29.5	0.0	0.5	22.2	4	1032.8
13		26	0.500	5.81	0.505	8.04	285	77	27.5	0.0	0.5	23.2	4	1040.9
14	Sept.	3	0.500	5.77	0.505	8.31	318	79	29.5	0.0	0.0	23.2	5	1051.0
15		9	0.500	5.86	0.510	8.33	328	56	27.5	0.0	0.0	23.2	4	1059.2
16		16	0.500	5.70	0.515	8.35	320	62	29.0	0.0	0.0	23.2	6	1071.5
17		23	0.500	5.65	0.500	8.20	328	57	27.0	0.0	0.5	24.2	6	1083.5
18		30	0.500	5.85	0.510	8.12	321	58	27.0	0.0	0.8	25.7	5	1093.7
19	Oct.	7	0.500	5.82	0.505	8.00	336	57	26.5	0.0	0.8	27.2	5	1103.8
20		14	0.500	6.05	0.500	7.95	350	60	28.0	0.0	1.0	29.2	6	1115.8

CELL 2
SAMPLE T-11

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.027	0.0135	0.0005	0.04	<0.005	<0.1	<0.1	0.0020	155	<0.01	<0.01	0.01	2.21	<0.01	<0.05	0.01	16.2
1	0.036	0.0122	0.0027	0.02	<0.005	<0.1	<0.1	0.0014	37.8	<0.01	<0.01	<0.01	1.06	<0.03	<0.05	<0.01	2.20
2	0.067	0.0094	0.0026	0.06	<0.005	<0.1	<0.1	0.0010	21.3	<0.01	<0.01	<0.01	0.78	<0.03	<0.05	<0.01	1.10
3	0.055	0.0079	0.0003	0.08	<0.005	<0.1	<0.1	0.0002	18.4	<0.01	<0.01	<0.01	0.71	<0.03	<0.05	<0.01	0.88
4	0.035	0.0068	0.0002	0.08	<0.005	<0.1	<0.1	0.0002	14.2	<0.01	<0.01	<0.01	0.49	<0.03	<0.05	<0.01	0.65
5	0.075	0.0086	0.0035	0.10	<0.005	<0.1	<0.1	0.0007	15.2	<0.01	<0.01	<0.01	0.66	<0.03	<0.05	<0.01	0.66
6																	
7																	
8	0.070	0.0072	0.0028	0.13	<0.005	<0.1	<0.1	0.0003	12.9	<0.01	<0.01	<0.01	0.62	<0.03	<0.05	<0.01	0.47
9																	
10																	
11	0.139	0.0057	0.0026	0.13	<0.005	<0.1	<0.1	<0.0002	11.3	<0.01	<0.01	<0.01	0.63	<0.03	<0.05	<0.01	0.32
12																	
13																	
14	0.099	0.0050	0.0022	0.14	<0.005	<0.1	<0.1	<0.0002	11.5	<0.01	<0.01	<0.01	0.58	<0.03	<0.05	<0.01	0.29
15																	
16																	
17	0.099	0.0035	0.0004	0.13	<0.005	<0.1	<0.1	<0.0002	11.2	<0.01	<0.01	<0.01	0.59	<0.03	<0.05	<0.01	0.26
18												<0.001			<0.001		
19												0.003			<0.001		
20	0.094	0.0037	0.0019	0.15	<0.005	<0.1	<0.1	<0.0002	12.0	<0.01	<0.01	<0.01	0.64	<0.03	<0.05	<0.01	0.24

CELL 2
SAMPLE T-11

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	0.102	<0.00005	6.26	<0.02	<0.3	18	0.0021	3.34	<0.0001	13	3.31	<0.1	<0.03	<0.01	<0.03	0.124
1	0.037	<0.00005	4.29	<0.02	0.3	6	0.0032	2.49	<0.0001	<2	1.63	<0.1	<0.03	<0.01	<0.03	0.027
2	0.032	<0.00005	3.43	<0.02	<0.3	3	0.0019	2.09	<0.0001	<2	1.96	<0.1	<0.03	<0.01	<0.03	0.017
3	0.033	<0.00005	3.15	<0.02	<0.3	3	0.0012	1.97	<0.0001	<2	2.12	<0.1	<0.03	<0.01	<0.03	0.010
4	0.029	<0.00005	2.02	<0.02	<0.3	2	0.0006	1.46	<0.0001	<2	1.89	<0.1	<0.03	<0.01	<0.03	0.008
5	0.030	<0.00005	2.13	<0.02	<0.3	2	0.0009	1.77	<0.0001	<2	2.08	<0.1	<0.03	<0.01	<0.03	0.007
6																
7																
8	0.018	<0.00005	0.96	<0.02	<0.3	2	0.0008	1.54	<0.0001	<2	1.91	<0.1	<0.03	<0.01	<0.03	0.016
9																
10																
11	0.013	<0.00005	0.31	<0.02	<0.3	<2	<0.0005	1.27	<0.0001	<2	1.57	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.013	<0.00005	0.18	<0.02	<0.3	<2	0.0006	1.14	<0.0001	<2	1.47	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.010	<0.00005	0.12	<0.02	<0.3	<2	<0.0005	0.97	<0.0001	<2	1.28	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.013	<0.00005	0.12	<0.02	<0.3	<2	<0.0005	0.96	<0.0001	<2	1.24	<0.1	<0.03	<0.01	<0.03	<0.005

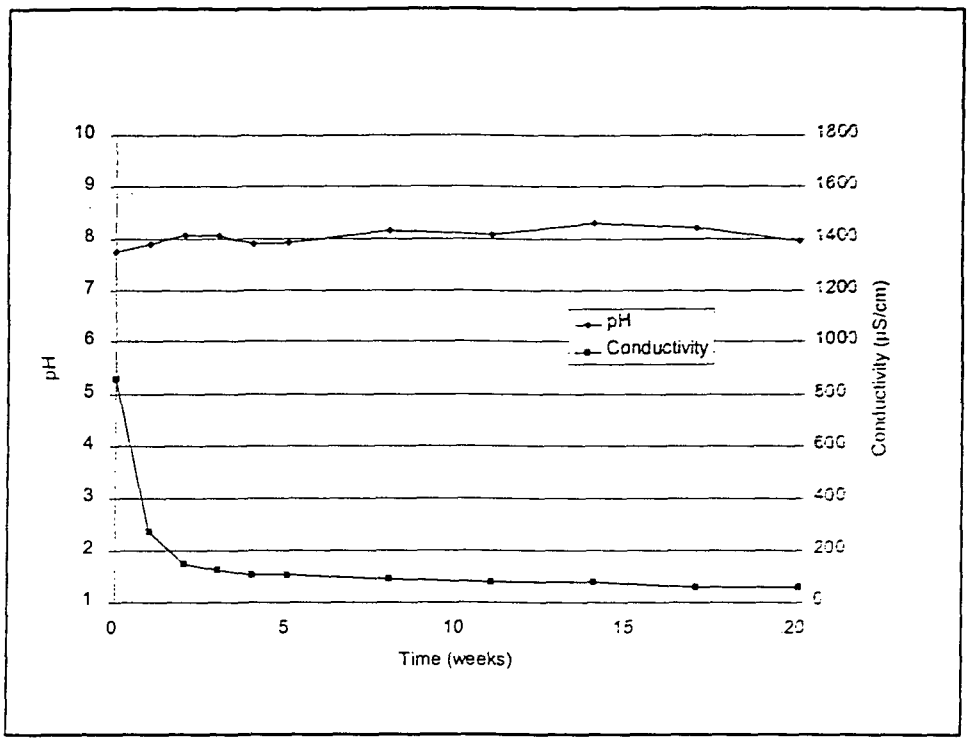
CELL 2
SAMPLE T-11

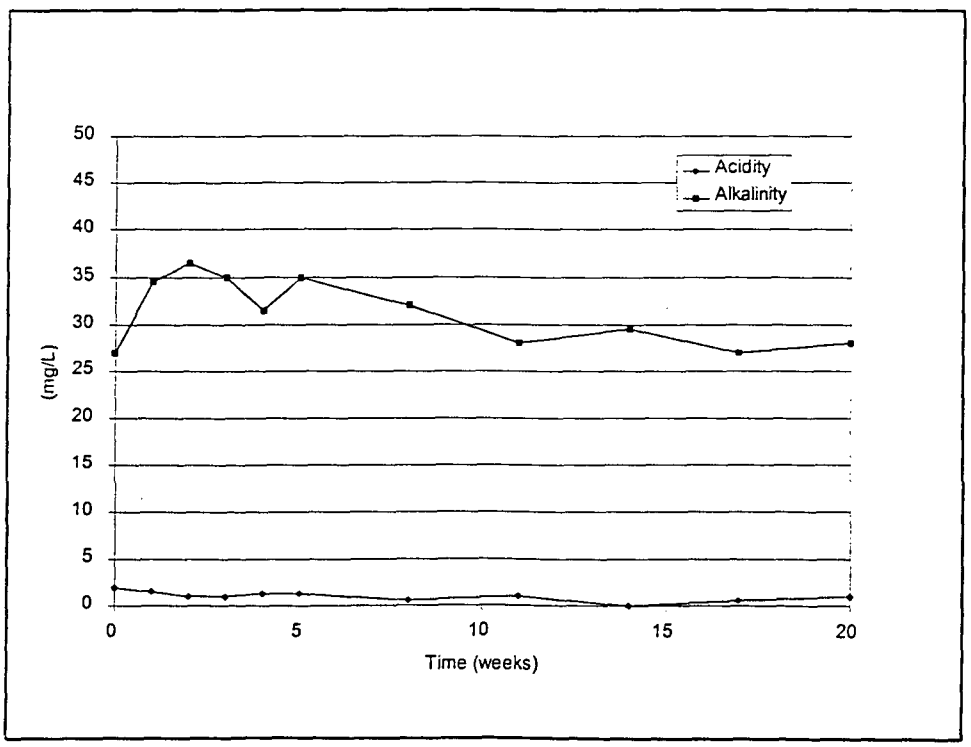
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly Acidity (pH=8.3) (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.00	732	3.4	45.4	45.4	260.40	27.2	764	764	3.71	27.22	10.52	0.02	0.21
1	0.73	141	2.9	67.6	113.0	74.09	4.3	203	968	2.08	4.31	8.41	0.02	0.05
2	0.36	40	2.0	73.0	186.0	42.60	2.2	116	1083	1.56	2.20	6.86	0.02	0.03
3	0.23	22	2.0	69.3	255.3	36.43	1.7	98	1182	1.41	1.74	6.24	0.02	0.02
4	0.22	16	2.5	63.0	318.3	28.40	1.3	76	1258	0.98	1.30	4.04	0.02	0.02
5	0.15	12	2.4	67.9	386.2	29.49	1.3	79	1337	1.28	1.28	4.13	0.02	0.01
6		12	1.0	63.4	449.5				1337					
7		12	0.5	58.1	507.7				1337					
8	0.15	10	1.0	63.4	571.0	25.54	0.9	68	1405	1.23	0.93	1.90	0.02	0.03
9		8	1.0	59.0	630.0				1405					
10		12	0.5	58.4	688.5				1405					
11	0.14	8	2.0	56.0	744.5	22.60	0.6	59	1464	1.26	0.64	0.62	0.02	0.01
12		8	1.0	58.4	802.9				1464					
13		8	1.0	55.6	858.4				1464					
14	0.17	10	0.0	59.6	918.0	23.23	0.6	61	1524	1.17	0.59	0.36	0.02	0.01
15		8	0.0	56.1	974.1				1524					
16		12	0.0	59.7	1033.8				1524					
17	0.22	12	1.0	54.0	1087.8	22.40	0.5	58	1583	1.18	0.52	0.24	0.02	0.01
18		10	1.5	55.1	1142.9				1583					
19		10	1.6	53.5	1196.5				1583					
20	0.20	12	2.0	56.0	1252.5	24.00	0.5	62	1645	0.00	0.48	0.24	0.02	0.01

CELL 2
SAMPLE T-11

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	3600	490	227	36	134	32700	0.10	5.55	4.63	0.05	0.16	2
1							0.16	6.43	8.34	0.10	0.19	3
2							0.20	6.88	11.36	0.16	0.22	3
3							0.24	7.24	14.11	0.21	0.24	3
4							0.27	7.50	15.89	0.27	0.25	3
5							0.31	7.77	17.71	0.32	0.26	3
6							0.31	7.77	17.71	0.32	0.26	3
7							0.31	7.77	17.71	0.32	0.26	3
8							0.34	7.96	18.54	0.38	0.28	3
9							0.34	7.96	18.54	0.38	0.28	3
10							0.34	7.96	18.54	0.38	0.28	3
11							0.38	8.09	18.82	0.43	0.28	3
12							0.38	8.09	18.82	0.43	0.28	3
13							0.38	8.09	18.82	0.43	0.28	3
14							0.41	8.21	18.98	0.49	0.29	3
15							0.41	8.21	18.98	0.49	0.29	3
16							0.41	8.21	18.98	0.49	0.29	3
17							0.44	8.31	19.08	0.54	0.29	3
18							0.44	8.31	19.08	0.54	0.29	3
19							0.44	8.31	19.08	0.54	0.29	3
20							0.44	8.41	19.19	0.60	0.30	3

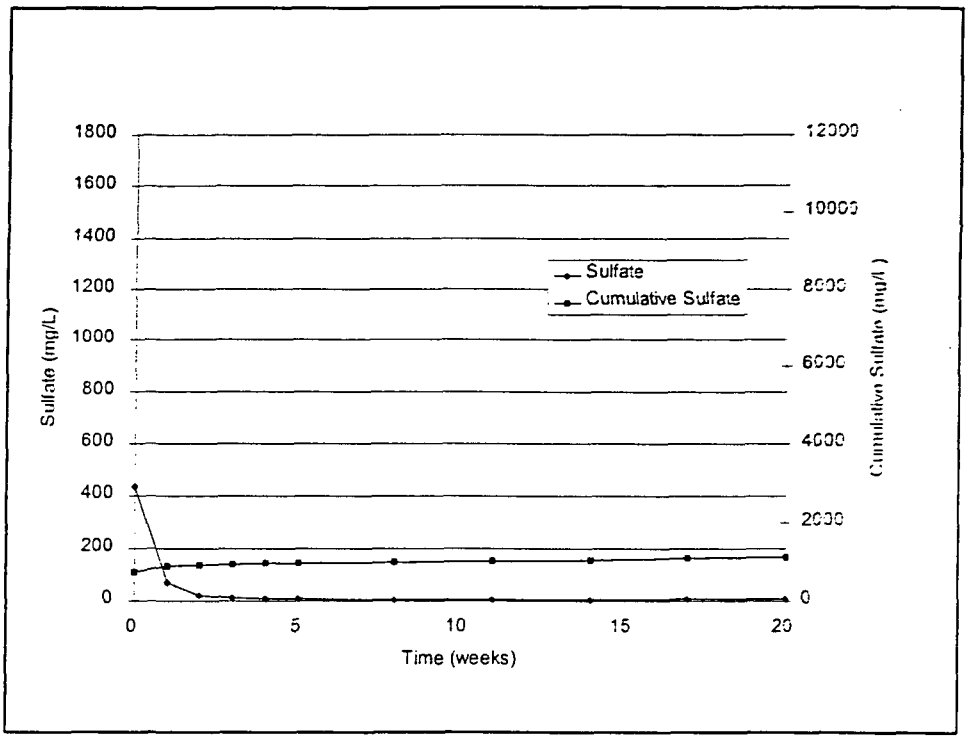
CELL 2 - Sample T-11

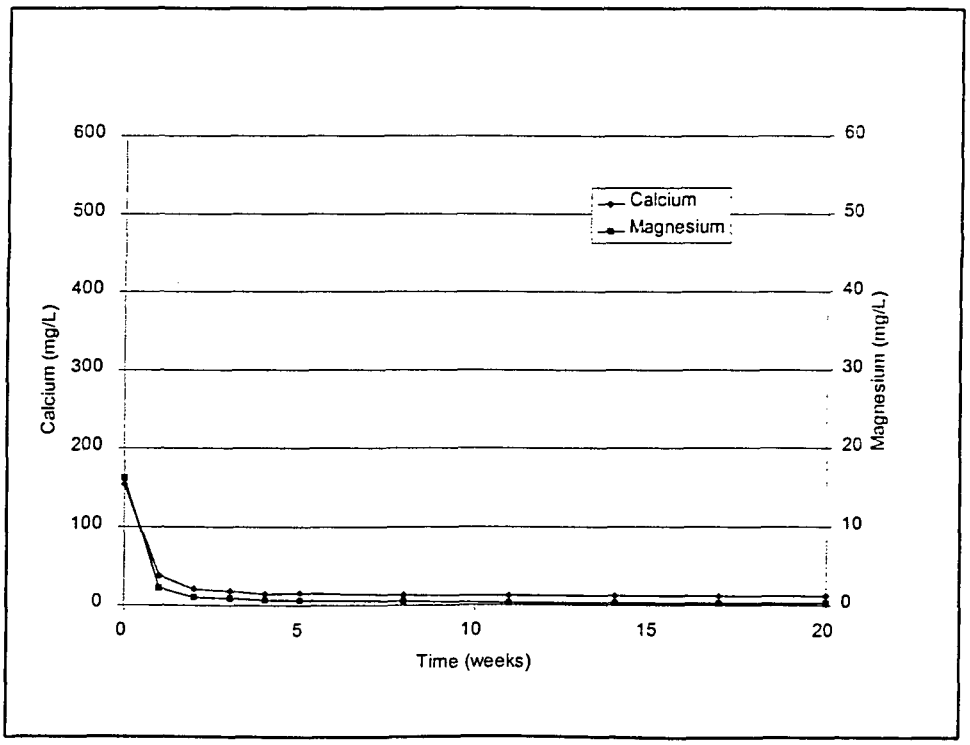




> *Aged surface sample*

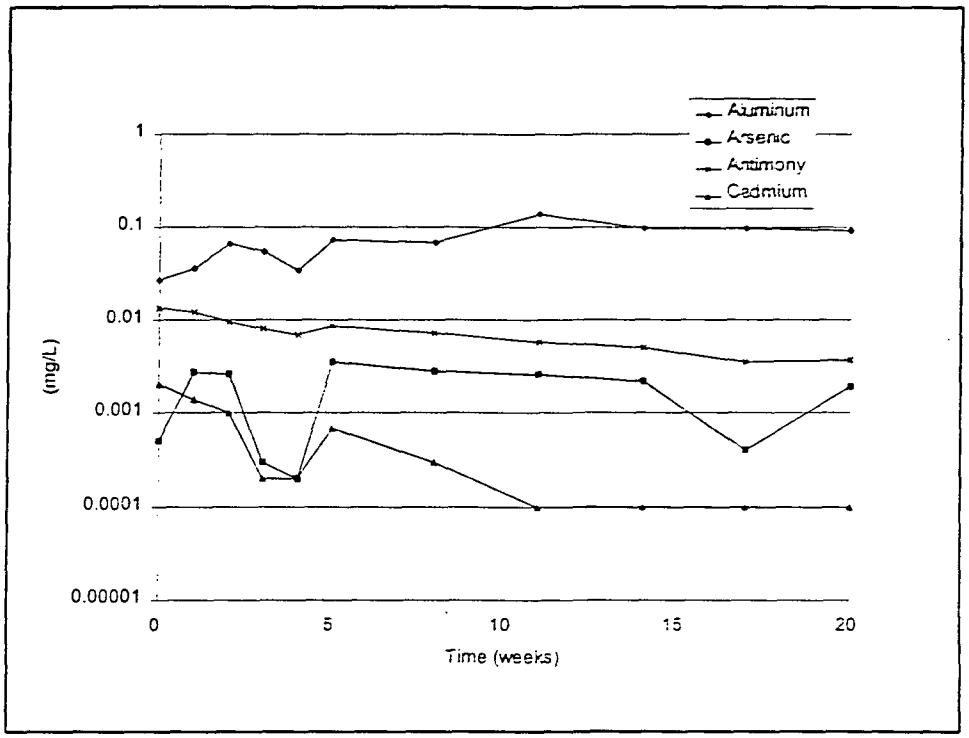
CELL 2 - Sample T-11

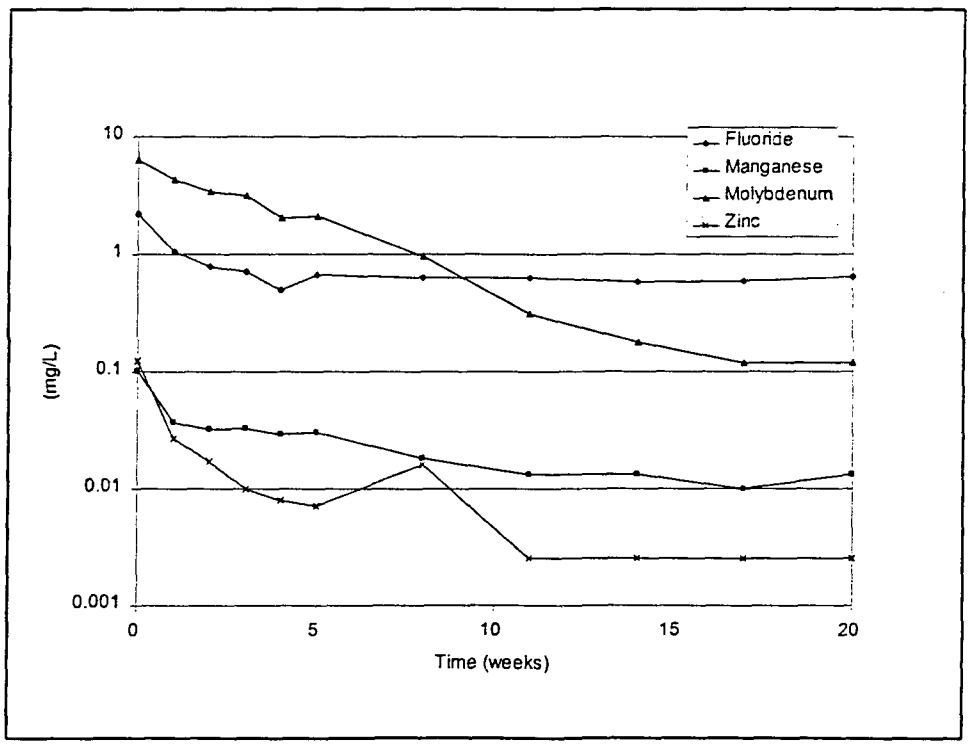




> *Aged surface sample*

CELL 2 - Sample T-11





> Aged surface sample

HUMIDITY CELL #3

Sample BH1-72sp
Aplite – potentially acid generating

pH = 7.30,
Conductivity = 591 µS,
NP/AP ~ 1.11,
Deposition year ~ 1969

CELL 3
SAMPLE BH1-72SP

Dry sample weight: **0.25 kg**

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	WATER ADDED pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.420	7.78	337	516	32.0	0.0	2.0	3.8	170	323.1
1	Jun.	3	0.440	5.55	0.440	7.78	330	195	39.5	0.0	2.0	7.8	28	378.8
2		10	0.440	5.99	0.430	8.01	347	116	33.3	0.0	0.5	8.8	8	394.4
3		17	0.440	5.70	0.435	8.03	330	98	31.8	0.0	0.5	9.7	4	402.3
4		24	0.440	5.61	0.430	7.89	352	105	29.0	0.0	1.0	11.7	6	413.9
5	Jul.	1	0.440	5.58	0.435	7.90	346	105	31.5	0.0	1.5	14.6	6	425.7
6		8	0.440	5.53	0.435	7.95	346	104	30.5	0.0	0.8	16.1	7	439.5
7		15	0.440	5.89	0.430	7.99	343	104	28.0	0.0	0.8	17.6	9	457.0
8		22	0.440	5.60	0.430	8.04	347	109	29.5	0.0	0.8	19.0	10	476.5
9		29	0.440	5.66	0.440	8.04	334	112	32.5	0.0	0.8	20.5	10	496.4
10	Aug.	6	0.440	5.58	0.440	8.00	325	111	29.0	0.0	0.8	22.0	10	516.3
11		12	0.440	5.71	0.435	7.87	337	90	26.5	0.0	1.3	24.5	7	530.1
12		19	0.440	5.64	0.435	7.91	338	92	25.0	0.0	1.0	26.4	8	545.8
13		26	0.440	5.81	0.440	7.78	304	90	25.5	0.0	1.5	29.4	8	561.8
14	Sept.	3	0.440	5.77	0.435	7.92	330	92	26.5	0.0	1.0	31.4	9	579.5
15		9	0.440	5.86	0.440	7.91	338	63	24.5	0.0	1.0	33.4	6	591.4
16		16	0.440	5.70	0.440	7.87	334	64	25.0	0.0	1.3	35.9	8	607.4
17		23	0.440	5.65	0.440	7.82	340	62	24.5	0.0	1.3	38.4	7	621.3
18		30	0.440	5.85	0.440	7.71	330	58	23.5	0.0	1.8	41.9	6	633.2
19	Oct.	7	0.440	5.82	0.435	7.67	336	58	21.5	0.0	1.5	44.8	7	647.0
20		14	0.440	6.05	0.440	7.65	354	58	23.5	0.0	1.8	48.3	6	659.0

CELL 3
SAMPLE BH1-72SP

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.038	0.0015	0.0008	<0.01	<0.005	<0.1	0.2	0.0165	62.3	<0.01	<0.01	0.04	7.00	<0.01	<0.05	0.01	8.31
1	0.040	0.0034	0.0046	0.01	<0.005	<0.1	<0.1	0.0082	21.7	<0.01	<0.01	0.01	3.23	<0.03	<0.05	<0.01	2.24
2	0.061	0.0046	0.0026	0.02	<0.005	<0.1	<0.1	0.0032	14.6	<0.01	<0.01	<0.01	2.44	<0.03	<0.05	<0.01	1.29
3	0.063	0.0036	0.0004	0.01	<0.005	<0.1	<0.1	0.0020	13.8	<0.01	<0.01	<0.01	2.24	<0.03	<0.05	<0.01	1.07
4	0.059	0.0054	0.0005	0.01	<0.005	<0.1	<0.1	0.0016	13.3	<0.01	<0.01	<0.01	2.73	<0.03	<0.05	<0.01	1.00
5	0.063	0.0082	0.0042	0.02	<0.005	<0.1	<0.1	0.0018	14.3	<0.01	<0.01	<0.01	2.29	<0.03	<0.05	<0.01	1.01
6																	
7																	
8	0.042	0.0056	0.0039	0.01	<0.005	<0.1	<0.1	0.0018	15.8	<0.01	<0.01	<0.01	1.76	<0.03	<0.05	<0.01	0.84
9																	
10																	
11	0.040	0.0042	0.0031	0.01	<0.005	<0.1	<0.1	0.0018	13.5	<0.01	<0.01	<0.01	1.22	<0.03	<0.05	<0.01	0.54
12																	
13																	
14	0.054	0.0032	0.0023	0.01	<0.005	<0.1	<0.1	0.0021	13.5	<0.01	<0.01	<0.01	1.12	<0.03	<0.05	<0.01	0.43
15																	
16																	
17	0.046	0.0024	0.0004	<0.01	<0.005	<0.1	<0.1	0.0015	12.4	<0.01	<0.01	<0.01	1.08	<0.03	<0.05	<0.01	0.33
18												0.002			<0.001		
19												0.004			<0.001		
20	0.038	0.0024	0.0019	0.01	<0.005	<0.1	<0.1	0.0015	12.1	<0.01	<0.01	<0.01	1.04	<0.03	<0.05	<0.01	0.23

CELL 3
SAMPLE BH1-72SP

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	1.34	<0.00005	5.25	<0.02	0.3	17	0.0029	3.47	<0.0001	18	0.734	<0.1	<0.03	<0.01	<0.03	0.078
1	0.544	<0.00005	1.69	<0.02	<0.3	7	0.0026	2.97	<0.0001	3	0.257	<0.1	<0.03	<0.01	<0.03	0.033
2	0.267	<0.00005	1.10	<0.02	<0.3	5	0.0012	2.74	<0.0001	<2	0.173	<0.1	<0.03	<0.01	<0.03	0.013
3	0.196	<0.00005	1.00	<0.02	<0.3	3	0.0006	2.74	<0.0001	<2	0.144	<0.1	<0.03	<0.01	<0.03	0.007
4	0.136	<0.00005	1.23	<0.02	<0.3	4	0.0006	3.28	<0.0001	<2	0.143	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.127	<0.00005	1.01	<0.02	<0.3	3	0.0009	3.05	<0.0001	<2	0.148	<0.1	<0.03	<0.01	<0.03	0.006
6																
7																
8	0.126	<0.00005	0.68	<0.02	<0.3	2	0.0005	2.37	<0.0001	<2	0.146	<0.1	<0.03	<0.01	<0.03	0.014
9																
10																
11	0.114	<0.00005	0.57	<0.02	<0.3	<2	<0.0005	1.63	<0.0001	<2	0.103	<0.1	<0.03	<0.01	<0.03	0.010
12																
13																
14	0.119	<0.00005	0.55	<0.02	<0.3	<2	<0.0005	1.30	<0.0001	<2	0.089	<0.1	<0.03	<0.01	<0.03	0.013
15																
16																
17	0.092	<0.00005	0.48	<0.02	<0.3	<2	<0.0005	1.09	<0.0001	<2	0.073	<0.1	<0.03	<0.01	<0.03	0.010
18																
19																
20	0.086	<0.00005	0.44	<0.02	<0.3	<2	<0.0005	1.10	<0.0001	<2	0.061	<0.1	<0.03	<0.01	<0.03	0.012

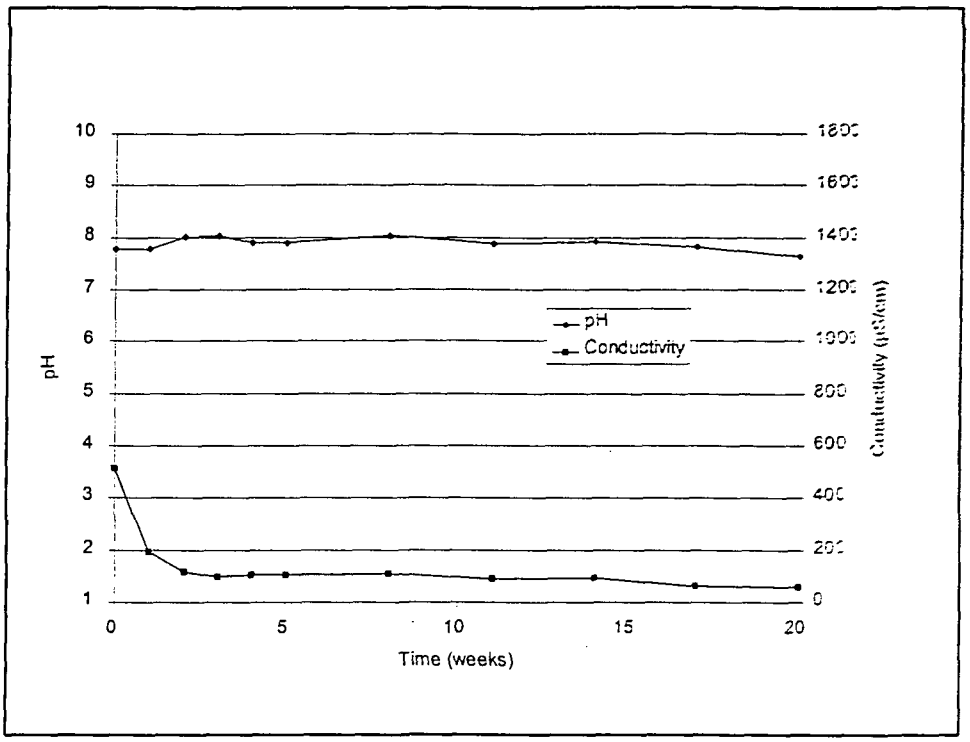
CELL 3
SAMPLE BH1-72SP

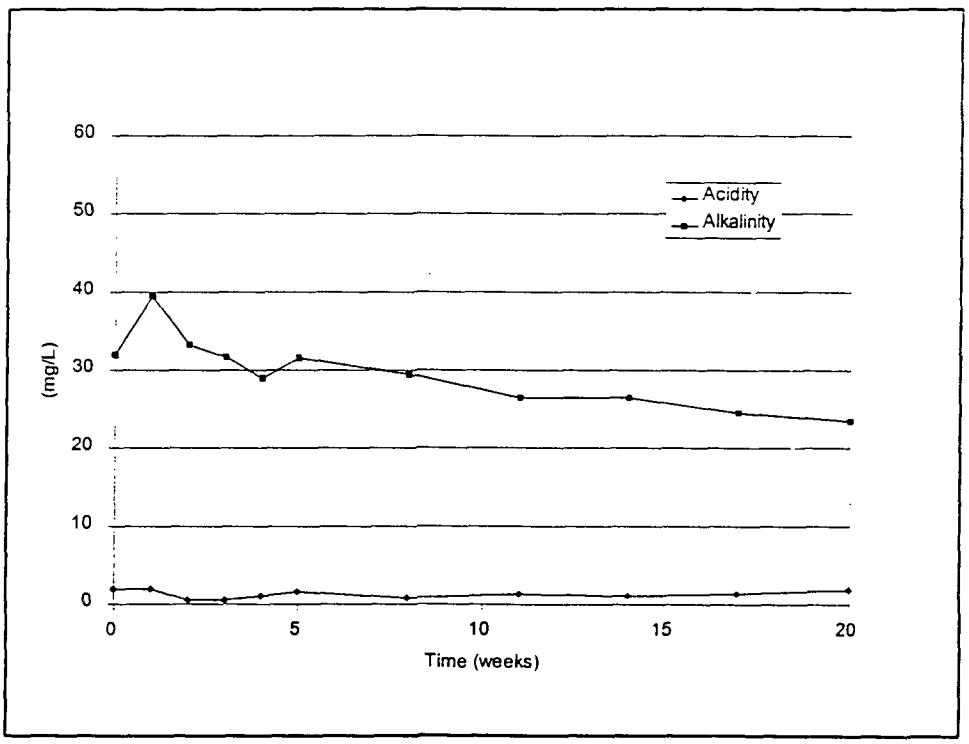
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	0.93	286	3.4	53.8	53.8	104.66	14.0	320	320	11.76	13.96	8.82	0.02	0.13
1	0.46	49	3.5	69.5	123.3	38.19	3.9	112	432	5.68	3.94	2.97	0.02	0.06
2	0.20	14	0.9	57.2	180.5	25.11	2.2	72	504	4.20	2.22	1.89	0.02	0.02
3	0.11	7	0.9	55.2	235.7	24.01	1.9	68	572	3.90	1.86	1.74	0.02	0.01
4	0.17	10	1.7	49.9	285.6	22.88	1.7	64	636	4.70	1.72	2.12	0.02	0.00
5	0.16	10	2.6	54.8	340.4	24.88	1.8	70	705	3.98	1.76	1.76	0.02	0.01
6		12	1.3	53.1	393.5				705					
7		15	1.3	48.2	441.6				705					
8	0.24	17	1.3	50.7	492.4	27.18	1.4	74	779	3.03	1.44	1.17	0.02	0.02
9		18	1.3	57.2	549.6				779					
10		18	1.3	51.0	600.6				779					
11	0.20	12	2.2	46.1	646.7	23.49	0.9	63	842	2.12	0.94	0.99	0.02	0.02
12		14	1.7	43.5	690.2				842					
13		14	2.6	44.9	735.1				842					
14	0.26	16	1.7	46.1	781.2	23.49	0.7	62	904	1.95	0.75	0.96	0.02	0.02
15		11	1.8	43.1	824.3				904					
16		14	2.2	44.0	868.3				904					
17	0.23	12	2.2	43.1	911.5	21.82	0.6	57	961	1.90	0.58	0.84	0.02	0.02
18		11	3.1	41.4	952.8				961					
19		12	2.6	37.4	990.2				961					
20	0.20	11	3.2	41.4	1031.6	21.30	0.4	55	1016	0.00	0.40	0.77	0.02	0.02

CELL 3
SAMPLE BH1-72SP

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	2000	597	255	5	335	9300	0.59	2.34	3.46	0.34	0.04	3
1							0.87	3.00	4.63	0.69	0.06	4
2							1.08	3.37	5.37	1.03	0.06	4
3							1.28	3.68	6.05	1.38	0.07	4
4							1.51	3.97	6.88	1.72	0.07	4
5							1.71	4.26	7.57	2.07	0.07	4
6							1.71	4.26	7.57	2.07	0.07	4
7							1.71	4.26	7.57	2.07	0.07	4
8							1.86	4.51	8.03	2.42	0.08	5
9							1.86	4.51	8.03	2.42	0.08	5
10							1.86	4.51	8.03	2.42	0.08	5
11							1.97	4.66	8.42	2.76	0.08	5
12							1.97	4.66	8.42	2.76	0.08	5
13							1.97	4.66	8.42	2.76	0.08	5
14							2.07	4.79	8.79	3.11	0.09	6
15							2.07	4.79	8.79	3.11	0.09	6
16							2.07	4.79	8.79	3.11	0.09	6
17							2.16	4.89	9.12	3.46	0.10	6
18							2.16	4.89	9.12	3.46	0.10	6
19							2.16	4.89	9.12	3.46	0.10	6
20							2.16	4.95	9.43	3.82	0.10	6

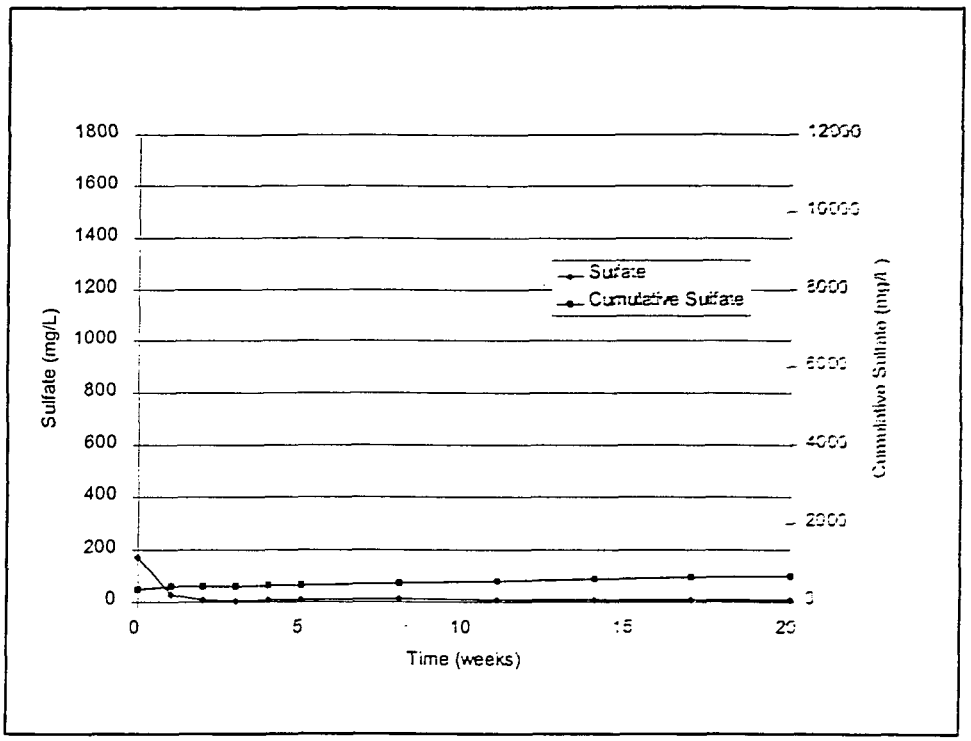
CELL 3 - Sample BH1-72sp

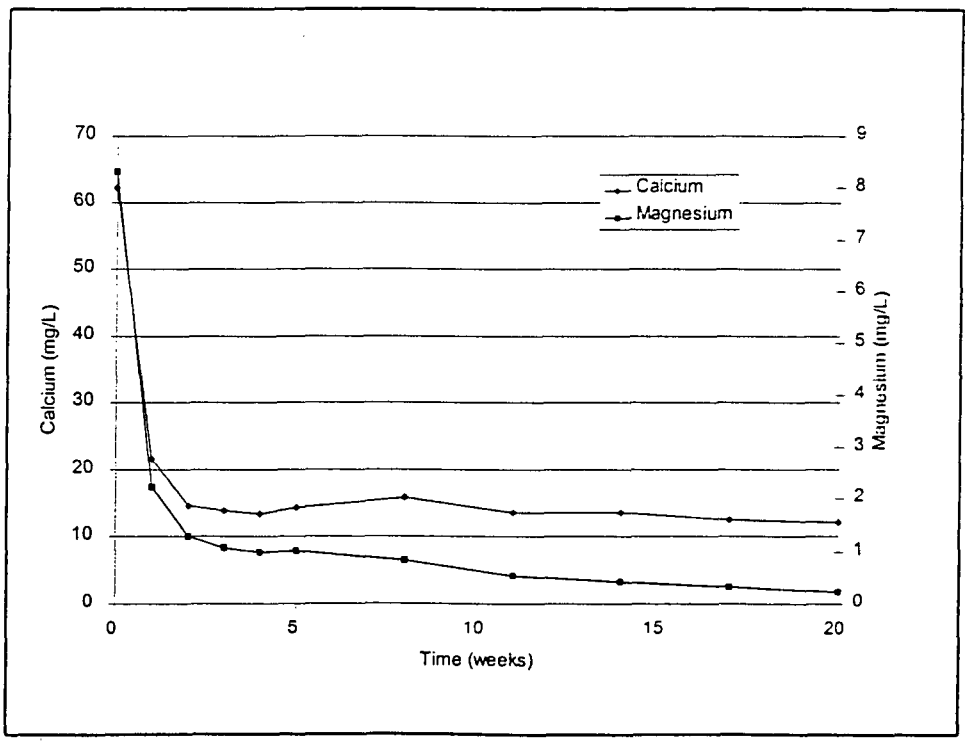




> High S content, NP/AP between 1 and 1.5, aplite

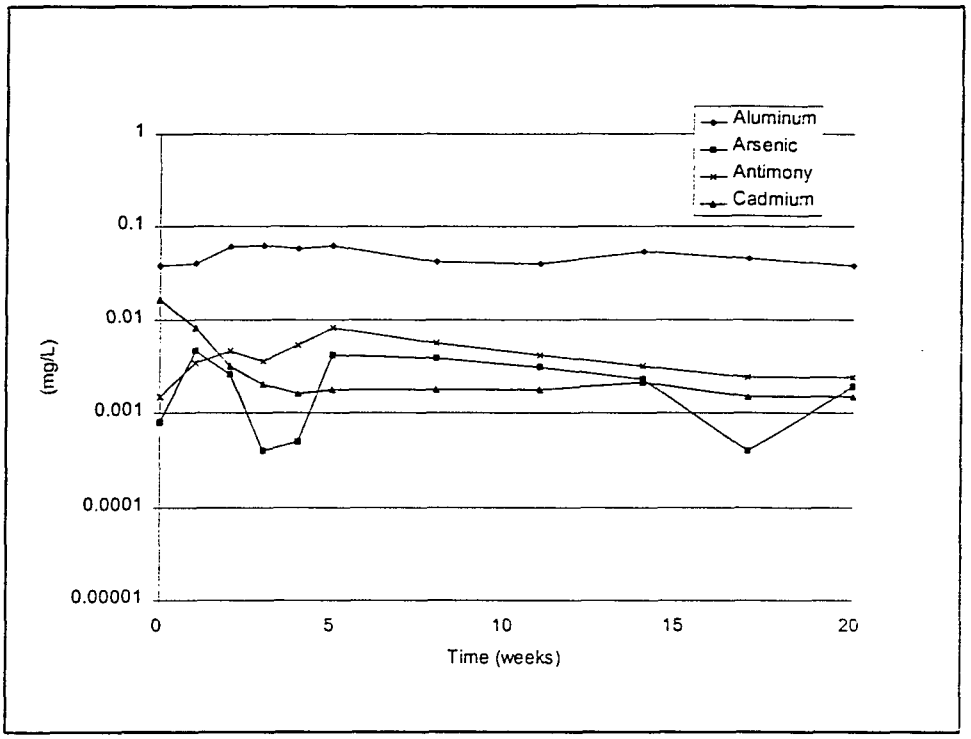
CELL 3 - Sample BH1-72sp

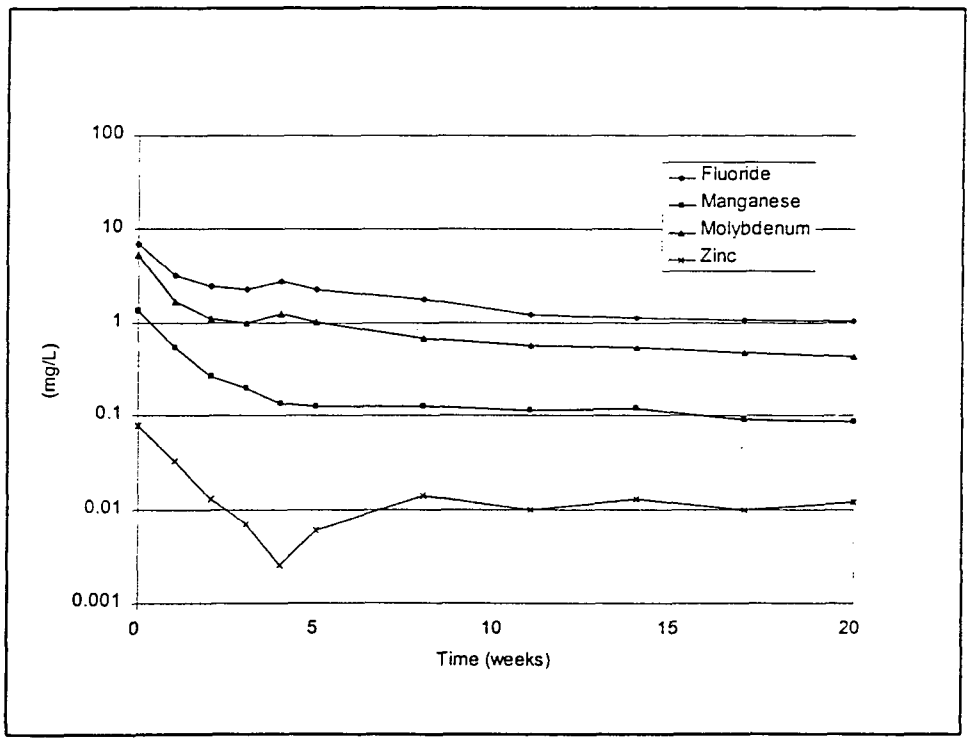




> High S content, NP/AP between 1 and 1.5, aplite

CELL 3 - Sample BH1-72sp





> High S content, NP/AP between 1 and 1.5, aplite

HUMIDITY CELL #4

Sample BH2-19
Andesite – potentially acid generating

pH = 7.00,
Conductivity = 1887 µS,
NP/AP = 1.14,
Deposition year ~ 1985

CELL 4
SAMPLE BH2-19

Dry sample w **0.3 kg**

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.415	7.53	341	1541	22.3	0.0	2.5	4.2	1227	2036.8
1	Jun.	3	0.500	5.55	0.505	7.52	367	1204	24.3	0.0	3.0	10.2	801	3654.8
2		10	0.500	5.99	0.490	7.78	378	1040	27.3	0.0	1.8	13.6	648	4924.9
3		17	0.500	5.70	0.495	7.83	364	597	27.3	0.0	1.5	16.6	277	5473.4
4		24	0.500	5.61	0.490	7.77	374	789	22.5	0.0	1.5	19.6	441	6337.7
5	Jul.	1	0.500	5.58	0.495	7.96	356	379	25.5	0.0	1.3	22.0	138	6611.0
6		8	0.500	5.53	0.470	8.00	357	302	28.5	0.0	1.0	23.9	97	6793.3
7		15	0.500	5.89	0.500	8.10	352	265	29.5	0.0	0.5	24.9	83	6959.3
8		22	0.500	5.60	0.490	8.13	354	228	32.0	0.0	0.5	25.9	61	7078.9
9		29	0.500	5.66	0.485	8.15	339	106	29.5	0.0	0.3	26.4	10	7098.3
10	Aug.	6	0.500	5.58	0.500	8.15	328	91	30.5	0.0	0.5	27.4	7	7112.3
11		12	0.500	5.71	0.495	8.05	341	81	29.0	0.0	0.8	28.9	5	7122.2
12		19	0.500	5.64	0.495	8.08	336	78	30.0	0.0	0.5	29.8	3	7128.1
13		26	0.500	5.81	0.500	8.00	308	86	31.0	0.0	0.8	31.3	4	7136.1
14	Sept.	3	0.500	5.77	0.485	8.19	328	86	32.5	0.0	0.5	32.3	4	7143.9
15		9	0.500	5.86	0.505	8.24	338	61	30.5	0.0	0.3	32.8	<3	7146.9
16		16	0.500	5.70	0.500	8.17	330	66	32.5	0.0	0.5	33.8	5	7156.9
17		23	0.500	5.65	0.500	8.14	337	64	32.5	0.0	1.0	35.8	5	7166.9
18		30	0.500	5.85	0.510	8.01	323	65	32.5	0.0	0.8	37.4	4	7175.1
19	Oct.	7	0.500	5.82	0.500	8.04	333	61	32.0	0.0	0.8	38.9	4	7183.1
20		14	0.500	6.05	0.505	7.90	350	63	32.5	0.0	1.0	40.9	4	7191.2

CELL 4
SAMPLE BH2-19

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.015	0.0322	0.0003	0.11	<0.005	<0.1	<0.1	0.0039	480	<0.01	<0.01	0.02	2.81	<0.01	<0.05	0.02	15.4
1	0.10	0.0208	0.0003	0.05	<0.005	<0.1	<0.1	0.0027	305	<0.01	<0.01	<0.01	1.27	<0.03	<0.05	<0.01	2.21
2	0.11	0.0127	0.0004	0.05	<0.005	<0.1	<0.1	0.0019	258	<0.01	<0.01	<0.01	1.22	<0.03	<0.05	0.01	0.57
3	0.091	0.0102	0.0003	0.04	<0.005	<0.1	<0.1	0.0008	119	<0.01	<0.01	<0.01	0.96	<0.03	<0.05	<0.01	0.15
4	0.028	0.0067	<0.0001	0.04	<0.005	<0.1	<0.1	0.0006	177	<0.01	<0.01	<0.01	0.68	<0.03	<0.05	<0.01	0.17
5	0.115	0.0096	0.0037	0.04	<0.005	<0.1	<0.1	0.0004	67.6	<0.01	<0.01	<0.01	0.81	<0.03	<0.05	<0.01	0.10
6																	
7																	
8	0.089	0.0088	0.0029	0.08	<0.005	<0.1	<0.1	0.0004	37.2	<0.01	<0.01	<0.01	0.83	<0.03	<0.05	<0.01	0.06
9																	
10																	
11	0.186	0.0058	0.0027	0.09	<0.005	<0.1	<0.1	<0.0002	12.2	<0.01	<0.01	<0.01	0.78	<0.03	<0.05	<0.01	<0.05
12																	
13																	
14	0.156	0.0065	0.0022	0.1	<0.005	<0.1	<0.1	<0.0002	13.0	<0.01	<0.01	<0.01	0.81	<0.03	<0.05	<0.01	<0.05
15																	
16																	
17	0.119	0.0056	0.0004	0.12	<0.005	<0.1	<0.1	<0.0002	12.9	<0.01	<0.01	<0.01	0.93	<0.03	<0.05	<0.01	<0.05
18																	
19																	
20	0.115	0.0052	0.0019	0.14	<0.005	<0.1	<0.1	<0.0002	13.4	<0.01	<0.01	<0.01	0.92	<0.03	<0.05	<0.01	<0.05

CELL 4
SAMPLE BH2-19

CYCLE	Mn	Hg	Mo	Ni	P	K	Se	Si	Ag	Na	Sr	Tl	Sn	Ti	V	Zn
	(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)	(mg/L)	(mg/L)	(mg/L)
0	1.14	<0.00005	2.12	<0.02	<0.3	26	0.0011	2.92	<0.0001	10	6.27	<0.1	<0.03	<0.01	<0.03	0.283
1	0.618	<0.00005	1.25	<0.02	<0.3	11	0.0013	2.05	0.0001	<2	2.97	<0.1	<0.03	<0.01	<0.03	0.127
2	0.385	<0.00005	1.51	<0.02	<0.3	9	<0.0005	2.06	0.0001	<2	2.50	<0.1	<0.03	<0.01	<0.03	0.084
3	0.153	<0.00005	1.21	<0.02	<0.3	5	0.0006	1.54	<0.0001	<2	1.62	<0.1	<0.03	<0.01	<0.03	0.038
4	0.131	<0.00005	0.92	<0.02	<0.3	6	<0.0005	1.31	<0.0001	<2	1.95	<0.1	<0.03	<0.01	<0.03	0.022
5	0.060	<0.00005	1.20	<0.02	<0.3	4	<0.0005	1.46	<0.0001	<2	1.29	<0.1	<0.03	<0.01	<0.03	0.011
6																
7																
8	0.051	<0.00005	1.04	<0.02	<0.3	3	0.0006	1.40	<0.0001	<2	1.56	<0.1	<0.03	<0.01	<0.03	0.009
9																
10																
11	0.033	<0.00005	0.51	<0.02	<0.3	<2	<0.0005	1.02	<0.0001	<2	0.917	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.041	<0.00005	0.50	<0.02	<0.3	<2	<0.0005	1.01	<0.0001	<2	0.978	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.044	<0.00005	0.38	<0.02	<0.3	<2	<0.0005	0.92	<0.0001	<2	0.887	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.046	<0.00005	0.25	<0.02	<0.3	<2	<0.0005	0.89	<0.0001	<2	0.851	<0.1	<0.03	<0.01	<0.03	<0.005

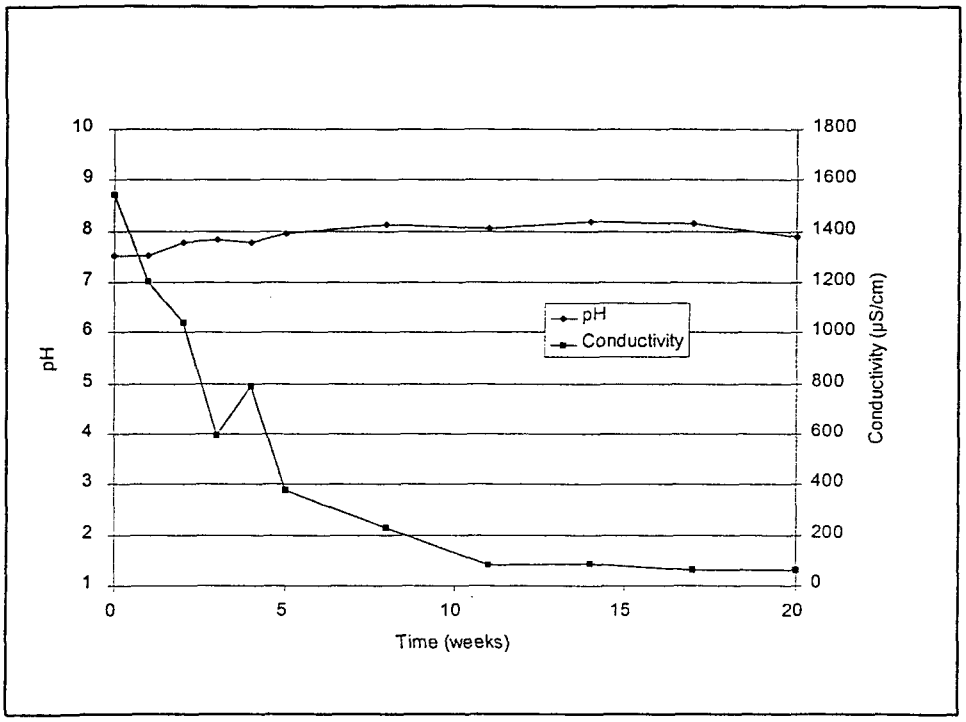
CELL 4
SAMPLE BH2-19

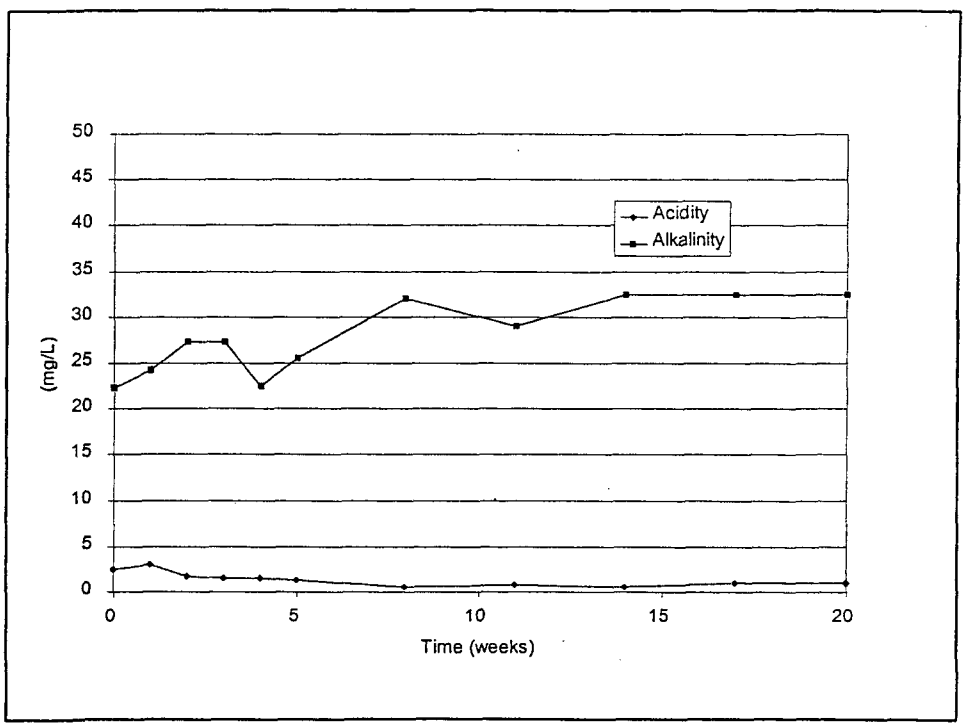
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.01	2037	4.2	36.9	36.9	796.80	25.6	2099	2099	4.66	25.56	3.52	0.02	0.47
1	1.08	1618	6.1	49.0	85.9	616.10	4.5	1559	3657	2.57	4.46	2.53	0.02	0.26
2	1.04	1270	3.4	53.4	139.3	505.68	1.1	1269	4926	2.39	1.12	2.96	0.02	0.16
3	0.97	548	3.0	54.0	193.3	235.62	0.3	590	5517	1.90	0.30	2.40	0.02	0.08
4	1.04	864	2.9	44.1	237.4	346.92	0.3	869	6385	1.33	0.33	1.80	0.02	0.04
5	0.85	273	2.5	50.5	287.9	133.85	0.2	335	6721	1.60	0.20	2.38	0.02	0.02
6		182	1.9	53.6	341.5				6721					
7		166	1.0	59.0	400.5				6721					
8	0.68	120	1.0	62.7	463.2	72.91	0.1	183	6903	1.63	0.12	2.04	0.02	0.02
9		19	0.5	57.2	520.4				6903					
10		14	1.0	61.0	581.4				6903					
11	0.17	10	1.5	57.4	638.8	24.16	0.05	61	6964	1.54	0.05	1.01	0.02	0.005
12		6	1.0	59.4	698.2				6964					
13		8	1.5	62.0	760.2				6964					
14	0.13	8	1.0	63.1	823.3	25.22	0.05	63	7027	1.57	0.05	0.97	0.02	0.005
15		3	0.5	61.6	884.9				7027					
16		10	1.0	65.0	949.9				7027					
17	0.16	10	2.0	65.0	1014.9	25.80	0.05	65	7092	1.86	0.05	0.76	0.02	0.01
18		8	1.5	66.3	1081.2				7092					
19		8	1.6	64.0	1145.2				7092					
20	0.12	8	2.0	65.7	1210.8	27.07	0.05	68	7160	0.00	0.05	0.51	0.02	0.01

CELL 4
SAMPLE BH2-19

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	2600	724	190	33	107	35700	0.18	3.53	1.85	0.05	0.44	6
1							0.28	4.15	3.18	0.11	0.68	10
2							0.37	4.30	4.74	0.17	0.83	14
3							0.44	4.34	6.00	0.23	0.90	15
4							0.49	4.39	6.95	0.29	0.94	18
5							0.56	4.42	8.20	0.35	0.96	19
6							0.56	4.42	8.20	0.35	0.96	19
7							0.56	4.42	8.20	0.35	0.96	19
8							0.62	4.43	9.27	0.41	0.98	20
9							0.62	4.43	9.27	0.41	0.98	20
10							0.62	4.43	9.27	0.41	0.98	20
11							0.68	4.44	9.80	0.47	0.98	20
12							0.68	4.44	9.80	0.47	0.98	20
13							0.68	4.44	9.80	0.47	0.98	20
14							0.74	4.45	10.31	0.53	0.99	20
15							0.74	4.45	10.31	0.53	0.99	20
16							0.74	4.45	10.31	0.53	0.99	20
17							0.81	4.45	10.71	0.59	0.99	20
18							0.81	4.45	10.71	0.59	0.99	20
19							0.81	4.45	10.71	0.59	0.99	20
20							0.81	4.46	10.98	0.65	1.00	20

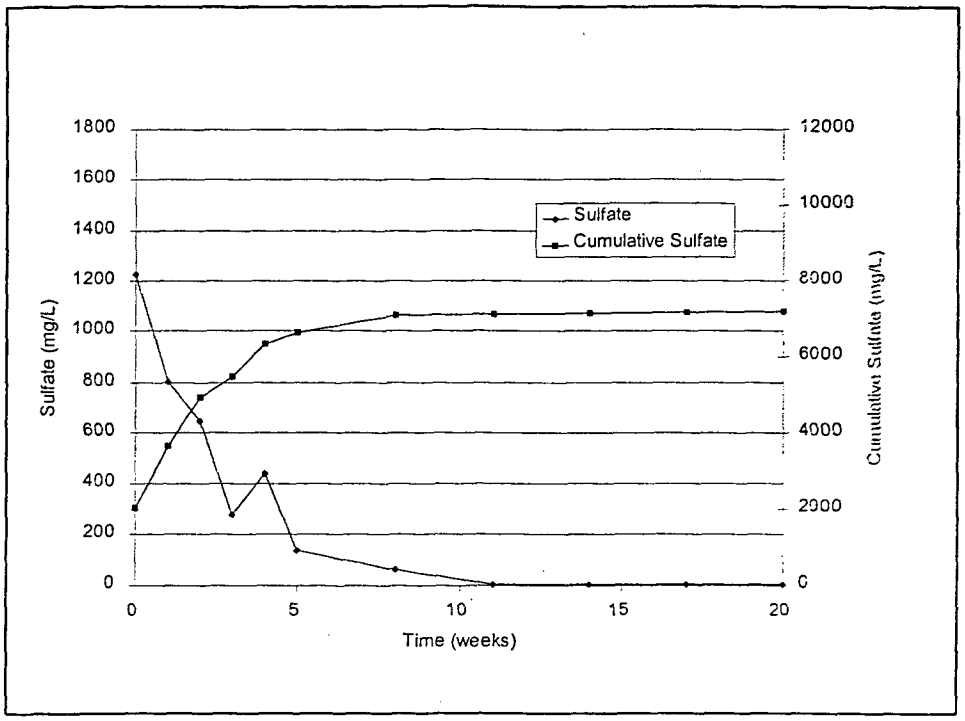
CELL 4 - Sample BH2-19

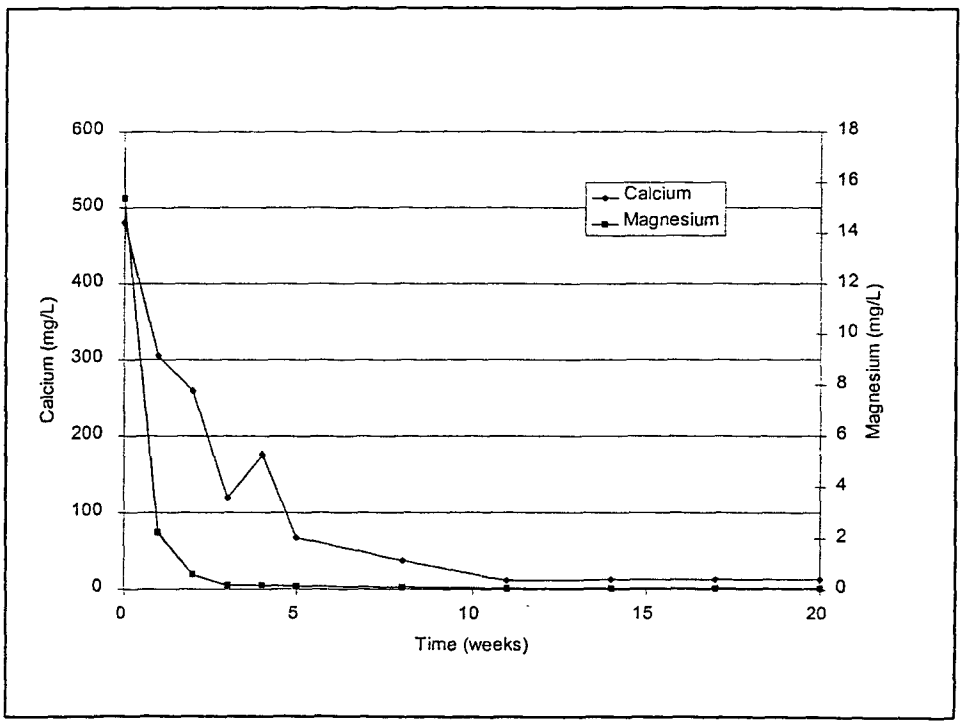




> High S content, NP/AP between 1 and 1.5, andesite

CELL 4 - Sample BH2-19





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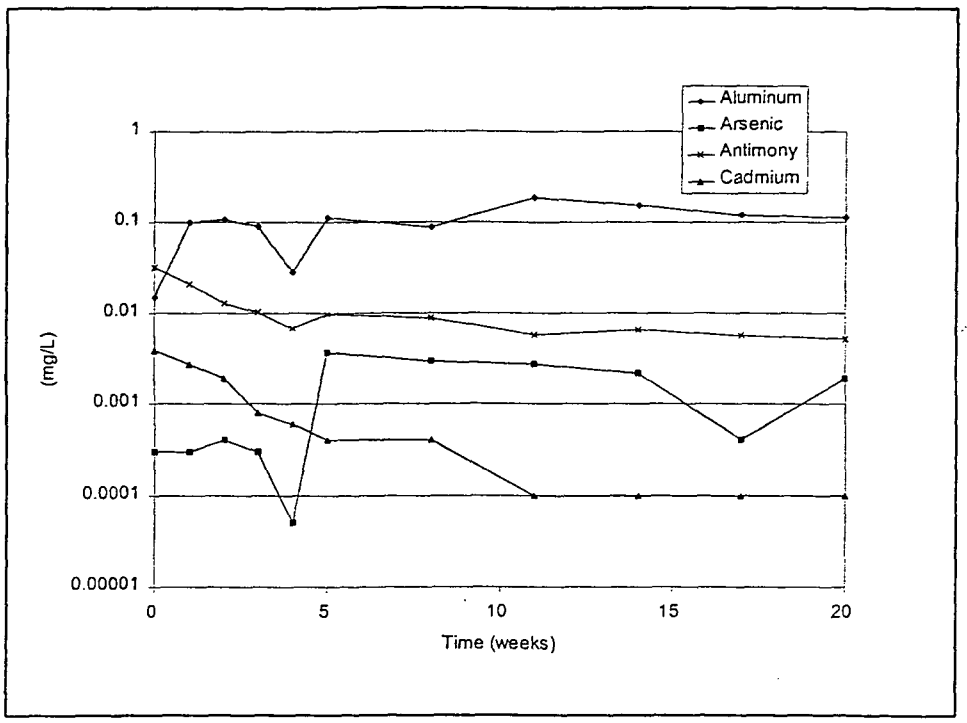
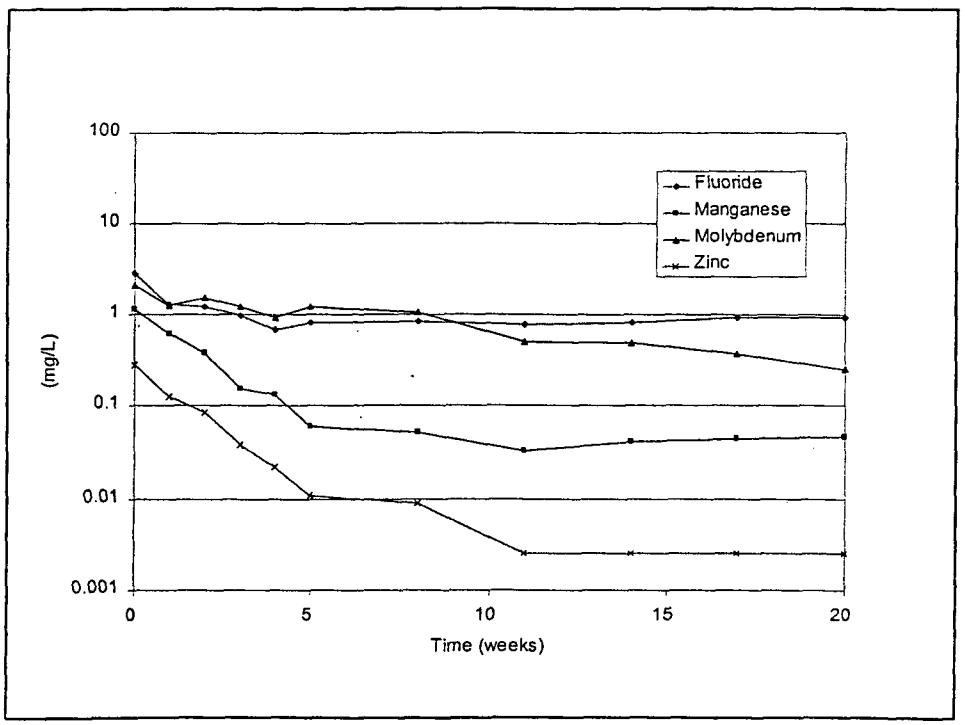
CELL 4 - Sample BH2-19





> High S content, NP/AP between 1 and 1.5, andesite

HUMIDITY CELL #5

Sample BH3-84
Aplite – uncertain acid generating potential

pH = 7.20,
Conductivity = 1064 µS,
NP/AP ~ 2.6,
Deposition year ~1975

CELL 5
SAMPLE BH3-84

Dry sample 0.25 kg

CYCLE	DATE 1997		WATER ADDED VOLUM (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.450	7.75	338	916	25.5	0.0	1.8	3.7	509	1080.4
1	Jun.	3	0.425	5.55	0.445	7.98	328	290	34.5	0.0	1.0	5.8	79	1246.3
2		10	0.425	5.99	0.435	8.10	344	113	36.5	0.0	1.0	7.9	10	1266.8
3		17	0.425	5.70	0.425	8.13	336	88	32.5	0.0	0.5	8.9	4	1274.8
4		24	0.425	5.61	0.430	7.76	346	73	25.0	0.0	1.5	11.9	4	1282.9
5	Jul.	1	0.425	5.58	0.430	8.03	343	89	35.0	0.0	1.3	14.4	3	1289.0
6		8	0.425	5.53	0.430	8.04	343	84	33.5	0.0	0.5	15.5	3	1295.1
7		15	0.425	5.89	0.420	8.12	342	81	32.5	0.0	0.3	16.0	3	1301.0
8		22	0.425	5.60	0.430	8.18	346	79	32.0	0.0	0.3	16.5	4	1309.1
9		29	0.425	5.66	0.420	8.21	337	76	31.0	0.0	0.3	17.0	3	1315.1
10	Aug.	6	0.425	5.58	0.415	8.20	324	77	32.0	0.0	0.5	17.9	4	1322.9
11		12	0.425	5.71	0.420	8.03	339	73	30.5	0.0	1.0	19.9	3	1328.8
12		19	0.425	5.64	0.420	8.10	336	72	29.5	0.0	0.8	21.4	3	1334.8
13		26	0.425	5.81	0.425	7.97	312	72	30.0	0.0	0.8	22.9	3	1340.8
14	Sept.	3	0.425	5.77	0.425	8.20	335	75	30.0	0.0	0.3	23.4	3	1346.8
15		9	0.425	5.86	0.430	8.18	339	52	28.0	0.0	0.5	24.4	<3	1349.9
16		16	0.425	5.70	0.435	8.17	330	54	29.0	0.0	0.5	25.4	5	1360.1
17		23	0.425	5.65	0.445	8.07	340	54	29.0	0.0	0.8	27.0	4	1368.5
18		30	0.425	5.85	0.430	7.96	331	55	30.0	0.0	1.0	29.1	3	1374.6
19	Oct.	7	0.425	5.82	4.25	7.91	337	53	29.0	0.0	1.0	31.1	3	1380.6
20		14	0.425	6.05	4.60	7.92	355	55	28.5	0.0	1.3	33.8	3	1387.1

CELL 5
SAMPLE BH3-84

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.020	0.0239	0.0005	0.05	<0.005	<0.1	<0.1	0.0027	188	<0.01	<0.01	0.02	2.30	<0.01	<0.05	0.01	10.8
1	0.050	0.0188	0.0023	0.02	<0.005	<0.1	<0.1	0.0008	42.8	<0.01	<0.01	<0.01	1.37	<0.03	<0.05	<0.01	0.82
2	0.085	0.0139	0.0026	0.03	<0.005	<0.1	<0.1	0.0004	16.9	<0.01	<0.01	<0.01	1.11	<0.03	<0.05	<0.01	0.27
3	0.095	0.0084	0.0005	0.03	<0.005	<0.1	<0.1	<0.0002	12.2	<0.01	<0.01	<0.01	0.94	<0.03	<0.05	<0.01	0.18
4	0.101	0.0074	0.0005	0.03	<0.005	<0.1	<0.1	<0.0002	10.7	<0.01	<0.01	<0.01	0.72	<0.03	<0.05	<0.01	0.19
5	0.064	0.0117	0.0052	0.05	<0.005	<0.1	<0.1	<0.0002	13.6	<0.01	<0.01	<0.01	0.96	<0.03	<0.05	<0.01	0.23
6																	
7																	
8	0.103	0.0071	0.0037	0.05	<0.005	<0.1	<0.1	<0.0002	12.5	<0.01	<0.01	<0.01	0.87	<0.03	<0.05	<0.01	0.16
9																	
10																	
11	0.128	0.0056	0.0032	0.04	<0.005	<0.1	<0.1	<0.0002	11.4	<0.01	<0.01	<0.01	0.90	<0.03	<0.05	<0.01	0.12
12																	
13																	
14	0.118	0.0049	0.0025	0.04	<0.005	<0.1	<0.1	<0.0002	12.0	<0.01	<0.01	<0.01	0.94	<0.03	<0.05	<0.01	0.13
15																	
16																	
17	0.128	0.0036	0.0003	0.04	<0.005	<0.1	<0.1	<0.0002	11.4	<0.01	<0.01	<0.01	1.04	<0.03	<0.05	<0.01	0.09
18												0.002			<0.001		
19												0.001			<0.001		
20	0.135	0.0037	0.0020	0.04	<0.005	<0.1	<0.1	<0.0002	11.7	<0.01	<0.01	<0.01	1.02	<0.03	<0.05	<0.01	0.06

CELL 5
SAMPLE BH3-84

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	1.06	<0.00005	0.48	<0.02	<0.3	20	0.0013	3.07	<0.0001	10	2.95	<0.1	<0.03	<0.01	<0.03	0.117
1	0.263	<0.00005	0.30	<0.02	<0.3	4	0.0011	2.27	<0.0001	<2	0.696	<0.1	<0.03	<0.01	<0.03	0.032
2	0.145	<0.00005	0.25	<0.02	<0.3	3	<0.0005	2.00	<0.0001	<2	0.503	<0.1	<0.03	<0.01	<0.03	0.019
3	0.087	<0.00005	0.23	<0.02	<0.3	2	0.0007	1.77	<0.0001	<2	0.407	<0.1	<0.03	<0.01	<0.03	0.006
4	0.062	<0.00005	0.29	<0.02	<0.3	2	<0.0005	2.00	<0.0001	<2	0.368	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.099	<0.00005	0.35	<0.02	<0.3	2	<0.0005	2.08	<0.0001	<2	0.483	<0.1	<0.03	<0.01	<0.03	0.005
6																
7																
8	0.083	<0.00005	0.33	<0.02	<0.3	2	<0.0005	1.79	<0.0001	<2	0.423	<0.1	<0.03	<0.01	<0.03	<0.005
9																
10																
11	0.064	<0.00005	0.33	<0.02	<0.3	<2	<0.0005	1.51	<0.0001	<2	0.344	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.067	<0.00005	0.28	<0.02	<0.3	<2	<0.0005	1.33	<0.0001	<2	0.317	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.049	<0.00005	0.26	<0.02	<0.3	<2	<0.0005	1.08	<0.0001	<2	0.262	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.049	<0.00005	0.23	<0.02	<0.3	<2	<0.0005	0.96	<0.0001	<2	0.225	<0.1	<0.03	<0.01	<0.03	<0.005

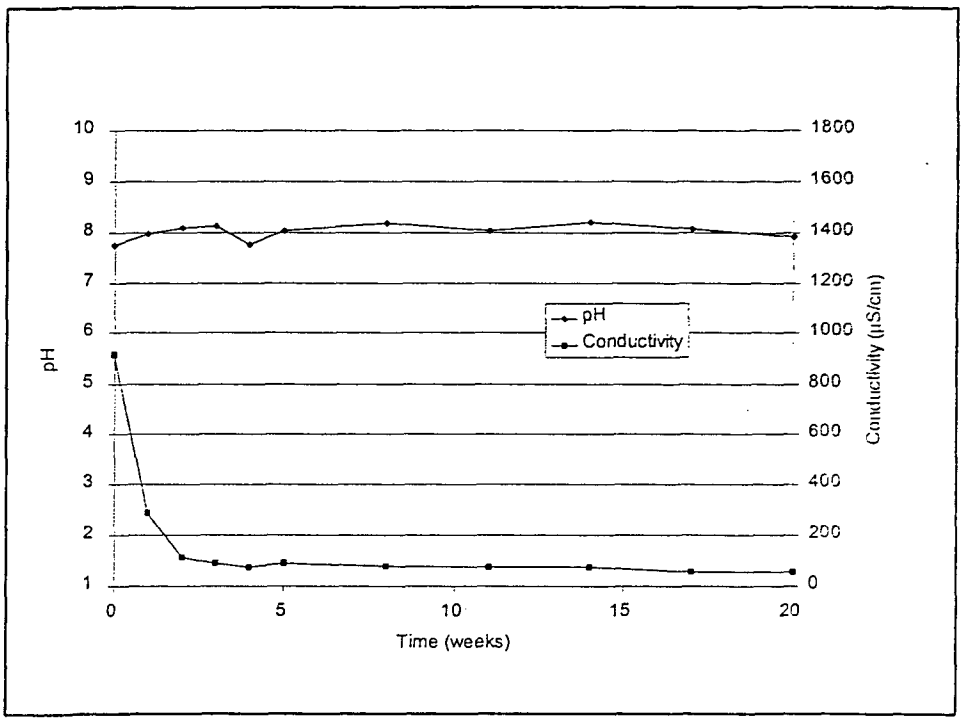
CELL 5
SAMPLE BH3-84

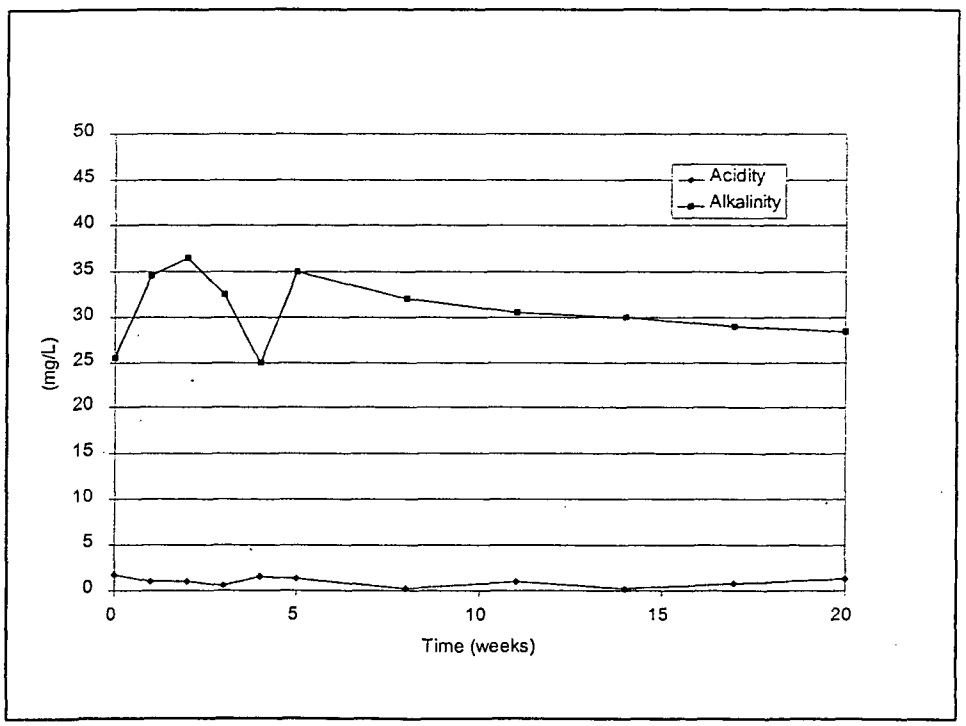
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.03	916	3.2	45.9	45.9	338.40	19.4	927	927	4.14	19.44	0.86	0.02	0.21
1	0.75	141	1.8	61.4	107.3	76.18	1.5	197	1124	2.44	1.46	0.53	0.02	0.08
2	0.24	17	1.7	63.5	170.8	29.41	0.5	75	1199	1.03	0.47	0.44	0.02	0.03
3	0.13	7	0.9	55.3	226.1	20.74	0.3	53	1252	1.60	0.31	0.39	0.02	0.01
4	0.15	7	2.6	43.0	269.1	18.40	0.3	47	1300	1.24	0.33	0.50	0.02	0.004
5	0.09	5	2.2	60.2	329.3	23.39	0.4	60	1360	1.65	0.40	0.60	0.02	0.01
6		5	0.9	57.6	386.9				1360					
7		5	0.4	54.6	441.5				1360					
8	0.13	7	0.4	55.0	496.5	21.50	0.3	55	1415	1.50	0.28	0.57	0.02	0.004
9		5	0.4	52.1	548.6				1415					
10		7	0.8	53.1	601.7				1415					
11	0.11	5	1.7	51.2	653.0	19.15	0.2	49	1463	1.51	0.20	0.55	0.02	0.004
12		5	1.3	49.6	702.5				1463					
13		5	1.3	51.0	753.5				1463					
14	0.10	5	0.4	51.0	804.5	20.40	0.2	52	1515	1.60	0.22	0.48	0.02	0.004
15		0	0.9	48.2	852.7				1515					
16		9	0.9	50.5	903.2				1515					
17	0.14	7	1.3	51.6	954.8	20.29	0.2	51	1567	1.85	0.16	0.46	0.02	0.004
18		5	1.7	51.6	1006.4				1567					
19		51	17.0	493.0	1499.4				1567					
20	0.11	55	23.9	524.4	2023.8	215.28	1.1	543	2109	0.00	1.10	4.23	0.18	0.046

CELL 5
SAMPLE BH3-84

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	2400	592	200	11	207	19500	0.17	3.28	0.43	0.16	0.10	4.70
1							0.27	3.53	0.70	0.33	0.13	5.42
2							0.35	3.61	0.92	0.48	0.15	5.51
3							0.42	3.66	1.11	0.64	0.15	5.54
4							0.47	3.72	1.36	0.79	0.15	5.58
5							0.54	3.78	1.66	0.95	0.16	5.61
6							0.54	3.78	1.66	0.95	0.16	5.63
7							0.54	3.78	1.66	0.95	0.16	5.66
8							0.60	3.83	1.95	1.11	0.16	5.69
9							0.60	3.83	1.95	1.11	0.16	5.72
10							0.60	3.83	1.95	1.11	0.16	5.75
11							0.67	3.86	2.22	1.26	0.16	5.78
12							0.67	3.86	2.22	1.26	0.16	5.80
13							0.67	3.86	2.22	1.26	0.16	5.83
14							0.73	3.90	2.46	1.41	0.16	5.86
15							0.73	3.90	2.46	1.41	0.16	5.86
16							0.73	3.90	2.46	1.41	0.16	5.90
17							0.81	3.93	2.69	1.58	0.16	5.94
18							0.81	3.93	2.69	1.58	0.16	5.98
19							0.81	3.93	2.69	1.58	0.16	6.23
20							0.81	4.11	4.81	3.25	0.19	6.51

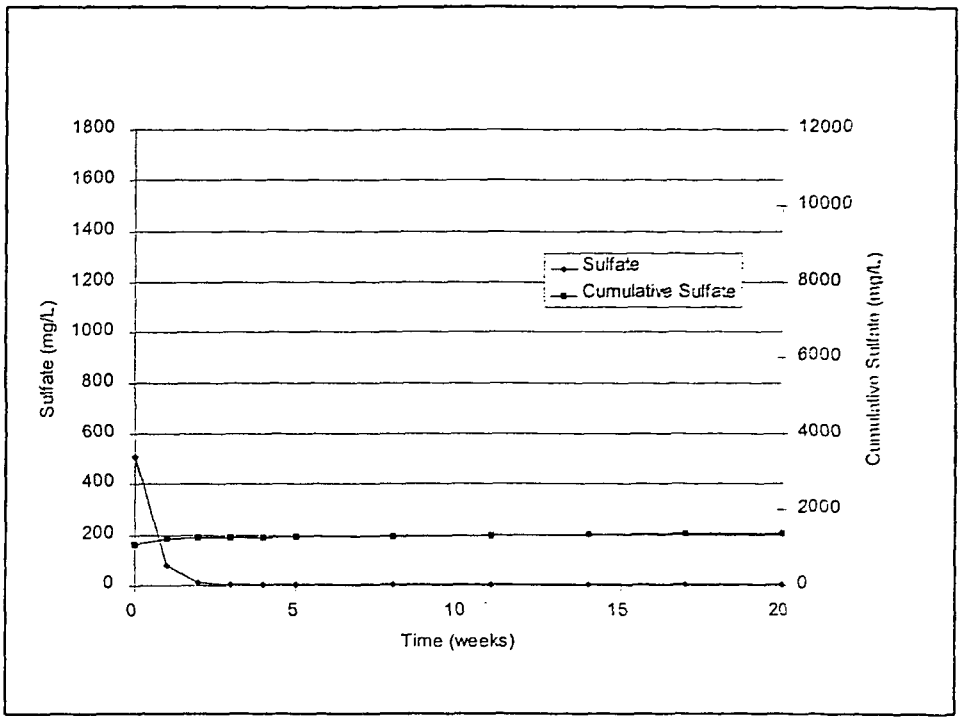
CELL 5 - Sample BH3-84

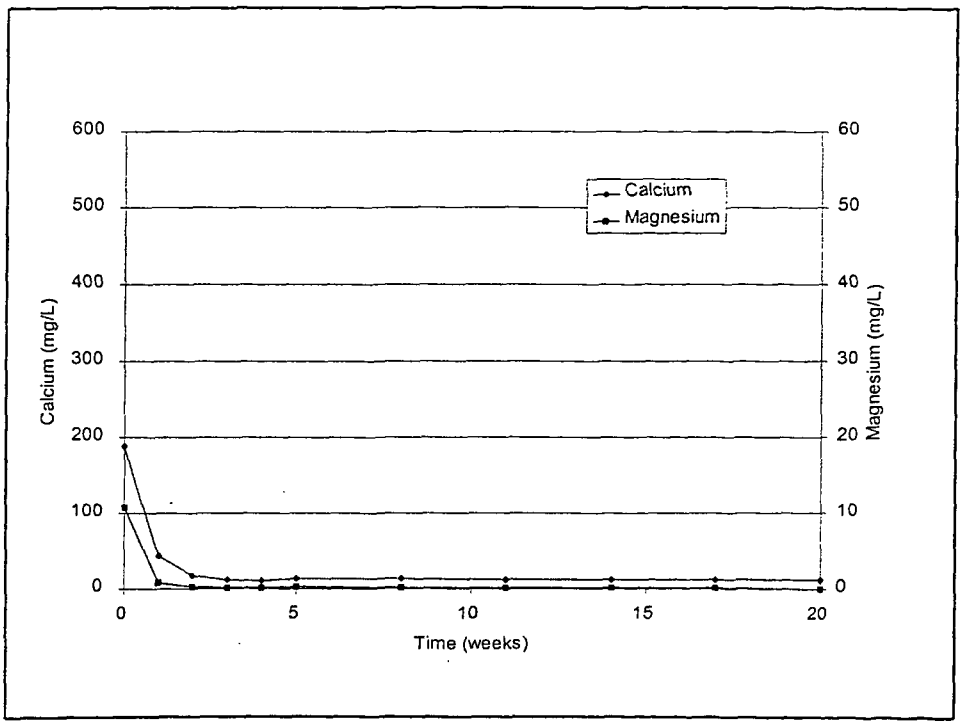




> High S content, NP/AP between 1.5 and 3, aplite

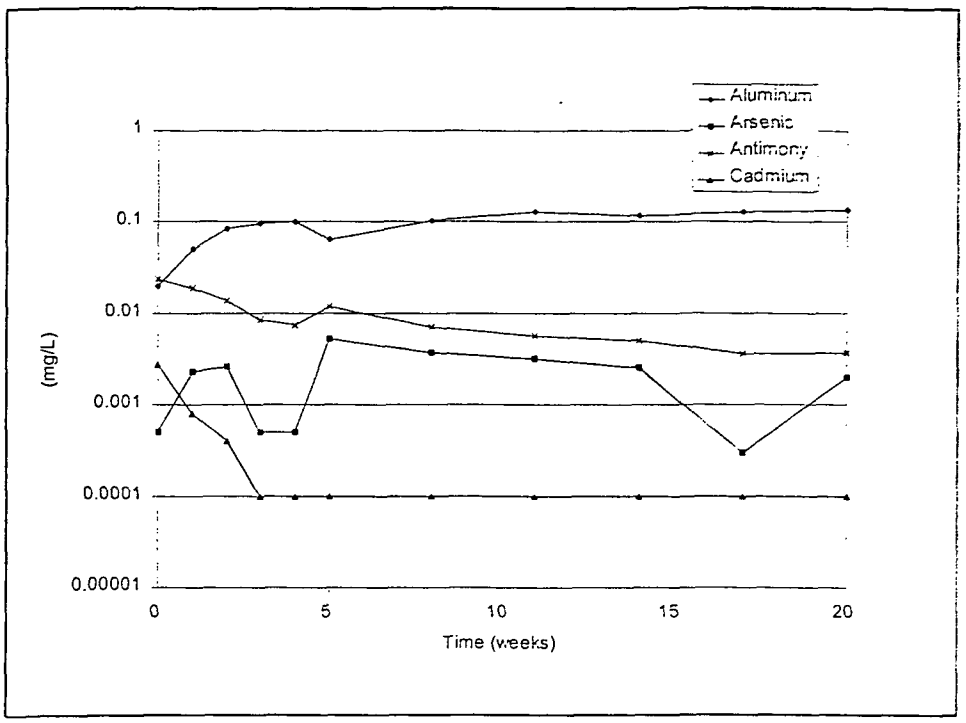
CELL 5 - Sample BH3-84

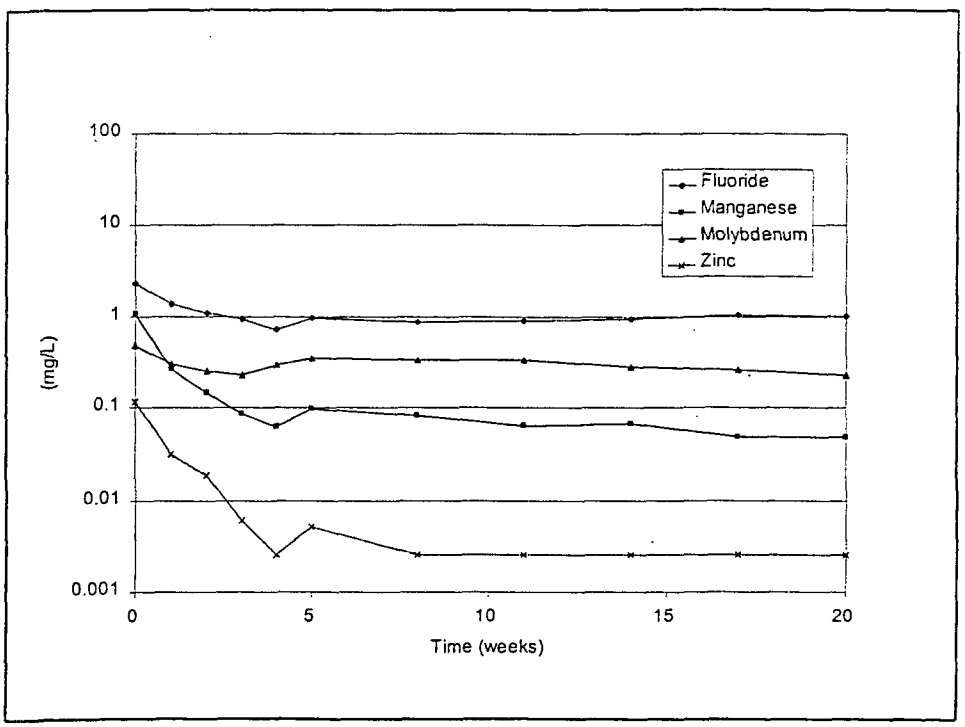




> *High S content, NP/AP between 1.5 and 3, aplite*

CELL 5 - Sample BH3-84





> High S content, NP/AP between 1.5 and 3, aplite

HUMIDITY CELL #6

Sample BH1-176

Andesite – uncertain acid generating potential

pH = 7.70,
Conductivity = 662 µS,
NP/AP = 1.67,
Deposition year ~ 1966

CELL 6
SAMPLE BH1-176

Dry sample weig 0.3 kg

CYCLE	DATE 1997		WATER ADDED VOLUM (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.405	7.90	334	656	40.3	0.0	1.5	2.4	254	411.5
1	Jun.	3	0.500	5.55	0.500	8.05	332	218	44.5	0.0	1.5	5.4	37	485.5
2		10	0.500	5.99	0.495	8.13	349	172	48.3	0.0	0.5	6.4	16	517.2
3		17	0.500	5.70	0.495	8.12	326	146	46.0	0.0	0.8	7.9	11	538.9
4		24	0.500	5.61	0.465	7.86	347	111	32.5	0.0	1.3	10.2	9	555.7
5	Jul.	1	0.500	5.58	0.480	7.99	350	100	31.5	0.0	1.3	12.6	6	567.2
6		8	0.500	5.53	0.490	8.07	342	101	34.0	0.0	0.5	13.6	6	579.0
7		15	0.500	5.89	0.490	8.12	344	98	33.5	0.0	0.5	14.6	5	588.8
8		22	0.500	5.60	0.500	8.15	351	86	29.5	0.0	0.5	15.6	6	600.8
9		29	0.500	5.66	0.495	8.12	341	90	30.5	0.0	0.3	16.1	5	610.7
10	Aug.	6	0.500	5.58	0.500	8.20	320	92	31.5	0.0	0.3	16.6	6	622.7
11		12	0.500	5.71	0.495	8.00	338	85	30.5	0.0	1.0	18.6	5	632.6
12		19	0.500	5.64	0.495	8.14	336	91	32.5	0.0	0.5	19.6	4	640.5
13		26	0.500	5.81	0.505	7.97	329	84	29.0	0.0	0.8	21.1	5	650.6
14	Sept.	3	0.500	5.77	0.505	8.24	338	94	33.5	0.0	0.3	21.6	5	660.7
15		9	0.500	5.86	0.505	8.21	340	76	29.0	0.0	0.3	22.1	4	668.8
16		16	0.500	5.70	0.500	8.10	338	58	25.0	0.0	0.3	22.6	6	680.8
17		23	0.500	5.65	0.500	8.03	344	58	27.0	0.0	0.8	24.1	6	692.8
18		30	0.500	5.85	0.505	7.94	335	58	26.5	0.0	1.0	26.1	5	702.9
19	Oct.	7	0.500	5.82	0.505	7.92	340	58	27.0	0.0	1.3	28.6	5	713.0
20		14	0.500	6.05	0.505	7.86	357	63	28.5	0.0	1.3	31.2	5	723.1

CELL 6
SAMPLE BH1-176

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.041	0.0551	0.0009	0.07	<0.005	<0.1	<0.1	0.0004	78.2	<0.01	<0.01	0.01	7.73	<0.01	<0.05	0.01	4.50
1	0.040	0.0363	0.0055	0.08	<0.005	<0.1	<0.1	0.0004	25.8	<0.01	<0.01	<0.01	4.18	<0.03	<0.05	<0.01	1.32
2	0.032	0.0256	0.0034	0.12	<0.005	<0.1	<0.1	0.0002	21.4	<0.01	<0.01	<0.01	3.32	<0.03	<0.05	<0.01	1.02
3	0.041	0.0158	0.0005	0.12	<0.005	<0.1	<0.1	<0.0002	18.5	<0.01	<0.01	<0.01	2.24	<0.03	<0.05	<0.01	0.83
4	0.067	0.0106	0.0003	0.11	<0.005	<0.1	<0.1	<0.0002	14.6	<0.01	<0.01	<0.01	1.48	<0.03	<0.05	<0.01	0.60
5	0.053	0.0119	0.0038	0.10	<0.005	<0.1	<0.1	<0.0002	13.7	<0.01	<0.01	<0.01	1.34	<0.03	<0.05	<0.01	0.54
6																	
7																	
8	0.060	0.0080	0.0039	0.09	<0.005	<0.1	<0.1	<0.0002	12.0	<0.01	<0.01	<0.01	1.11	<0.03	<0.05	<0.01	0.42
9																	
10																	
11	0.078	0.0068	0.0027	0.09	<0.005	<0.1	<0.1	<0.0002	12.0	<0.01	<0.01	<0.01	1.08	<0.03	<0.05	<0.01	0.38
12																	
13																	
14	0.09	0.0059	0.0023	0.1	<0.005	<0.1	<0.1	<0.0002	13.2	<0.01	<0.01	<0.01	1.10	<0.03	<0.05	<0.01	0.41
15																	
16																	
17	0.060	0.0042	0.0003	0.08	<0.005	<0.1	<0.1	<0.0002	10.8	<0.01	<0.01	<0.01	0.85	<0.03	<0.05	<0.01	0.30
18												0.002			<0.001		
19												0.002			<0.001		
20	0.063	0.0046	0.0022	0.09	<0.005	<0.1	<0.1	<0.0002	12.1	<0.01	<0.01	<0.01	0.90	<0.03	<0.05	<0.01	0.30

CELL 6
SAMPLE BH1-176

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	0.284	<0.00005	6.35	<0.02	<0.3	14	0.0017	2.69	0.0001	43	3.20	<0.1	<0.03	<0.01	<0.03	0.078
1	0.119	<0.00005	1.35	<0.02	<0.3	8	0.0014	2.41	<0.0001	7	1.74	<0.1	<0.03	<0.01	<0.03	0.025
2	0.096	<0.00005	0.71	<0.02	<0.3	7	<0.0005	2.32	<0.0001	3	1.54	<0.1	<0.03	<0.01	<0.03	0.015
3	0.074	<0.00005	0.56	<0.02	0.3	5	0.0013	2.12	<0.0001	<2	1.26	<0.1	<0.03	<0.01	<0.03	0.013
4	0.043	<0.00005	0.50	<0.02	<0.3	4	0.0007	1.52	<0.0001	<2	0.988	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.036	<0.00005	0.41	<0.02	<0.3	4	<0.0005	1.34	<0.0001	<2	0.896	<0.1	<0.03	<0.01	<0.03	<0.005
6																
7																
8	0.033	<0.00005	0.30	<0.02	<0.3	4	0.0008	1.15	<0.0001	<2	0.733	<0.1	<0.03	<0.01	<0.03	<0.005
9																
10																
11	0.030	<0.00005	0.22	<0.02	<0.3	3	0.0006	1.16	<0.0001	<2	0.671	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.034	<0.00005	0.18	<0.02	<0.3	3	0.0005	1.23	<0.0001	<2	0.694	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.024	<0.00005	0.12	<0.02	<0.3	3	<0.0005	0.83	<0.0001	<2	0.527	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.028	<0.00005	0.11	<0.02	<0.3	2	<0.0005	0.90	<0.0001	<2	0.555	<0.1	<0.03	<0.01	<0.03	<0.005

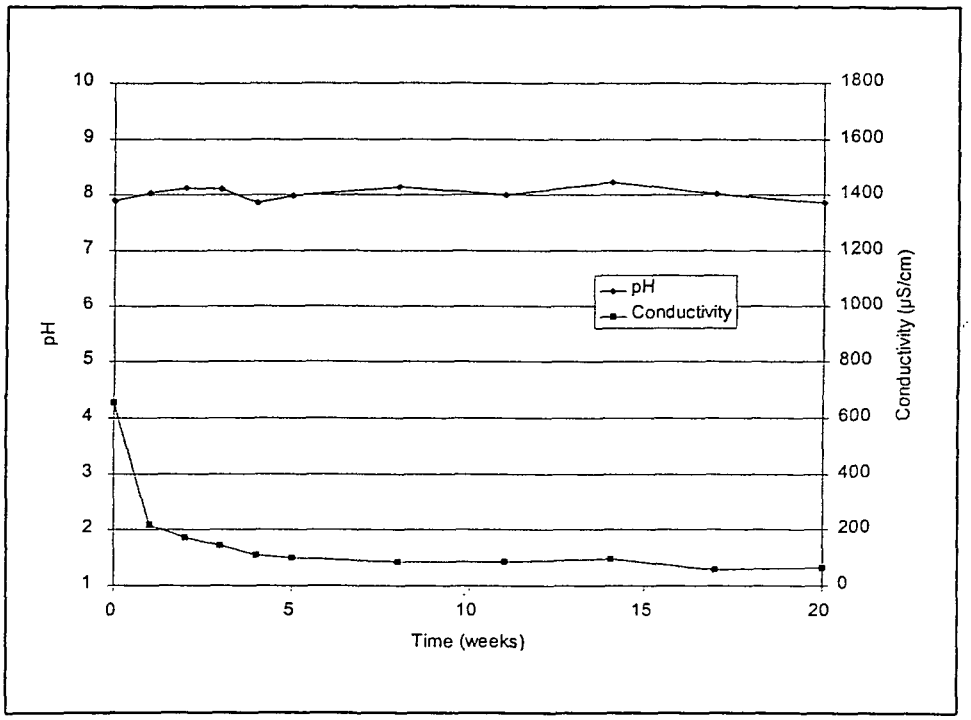
CELL 6
SAMPLE BH1-176

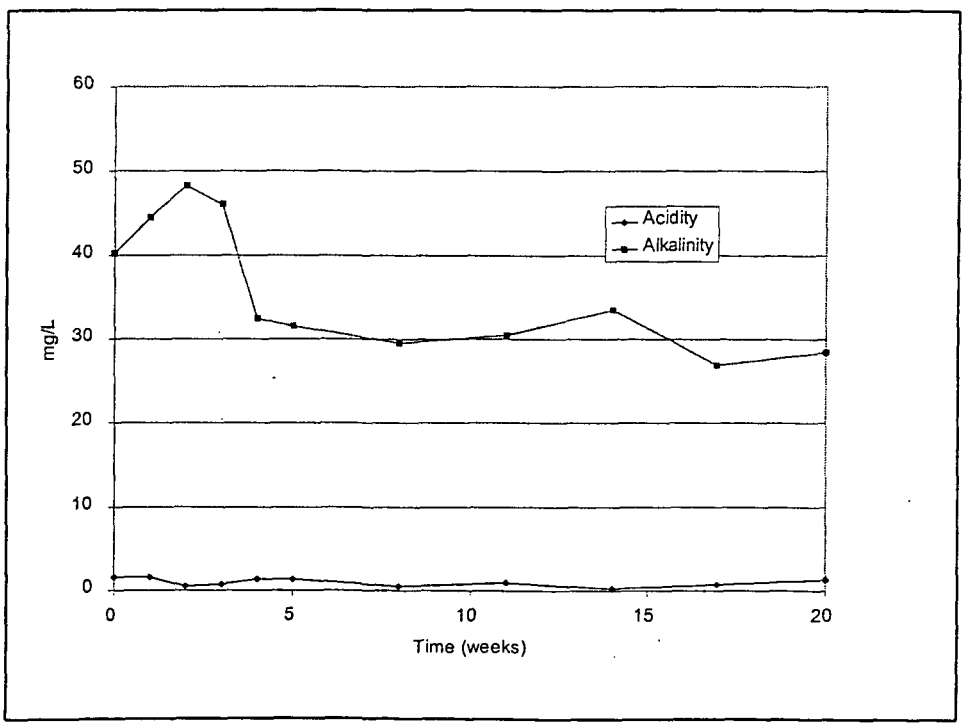
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.24	411	2.4	65.2	65.2	126.68	7.3	347	347	12.52	7.29	10.29	0.02	0.13
1	0.55	74	3.0	89.0	154.2	51.60	2.6	140	487	8.36	2.64	2.70	0.02	0.05
2	0.29	32	1.0	95.5	249.7	42.37	2.0	114	601	6.57	2.02	1.41	0.02	0.03
3	0.23	22	1.5	91.1	340.8	36.63	1.6	98	700	4.44	1.64	1.11	0.02	0.03
4	0.24	17	2.3	60.5	401.3	27.16	1.1	73	772	2.75	1.12	0.93	0.02	0.005
5	0.17	12	2.4	60.5	461.8	26.30	1.0	70	842	2.57	1.04	0.79	0.02	0.00
6		12	1.0	66.6	528.4				842					
7		10	1.0	65.7	594.1				842					
8	0.20	12	1.0	59.0	653.1	24.00	0.8	64	906	2.22	0.84	0.60	0.02	0.005
9		10	0.5	60.4	713.4				906					
10		12	0.5	63.0	776.4				906					
11	0.17	10	2.0	60.4	836.8	23.76	0.8	63	969	2.14	0.75	0.44	0.02	0.005
12		8	1.0	64.4	901.2				969					
13		10	1.5	58.6	959.8				969					
14	0.15	10	0.5	67.7	1027.4	26.66	0.8	70	1039	2.22	0.83	0.36	0.02	0.005
15		8	0.5	58.6	1086.0				1039					
16		12	0.5	50.0	1136.0				1039					
17	0.22	12	1.5	54.0	1190.0	21.60	0.6	57	1095	1.70	0.60	0.24	0.02	0.005
18		10	2.0	53.5	1243.5				1095					
19		10	2.6	54.5	1298.1				1095					
20	0.17	10	2.6	57.6	1355.7	24.44	0.6	64	1159	0.00	0.61	0.22	0.02	0.005

CELL 6
SAMPLE BH1-176

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	4100	728	170	58	88	34800	0.31	1.00	6.05	0.03	0.14	1.18
1							0.51	1.36	7.64	0.06	0.20	1.40
2							0.67	1.64	8.47	0.10	0.23	1.49
3							0.78	1.87	9.12	0.13	0.26	1.55
4							0.84	2.02	9.67	0.16	0.27	1.60
5							0.91	2.16	10.13	0.20	0.27	1.63
6							0.91	2.16	10.13	0.20	0.27	1.66
7							0.91	2.16	10.13	0.20	0.27	1.69
8							0.96	2.28	10.48	0.23	0.28	1.73
9							0.96	2.28	10.48	0.23	0.28	1.75
10							0.96	2.28	10.48	0.23	0.28	1.79
11							1.01	2.38	10.74	0.26	0.29	1.82
12							1.01	2.38	10.74	0.26	0.29	1.84
13							1.01	2.38	10.74	0.26	0.29	1.87
14							1.07	2.50	10.95	0.30	0.29	1.90
15							1.07	2.50	10.95	0.30	0.29	1.92
16							1.07	2.50	10.95	0.30	0.29	1.96
17							1.11	2.58	11.09	0.33	0.30	1.99
18							1.11	2.58	11.09	0.33	0.30	2.02
19							1.11	2.58	11.09	0.33	0.30	2.05
20							1.11	2.66	11.22	0.37	0.30	2.08

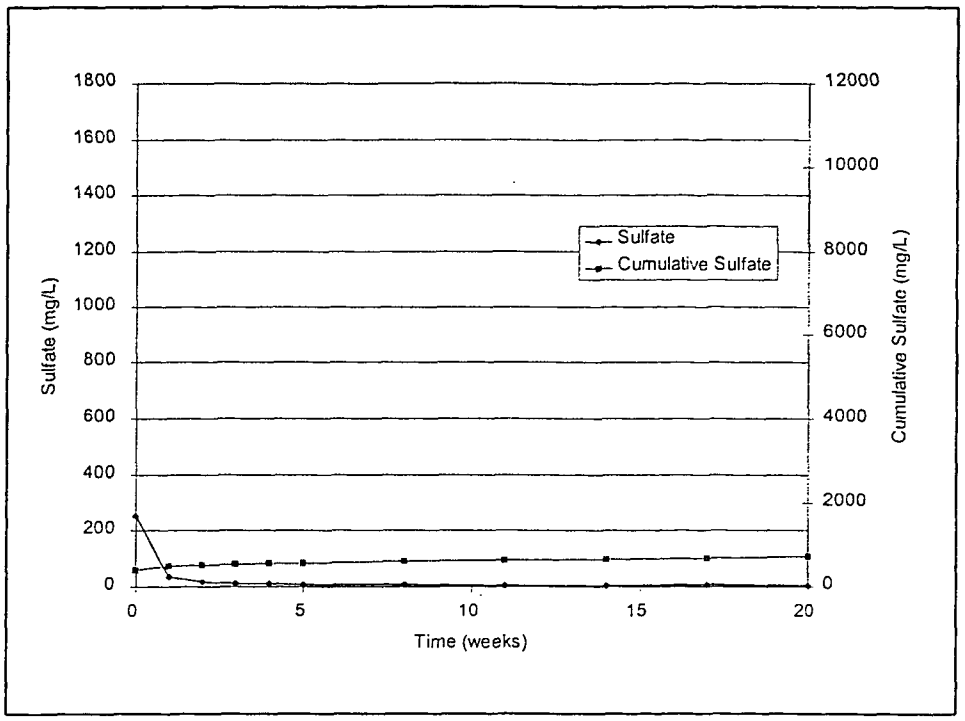
CELL 6 - Sample BH1-176

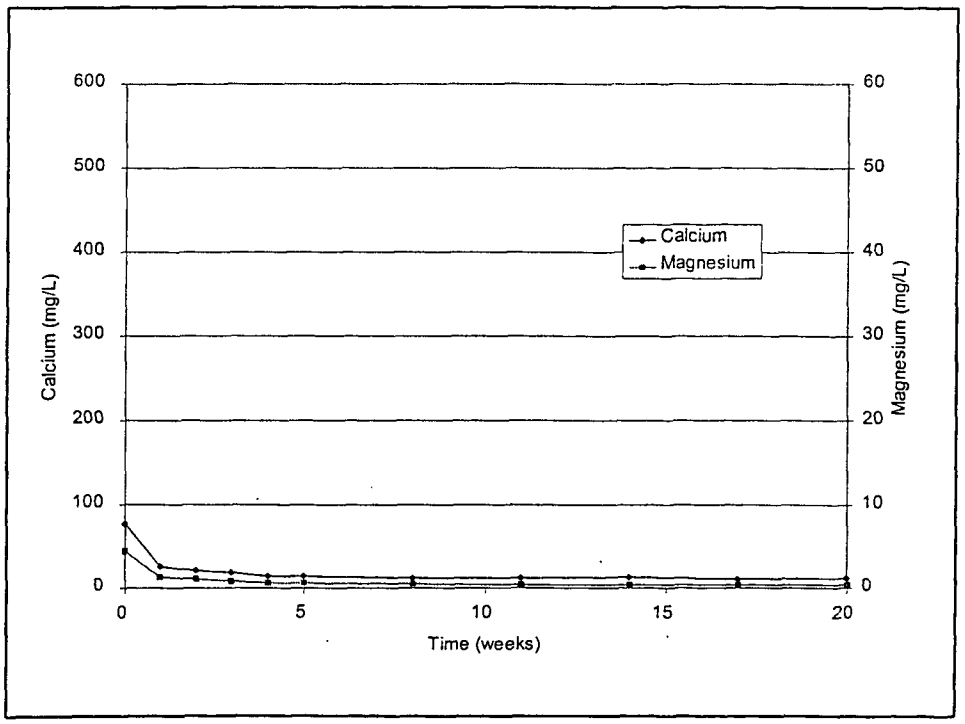




> High S content, NP/AP between 1.5 and 3, andesite

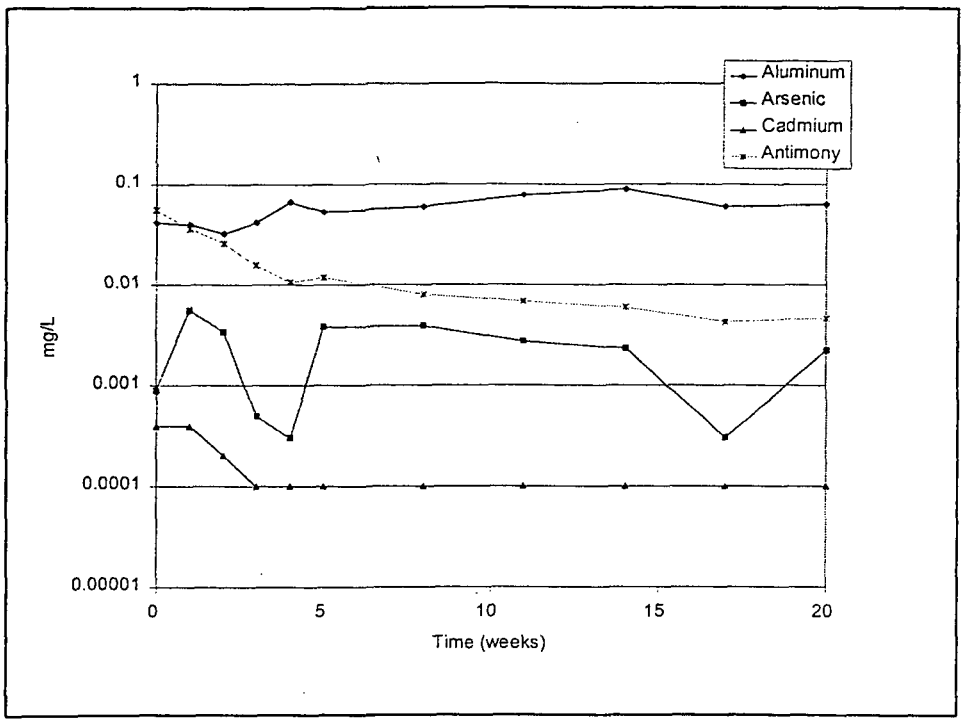
CELL 6 - Sample BH1-176

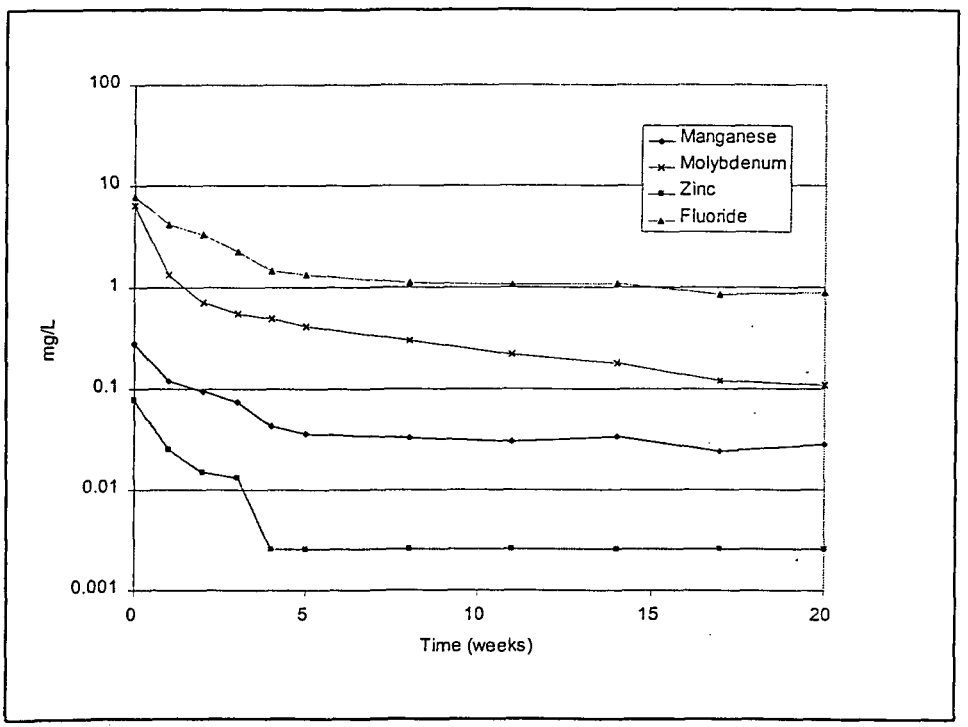




> High S content, NP/AP between 1.5 and 3, andesite

CELL 6 - Sample BH1-176





> High S content, NP/AP between 1.5 and 3, andesite

HUMIDITY CELL #7

Sample BH3-111
Aplite – potentially non-acid generating

pH = 7.20,
Conductivity = 757 µS,
NP/AP = 4.20,
Deposition year ~ 1972

CELL 7
SAMPLE BH3-111

Dry sampl 0.3 kg

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.435	7.84	338	453	26.8	0.0	1.3	3.5	149	412.8
1	Jun.	3	0.315	5.55	0.320	7.88	343	151	33.5	0.0	1.3	6.0	24	461.8
2		10	0.315	5.99	0.315	8.14	327	122	45.5	0.0	0.5	7.0	5	471.8
3		17	0.315	5.70	0.310	8.05	345	90	34.5	0.0	0.8	8.5	4	479.7
4		24	0.315	5.61	0.320	7.76	349	62	22.5	0.0	1.3	11.0	3	485.8
5	Jul.	1	0.315	5.58	0.310	7.94	340	80	31.5	0.0	1.3	13.5	3	491.7
6		8	0.315	5.53	0.310	7.96	342	78	31.0	0.0	1.0	15.5	3	497.6
7		15	0.315	5.89	0.310	8.05	345	75	29.0	0.0	0.5	16.5	3	503.6
8		22	0.315	5.60	0.315	8.10	350	74	30.5	0.0	0.5	17.5	4	511.6
9		29	0.315	5.66	0.300	8.08	339	72	29.5	0.0	0.5	18.4	4	519.2
10	Aug.	6	0.315	5.58	0.310	8.10	302	72	29.5	0.0	0.5	19.4	4	527.1
11		12	0.315	5.71	0.315	8.00	341	71	29.5	0.0	1.0	21.4	3	533.2
12		19	0.315	5.64	0.305	8.03	342	72	29.0	0.0	0.8	22.9	3	539.0
13		26	0.315	5.81	0.315	7.88	334	71	29.5	0.0	1.3	25.4	3	545.0
14	Sept.	3	0.315	5.77	0.310	8.07	340	72	29.5	0.0	0.5	26.4	3	550.9
15		9	0.315	5.86	0.305	8.07	343	64	29.0	0.0	0.5	27.3	<3	553.8
16		16	0.315	5.70	0.310	8.00	337	53	29.0	0.0	1.0	29.3	5	563.7
17		23	0.315	5.65	0.315	7.99	341	54	29.5	0.0	1.0	31.3	5	573.7
18		30	0.315	5.85	0.310	7.90	334	54	29.0	0.0	1.3	33.8	4	581.6
19	Oct.	7	0.315	5.82	0.305	7.88	338	54	29.5	0.0	1.3	36.2	4	589.4
20		14	0.315	6.05	0.305	7.83	356	55	30.0	0.0	1.3	38.7	4	597.2

CELL 7
SAMPLE BH3-111

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.097	0.0314	0.0011	0.04	<0.005	<0.1	<0.1	0.0010	59.2	<0.01	<0.01	<0.01	1.71	<0.01	<0.05	<0.01	4.91
1	0.113	0.0426	0.0060	0.03	<0.005	<0.1	<0.1	0.0003	20.2	<0.01	<0.01	<0.01	0.92	<0.03	<0.05	<0.01	1.09
2	0.055	0.0421	0.0025	0.04	<0.005	<0.1	<0.1	0.0003	17.3	<0.01	<0.01	<0.01	1.07	<0.03	<0.05	<0.01	0.81
3	0.097	0.0168	0.0008	0.04	<0.005	<0.1	<0.1	<0.0002	12.9	<0.01	<0.01	<0.01	0.74	<0.03	<0.05	<0.01	0.50
4	0.167	0.0099	0.0010	0.03	<0.005	<0.1	<0.1	<0.0002	8.87	<0.01	<0.01	<0.01	0.60	<0.03	<0.05	<0.01	0.28
5	0.108	0.0164	0.0061	0.04	<0.005	<0.1	<0.1	<0.0002	12.3	<0.01	<0.01	<0.01	0.73	<0.03	<0.05	<0.01	0.42
6																	
7																	
8	0.148	0.0098	0.0057	0.04	<0.005	<0.1	<0.1	<0.0002	11.8	<0.01	<0.01	<0.01	0.77	<0.03	<0.05	<0.01	0.32
9																	
10																	
11	0.190	0.0077	0.0034	0.03	<0.005	<0.1	<0.1	<0.0002	10.9	<0.01	<0.01	<0.01	0.78	<0.03	<0.05	<0.01	0.24
12																	
13																	
14	0.190	0.0063	0.003	0.03	<0.005	<0.1	<0.1	<0.0002	10.8	<0.01	<0.01	<0.01	0.78	<0.03	<0.05	<0.01	0.18
15																	
16																	
17	0.161	0.0049	0.0005	0.02	<0.005	<0.1	<0.1	<0.0002	11.6	<0.01	<0.01	<0.01	0.85	<0.03	<0.05	<0.01	0.15
18												0.003			<0.001		
19												0.002			<0.001		
20	0.154	0.0048	0.0027	0.03	<0.005	<0.1	<0.1	<0.0002	12.1	<0.01	<0.01	<0.01	0.88	<0.03	<0.05	<0.01	0.14

CELL 7
SAMPLE BH3-111

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	0.374	<0.00005	1.32	<0.02	<0.3	12	0.0014	2.71	<0.0001	8	0.997	<0.1	<0.03	<0.01	<0.03	0.048
1	0.198	<0.00005	0.56	<0.02	<0.3	5	0.0008	2.51	<0.0001	<2	0.382	<0.1	<0.03	<0.01	<0.03	0.024
2	0.228	<0.00005	0.56	<0.02	0.4	4	<0.0005	2.95	<0.0001	<2	0.344	<0.1	<0.03	<0.01	<0.03	0.015
3	0.152	<0.00005	0.28	<0.02	0.4	<2	0.0007	2.24	<0.0001	<2	0.231	<0.1	<0.03	<0.01	<0.03	0.012
4	0.083	<0.00005	0.21	<0.02	<0.3	<2	<0.0005	1.98	<0.0001	<2	0.148	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.128	<0.00005	0.25	<0.02	<0.3	2	<0.0005	2.17	<0.0001	<2	0.201	<0.1	<0.03	<0.01	<0.03	0.005
6																
7																
8	0.105	<0.00005	0.22	<0.02	<0.3	<2	0.0005	2.01	<0.0001	<2	0.169	<0.1	<0.03	<0.01	<0.03	<0.005
9																
10																
11	0.094	<0.00005	0.18	<0.02	<0.3	<2	<0.0005	1.60	<0.0001	<2	0.133	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.090	<0.00005	0.15	<0.02	<0.3	<2	<0.0005	1.42	<0.0001	<2	0.113	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.095	<0.00005	0.13	<0.02	<0.3	<2	<0.0005	1.19	<0.0001	<2	0.104	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.099	<0.00005	0.13	<0.02	<0.3	<2	<0.0005	1.19	<0.0001	<2	0.089	<0.1	<0.03	<0.01	<0.03	<0.005

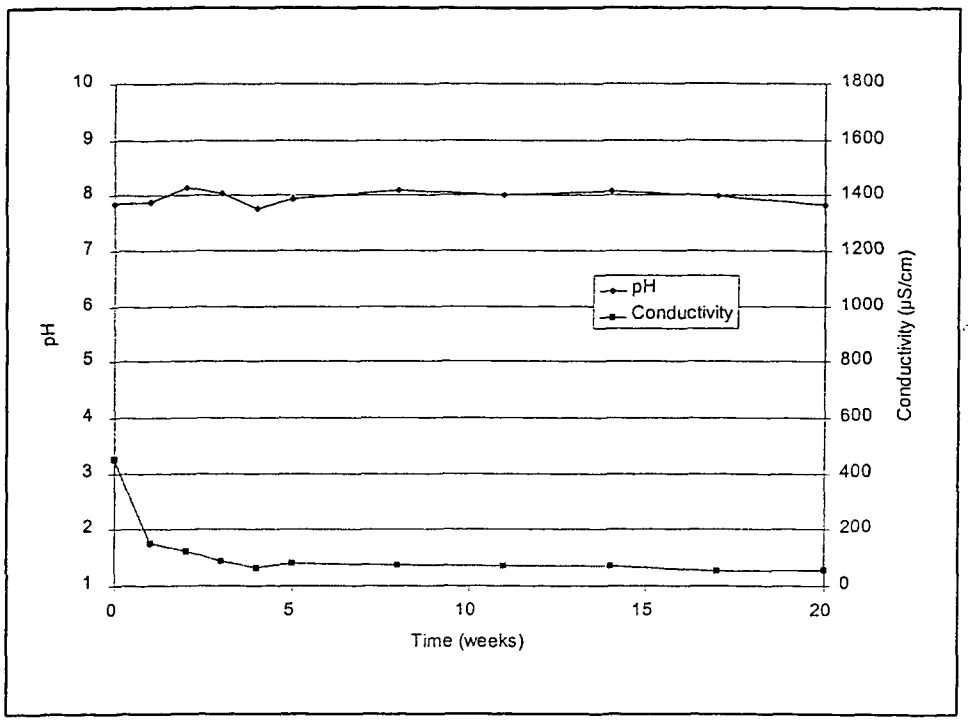
CELL 7
SAMPLE BH3-111

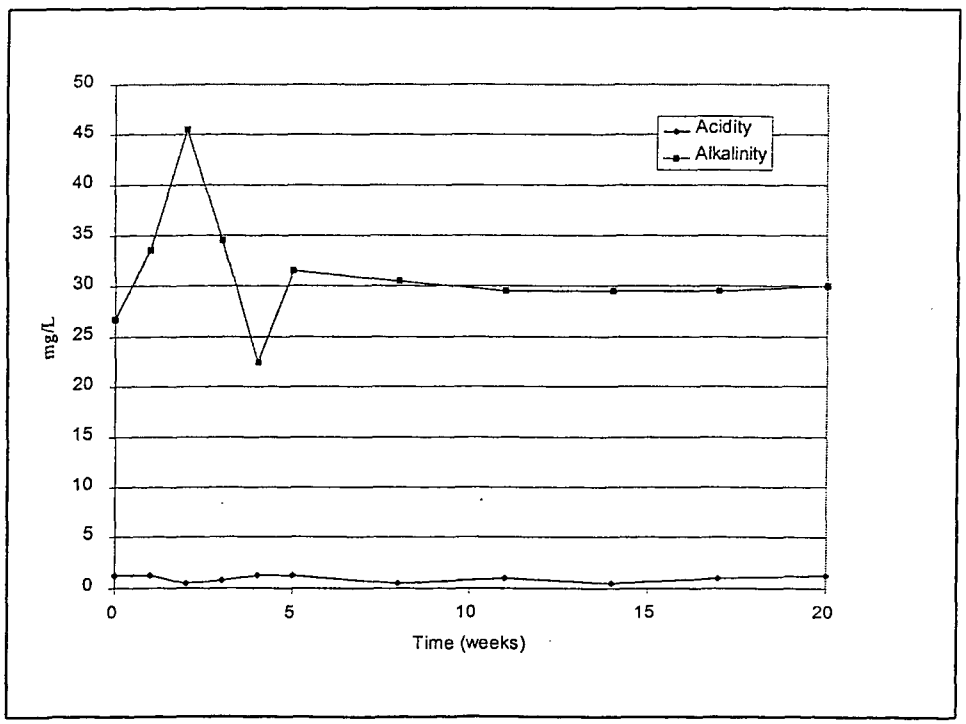
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	0.92	259	2.2	46.5	46.5	103.01	8.5	293	293	2.98	8.54	2.30	0.02	0.08
1	0.46	31	1.6	42.9	89.4	25.86	1.4	70	364	1.18	1.40	0.72	0.01	0.03
2	0.11	6	0.6	57.3	146.8	21.80	1.0	59	422	1.35	1.02	0.71	0.01	0.02
3	0.12	5	0.9	42.8	189.5	16.00	0.6	43	465	0.92	0.62	0.35	0.01	0.01
4	0.13	4	1.6	28.8	218.3	11.35	0.4	30	495	0.77	0.36	0.27	0.01	0.003
5	0.10	4	1.6	39.1	257.4	15.25	0.5	40	535	0.91	0.52	0.31	0.01	0.01
6		4	1.2	38.4	295.8				535					
7		4	0.6	36.0	331.8				535					
8	0.14	5	0.6	38.4	370.2	14.87	0.4	39	574	0.97	0.40	0.28	0.01	0.003
9		5	0.6	35.4	405.6				574					
10		5	0.6	36.6	442.2				574					
11	0.11	4	1.3	37.2	479.4	13.73	0.3	36	610	0.98	0.30	0.23	0.01	0.003
12		4	0.9	35.4	514.8				610					
13		4	1.6	37.2	551.9				610					
14	0.11	4	0.6	36.6	588.5	13.39	0.2	34	644	0.97	0.22	0.19	0.01	0.003
15		0	0.6	35.4	623.9				644					
16		6	1.2	36.0	659.8				644					
17	0.18	6	1.3	37.2	697.0	14.62	0.2	37	681	1.07	0.19	0.16	0.01	0.003
18		5	1.6	36.0	733.0				681					
19		5	1.6	36.0	769.0				681					
20	0.14	5	1.6	36.6	805.6	14.76	0.2	38	719	0.00	0.17	0.16	0.01	0.003

CELL 7
SAMPLE BH3-111

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	2200	713	215	4	153	9000	0.14	1.20	1.07	0.44	0.05	2.88
1							0.19	1.39	1.40	0.76	0.07	3.22
2							0.25	1.54	1.73	1.07	0.09	3.29
3							0.29	1.62	1.89	1.38	0.10	3.35
4							0.33	1.67	2.02	1.70	0.10	3.39
5							0.37	1.75	2.16	2.01	0.10	3.43
6							0.37	1.75	2.16	2.01	0.10	3.47
7							0.37	1.75	2.16	2.01	0.10	3.51
8							0.41	1.80	2.29	2.33	0.10	3.57
9							0.41	1.80	2.29	2.33	0.10	3.62
10							0.41	1.80	2.29	2.33	0.10	3.68
11							0.46	1.85	2.39	2.64	0.11	3.72
12							0.46	1.85	2.39	2.64	0.11	3.76
13							0.46	1.85	2.39	2.64	0.11	3.80
14							0.50	1.88	2.48	2.95	0.11	3.84
15							0.50	1.88	2.48	2.95	0.11	3.84
16							0.50	1.88	2.48	2.95	0.11	3.91
17							0.55	1.90	2.56	3.27	0.11	3.98
18							0.55	1.90	2.56	3.27	0.11	4.04
19							0.55	1.90	2.56	3.27	0.11	4.09
20							0.55	1.93	2.63	3.57	0.11	4.15

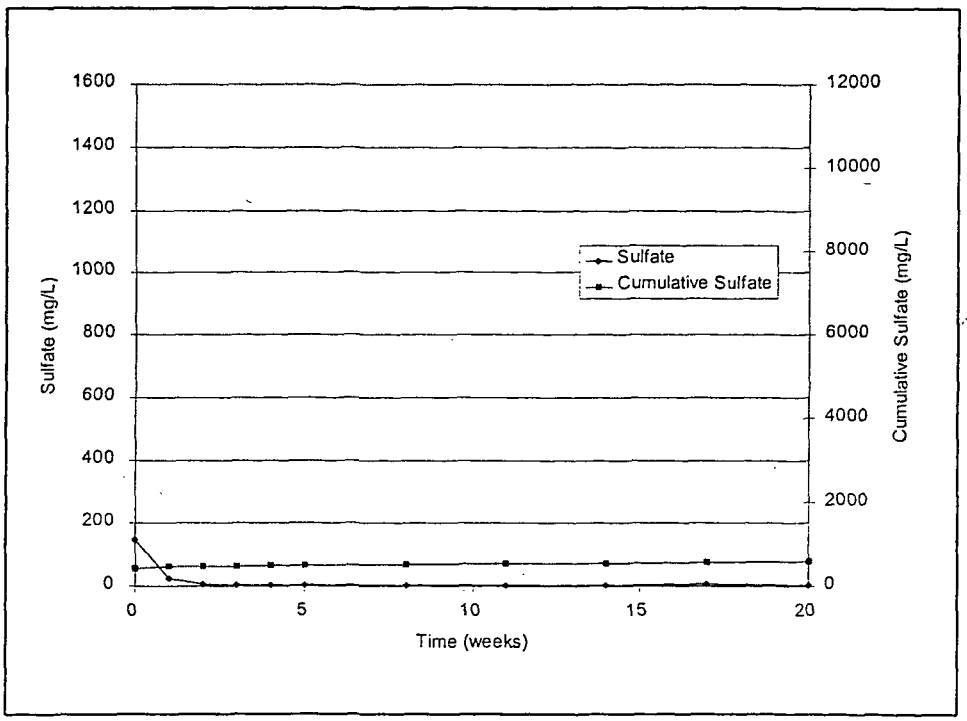
CELL 7 - Sample BH3-111

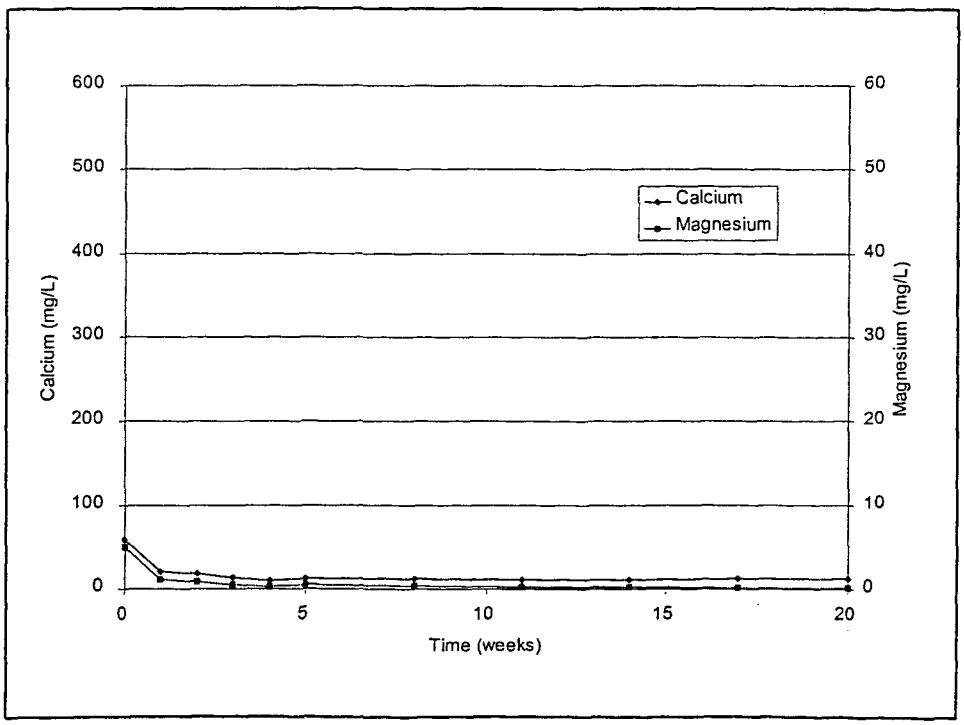




> Potentially non-acid generating, NP/AP >3, aplite

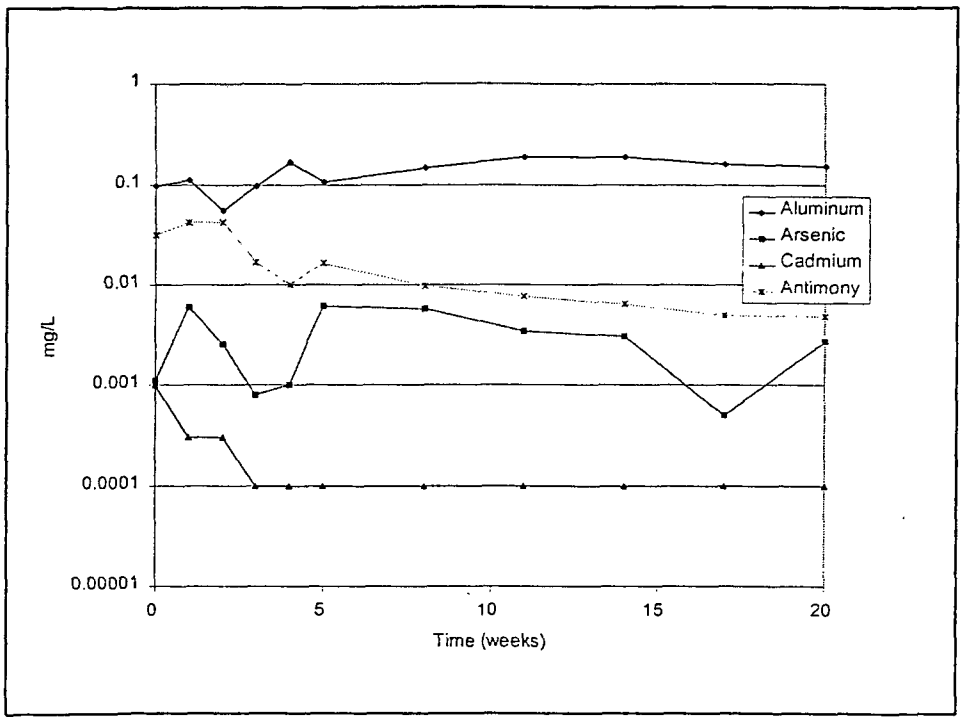
CELL 7 - Sample BH3-111

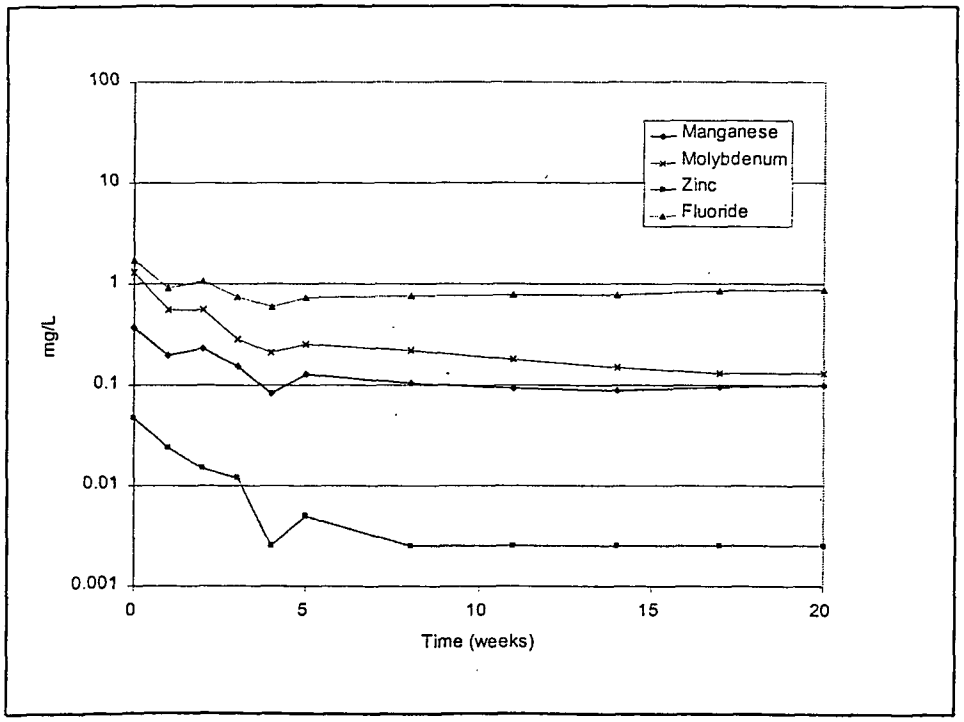




> Potentially non-acid generating, NP/AP >3, aplite

CELL 7 - Sample BH3-111





> Potentially non-acid generating, NP/AP >3, aplite

HUMIDITY CELL #8

Sample BH1-123
Andesite – potentially non-acid generating

pH = 7.50;
Conductivity = 702 µS;
NP/AP = 3.25;
Deposition year ≈ 1967

CELL 8
SAMPLE BH1-123

Dry sample **0.3 kg**

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.410	7.76	341	595	37.8	0.0	2.3	3.7	224	367.4
1	Jun.	3	0.500	5.55	0.505	7.92	316	159	40.8	0.0	1.5	6.7	17	401.7
2		10	0.500	5.99	0.505	8.03	309	139	42.3	0.0	0.8	8.2	10	421.9
3		17	0.500	5.70	0.495	8.05	314	129	42.0	0.0	0.8	9.7	7	435.8
4		24	0.500	5.61	0.500	7.82	342	117	35.0	0.0	1.5	12.7	8	451.8
5	Jul.	1	0.500	5.58	0.495	8.04	338	105	36.5	0.0	1.3	15.2	4	459.7
6		8	0.500	5.53	0.480	8.06	344	103	36.0	0.0	0.8	16.6	4	467.4
7		15	0.500	5.89	0.510	8.08	344	97	34.0	0.0	0.5	17.7	4	475.5
8		22	0.500	5.60	0.480	8.15	349	98	34.5	0.0	0.5	18.6	5	485.1
9		29	0.500	5.66	0.500	8.10	340	92	33.0	0.0	0.5	19.6	5	495.1
10	Aug.	6	0.500	5.58	0.490	8.14	311	96	34.0	0.0	0.5	20.6	6	506.9
11		12	0.500	5.71	0.490	8.02	338	90	33.0	0.0	0.8	22.1	5	516.7
12		19	0.500	5.64	0.490	8.06	341	91	32.0	0.0	0.8	23.5	4	524.5
13		26	0.500	5.81	0.495	7.94	336	91	32.0	0.0	1.3	26.0	4	532.4
14	Sept.	3	0.500	5.77	0.490	8.16	338	93	34.0	0.0	0.5	27.0	4	540.3
15		9	0.500	5.86	0.500	8.12	342	82	31.5	0.0	0.5	28.0	4	548.3
16		16	0.500	5.70	0.500	8.05	331	67	31.0	0.0	0.8	29.5	6	560.3
17		23	0.500	5.65	0.490	8.10	343	68	31.0	0.0	0.5	30.5	6	572.0
18		30	0.500	5.85	0.490	7.96	336	67	32.5	0.0	1.3	32.9	4	579.9
19	Oct.	7	0.500	5.82	0.495	7.91	340	66	31.5	0.0	1.3	35.4	4	587.8
20		14	0.500	6.05	0.495	7.90	358	69	33.5	0.0	1.8	38.9	5	597.7

CELL 8
SAMPLE BH1-123

ICP ANALYSIS RESULTS FOR LEACHATE

CYCLE	Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Ca (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	F (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mg (mg/L)
0	0.031	0.0181	0.0006	0.07	<0.005	<0.1	<0.1	0.0008	77.0	<0.01	<0.01	0.01	6.46	<0.01	<0.05	0.01	11.8
1	0.059	0.0238	0.0050	0.08	<0.005	<0.1	<0.1	0.0004	18.6	<0.01	<0.01	<0.01	2.57	<0.03	<0.05	<0.01	2.07
2	0.070	0.0162	0.0025	0.10	<0.005	<0.1	<0.1	0.0003	16.6	<0.01	<0.01	<0.01	2.07	<0.03	<0.05	<0.01	1.67
3	0.041	0.0112	0.0004	0.11	<0.005	<0.1	<0.1	<0.0002	16.0	<0.01	<0.01	<0.01	1.99	<0.03	<0.05	<0.01	1.43
4	0.044	0.0135	0.0003	0.12	<0.005	<0.1	<0.1	<0.0002	14.9	<0.01	<0.01	<0.01	1.99	<0.03	<0.05	<0.01	1.20
5	0.060	0.0106	0.0046	0.12	<0.005	<0.1	<0.1	<0.0002	13.9	<0.01	<0.01	<0.01	1.67	<0.03	<0.05	<0.01	1.09
6																	
7																	
8	0.073	0.0072	0.0035	0.12	<0.005	<0.1	<0.1	<0.0002	14.1	<0.01	<0.01	<0.01	1.52	<0.03	<0.05	<0.01	0.86
9																	
10																	
11	0.099	0.0053	0.0030	0.10	<0.005	<0.1	<0.1	<0.0002	12.8	<0.01	<0.01	<0.01	1.26	<0.03	<0.05	<0.01	0.64
12																	
13																	
14	0.100	0.0044	0.0025	0.09	<0.005	<0.1	<0.1	<0.0002	13.0	<0.01	<0.01	<0.01	1.19	<0.03	<0.05	<0.01	0.54
15																	
16																	
17	0.093	0.0028	0.0004	0.08	<0.005	<0.1	<0.1	<0.0002	13.2	<0.01	<0.01	<0.01	1.17	<0.03	<0.05	<0.01	0.45
18												0.001			<0.001		
19												0.002			<0.001		
20	0.097	0.0032	0.0021	0.09	<0.005	<0.1	<0.1	<0.0002	14.4	<0.01	<0.01	<0.01	1.15	<0.03	<0.05	<0.01	0.38

CELL 8
SAMPLE BH1-123

CYCLE	Mn	Hg	Mo	Ni	P	K	Se	Si	Ag	Na	Sr	Tl	Sn	Ti	V	Zn
	(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)	(mg/L)	(mg/L)	(mg/L)
0	1.11	<0.00005	5.11	<0.02	<0.3	20	0.0010	2.40	<0.0001	13	2.49	<0.1	<0.03	<0.01	<0.03	0.061
1	0.283	<0.00005	1.35	<0.02	<0.3	9	0.0009	2.01	<0.0001	<2	0.876	<0.1	<0.03	<0.01	<0.03	0.016
2	0.242	<0.00005	0.87	<0.02	<0.3	6	<0.0005	1.76	<0.0001	<2	0.746	<0.1	<0.03	<0.01	<0.03	0.012
3	0.198	<0.00005	0.88	<0.02	<0.3	5	<0.0005	1.74	<0.0001	<2	0.668	<0.1	<0.03	<0.01	<0.03	0.009
4	0.116	<0.00005	1.03	<0.02	<0.3	4	0.0008	1.75	<0.0001	<2	0.617	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.107	<0.00005	0.65	<0.02	<0.3	4	0.0007	1.65	<0.0001	<2	0.558	<0.1	<0.03	<0.01	<0.03	<0.005
6																
7																
8	0.081	<0.00005	0.55	<0.02	<0.3	3	<0.0005	1.56	<0.0001	<2	0.518	<0.1	<0.03	<0.01	<0.03	<0.005
9																
10																
11	0.062	<0.00005	0.38	<0.02	<0.3	3	0.0005	1.29	<0.0001	<2	0.411	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	0.058	<0.00005	0.28	<0.02	<0.3	<2	0.0005	1.13	<0.0001	<2	0.370	<0.1	<0.03	<0.01	<0.03	<0.005
15																
16																
17	0.057	<0.00005	0.21	<0.02	<0.3	2	<0.0005	0.94	<0.0001	<2	0.325	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.060	<0.00005	0.2	<0.02	<0.3	2	<0.0005	0.92	<0.0001	<2	0.307	<0.1	<0.03	<0.01	<0.03	<0.005

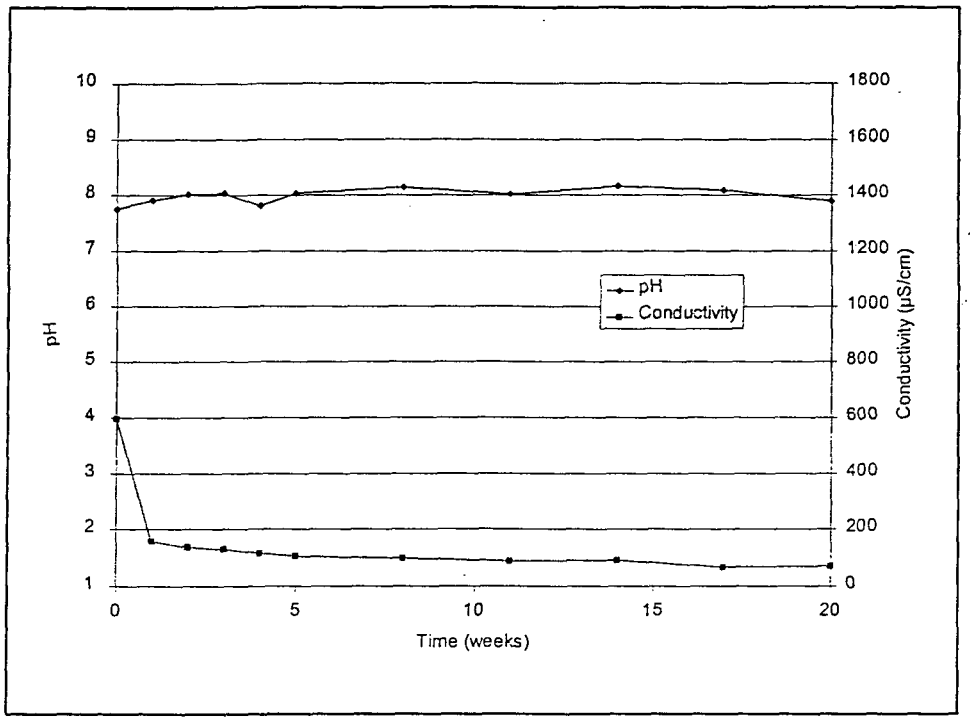
CELL 8
SAMPLE BH1-123

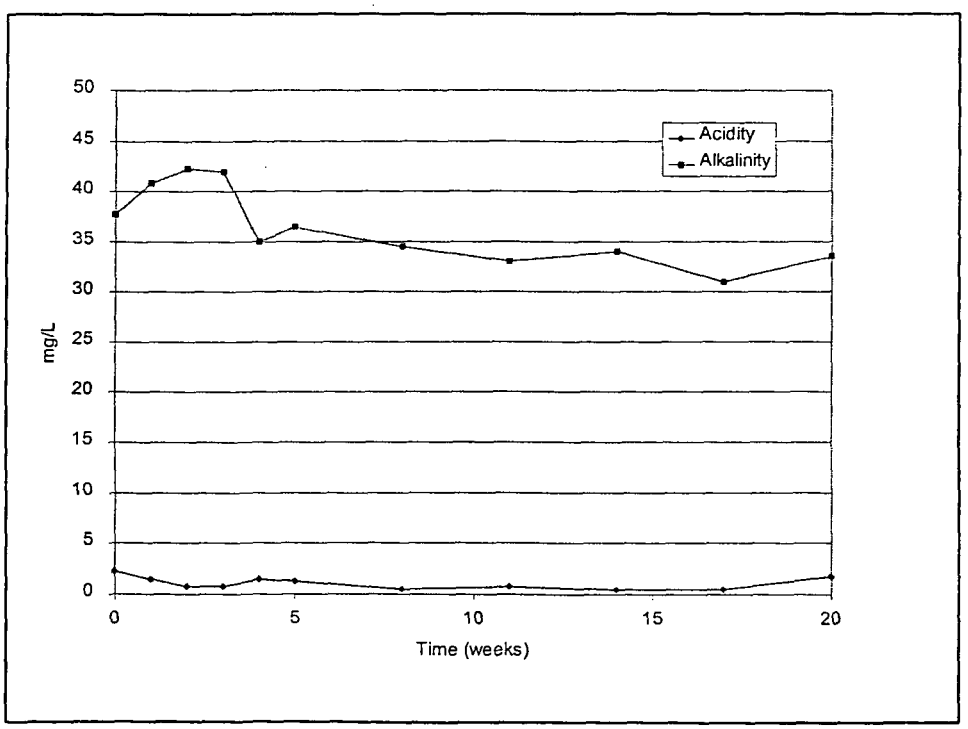
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly cidity (pH=8.3 (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	0.97	367	3.7	61.9	61.9	126.28	19.4	396	396	10.59	19.35	8.38	0.02	0.10
1	0.32	34	3.0	82.3	144.2	37.57	4.2	111	508	5.19	4.18	2.73	0.02	0.03
2	0.22	20	1.5	85.3	229.6	33.53	3.4	98	606	4.18	3.37	1.76	0.02	0.02
3	0.16	14	1.5	83.2	312.7	31.68	2.8	91	697	3.94	2.83	1.74	0.02	0.02
4	0.20	16	3.0	70.0	382.7	29.80	2.4	85	781	3.98	2.40	2.06	0.02	0.005
5	0.11	8	2.5	72.3	455.0	27.52	2.2	78	859	3.31	2.16	1.29	0.02	0.00
6		8	1.4	69.1	524.1				859					
7		8	1.0	69.4	593.5				859					
8	0.13	10	1.0	66.2	659.7	27.07	1.7	75	933	2.92	1.65	1.06	0.02	0.005
9		10	1.0	66.0	725.7				933					
10		12	1.0	66.6	792.4				933					
11	0.15	10	1.5	64.7	857.0	25.09	1.3	68	1001	2.47	1.25	0.74	0.02	0.005
12		8	1.5	62.7	919.8				1001					
13		8	2.5	63.4	983.1				1001					
14	0.12	8	1.0	66.6	1049.8	25.48	1.1	68	1069	2.33	1.06	0.55	0.02	0.005
15		8	1.0	63.0	1112.8				1069					
16		12	1.5	62.0	1174.8				1069					
17	0.18	12	1.0	60.8	1235.5	25.87	0.9	68	1138	2.29	0.88	0.41	0.02	0.005
18		8	2.5	63.7	1299.2				1138					
19		8	2.6	62.4	1361.6				1138					
20	0.14	10	3.6	66.3	1427.9	28.51	0.8	74	1212	0.00	0.75	0.40	0.02	0.005

CELL 8
SAMPLE BH1-123

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	3400	693	190	32	93	16500	0.31	2.79	4.41	0.05	0.11	2.23
1							0.46	3.40	5.85	0.11	0.14	2.43
2							0.59	3.88	6.77	0.18	0.17	2.56
3							0.70	4.29	7.69	0.24	0.19	2.64
4							0.82	4.64	8.77	0.30	0.19	2.74
5							0.92	4.95	9.45	0.36	0.20	2.79
6							0.92	4.95	9.45	0.36	0.20	2.83
7							0.92	4.95	9.45	0.36	0.20	2.88
8							1.00	5.19	10.01	0.42	0.20	2.94
9							1.00	5.19	10.01	0.42	0.20	3.00
10							1.00	5.19	10.01	0.42	0.20	3.07
11							1.08	5.37	10.40	0.49	0.21	3.13
12							1.08	5.37	10.40	0.49	0.21	3.18
13							1.08	5.37	10.40	0.49	0.21	3.23
14							1.14	5.52	10.69	0.55	0.21	3.27
15							1.14	5.52	10.69	0.55	0.21	3.32
16							1.14	5.52	10.69	0.55	0.21	3.40
17							1.21	5.65	10.90	0.61	0.22	3.47
18							1.21	5.65	10.90	0.61	0.22	3.51
19							1.21	5.65	10.90	0.61	0.22	3.56
20							1.21	5.76	11.11	0.67	0.22	3.62

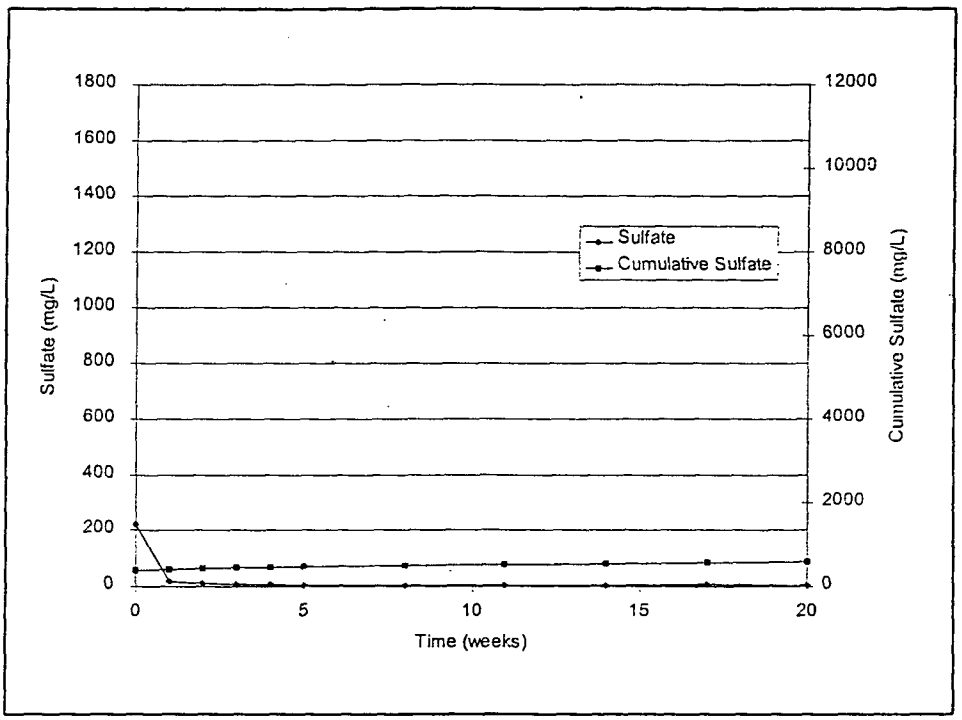
CELL 8 - Sample BH1-123

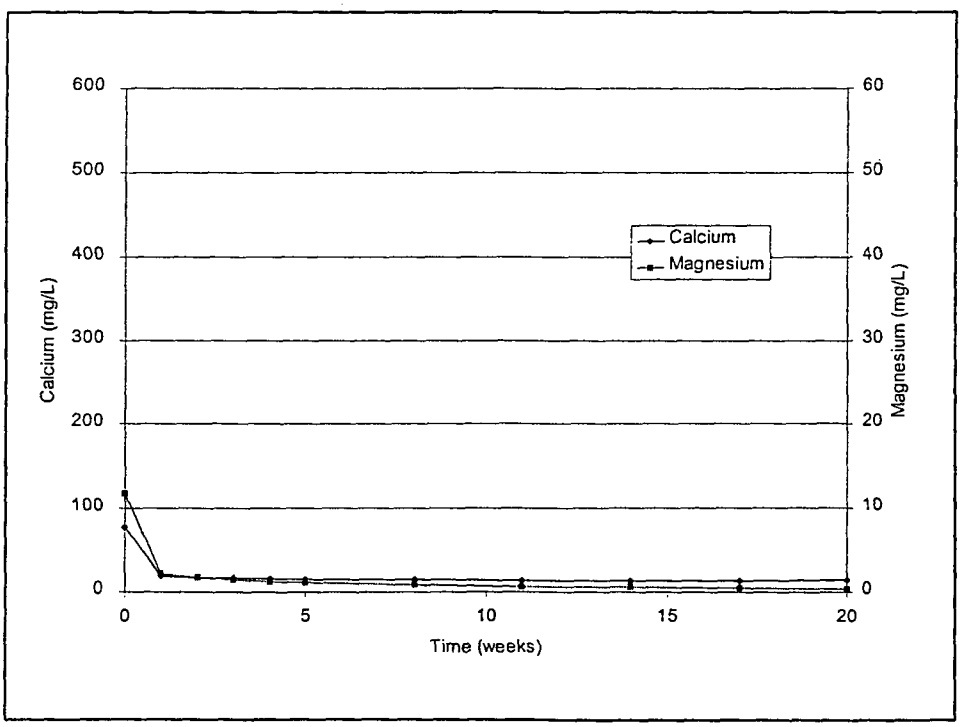




> Potentially non-acid generating, NP/AP >3, andesite

CELL 8 - Sample BH1-123





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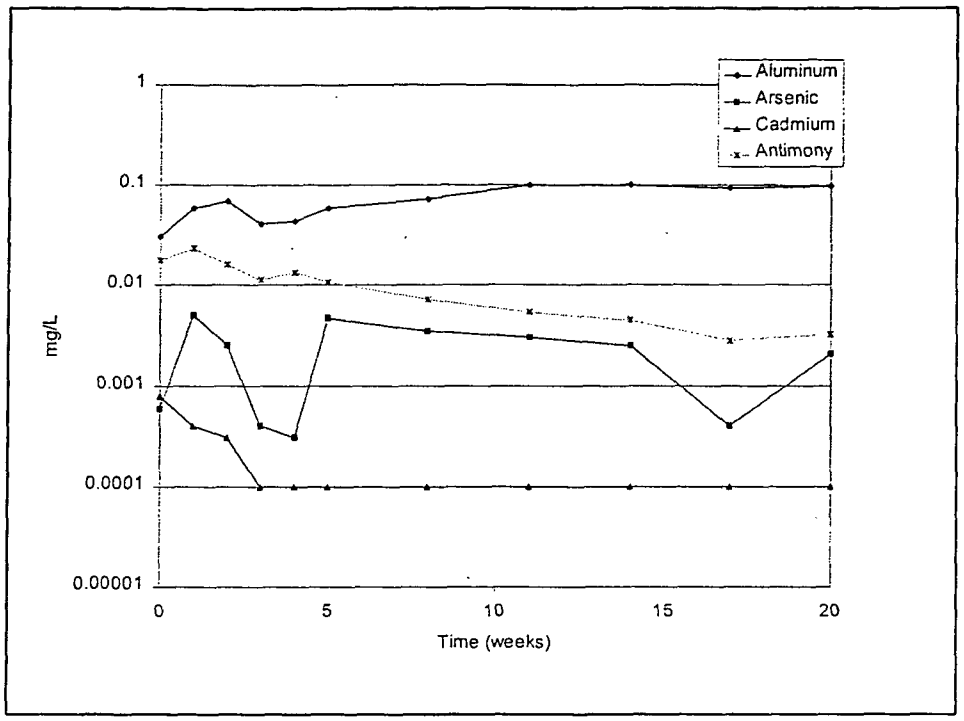
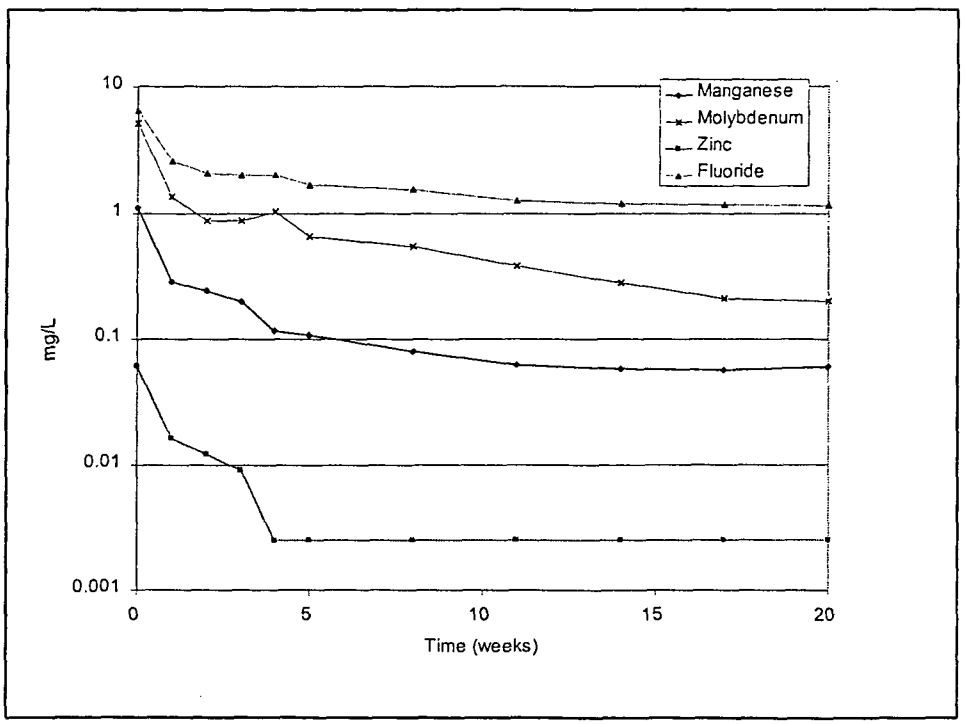
CELL 8 - Sample BH1-123





> Potentially non-acid generating, NP/AP >3, andesite

HUMIDITY CELL #9

Sample BH4-75-80
Slimes – uncertain acid generating potential

pH = 7.20;
Conductivity = 1315 µS;
NP/AP = 2.47;
Deposition year ~ 1979

CELL 9
SAMPLE BH4-75-80

Dry sample weig 0.3 kg

CYCLE	DATE 1997		WATER ADDED VOLUME (L)	pH	LEACHATE COLLECTED (L)	pH	REDOX mV	CONDUCTIVITY (uS/cm)	ALKALINITY (mg CaCO3/L)	ACIDITY (pH 4.5) (mg CaCO3/L)	ACIDITY (pH 8.3) (mg CaCO3/L)	CUMULATIVE ACIDITY (mg CaCO3/kg)	SULPHATE (mg/L)	CUMULATIVE SULPHATE (mg/kg)
0	May	30	0.500	5.65	0.385	7.84	350	1289	38.0	0.0	2.5	3.9	873	1344.4
1	Jun.	3	0.500	5.55	0.500	7.93	334	538	45.8	0.0	2.0	7.9	194	1732.4
2		10	0.500	5.99	0.515	8.12	321	303	57.8	0.0	0.8	9.4	76	1889.0
3		17	0.500	5.70	0.495	8.20	326	210	49.5	0.0	0.5	10.4	38	1964.2
4		24	0.500	5.61	0.480	7.91	348	108	22.5	0.0	1.0	12.3	6	1975.7
5	Jul.	1	0.500	5.58	0.490	7.80	358	72	18.5	0.0	1.0	14.3	8	1991.4
6		8	0.500	5.53	0.495	7.78	362	79	18.8	0.0	1.0	16.2	10	2011.2
7		15	0.500	5.89	0.500	7.82	361	81	17.3	0.0	0.8	17.7	14	2039.2
8		22	0.500	5.60	0.495	7.92	365	78	17.0	0.0	1.0	19.7	12	2063.0
9		29	0.500	5.66	0.490	7.80	355	72	15.0	0.0	0.8	21.2	11	2084.5
10	Aug.	6	0.500	5.58	0.500	7.73	330	68	14.0	0.0	1.0	23.2	10	2104.5
11		12	0.500	5.71	0.500	7.60	358	69	14.5	0.0	1.3	25.7	11	2126.5
12		19	0.500	5.64	0.495	7.70	360	66	13.8	0.0	1.0	27.7	10	2146.3
13		26	0.500	5.81	0.500	7.47	352	68	14.5	0.0	1.5	30.7	10	2166.3
14	Sept.	3	0.500	5.77	0.500	7.71	353	66	13.5	0.0	1.0	32.7	9	2184.3
15		9	0.500	5.86	0.500	7.69	360	57	13.3	0.0	1.0	34.7	8	2200.3
16		16	0.500	5.70	0.505	7.65	351	48	13.3	0.0	1.8	38.2	9	2218.5
17		23	0.500	5.65	0.500	7.64	354	47	13.8	0.0	1.3	40.7	10	2238.5
18		30	0.500	5.85	0.500	7.48	353	44	13.0	0.0	2.0	44.7	8	2254.5
19	Oct.	7	0.500	5.82	0.500	7.53	358	43	12.8	0.0	1.0	46.7	8	2270.5
20		14	0.500	6.05	0.500	7.52	374	45	13.3	0.0	1.3	49.2	8	2286.5

CELL 9
SAMPLE BH4-75-80

CYCLE	ICP ANALYSIS RESULTS FOR LEACHATE																
	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Cr	Co	Cu	F	Fe	Pb	Li	Mg
	(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)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0	0.014	0.0166	0.0008	0.04	<0.005	<0.1	<0.1	0.0007	277	<0.01	<0.01	0.02	3.63	<0.01	<0.05	0.02	22.8
1	0.022	0.0145	0.0032	0.02	<0.005	<0.1	<0.1	0.0004	88.5	<0.01	<0.01	<0.01	1.85	<0.03	<0.05	<0.01	5.47
2	0.026	0.0106	0.0029	0.03	<0.005	<0.1	<0.1	0.0002	44.2	<0.01	<0.01	<0.01	1.70	<0.03	<0.05	<0.01	2.37
3	0.027	0.0061	0.0007	0.04	<0.005	<0.1	<0.1	<0.0002	28.5	<0.01	<0.01	<0.01	1.37	<0.03	<0.05	<0.01	1.43
4	0.044	0.0026	0.0001	0.01	<0.005	<0.1	<0.1	<0.0002	8.38	<0.01	<0.01	<0.01	0.28	<0.03	<0.05	<0.01	0.31
5	0.045	0.0031	0.0039	0.01	<0.005	<0.1	<0.1	<0.0002	9.63	<0.01	<0.01	<0.01	0.32	<0.03	<0.05	<0.01	0.39
6																	
7																	
8	0.039	0.0024	0.0031	0.01	<0.005	<0.1	<0.1	<0.0002	10.6	<0.01	<0.01	<0.01	0.34	<0.03	<0.05	<0.01	0.39
9																	
10																	
11	0.036	0.0022	0.0029	<0.01	<0.005	<0.1	<0.1	<0.0002	9.33	<0.01	<0.01	<0.01	0.33	<0.03	<0.05	<0.01	0.35
12																	
13																	
14	0.030	0.0019	0.0024	0.02	<0.005	<0.1	<0.1	<0.0002	18	<0.01	<0.01	<0.01	0.31	<0.03	<0.05	<0.01	1.09
15																	
16																	
17	0.021	0.0015	<0.0002	<0.01	<0.005	<0.1	<0.1	<0.0002	8.21	<0.01	<0.01	<0.01	0.30	<0.03	<0.05	<0.01	0.30
18												0.002			<0.001		
19												0.001			<0.001		
20	0.019	0.0018	0.002	0.01	<0.005	<0.1	<0.1	<0.0002	8.10	<0.01	<0.01	<0.01	0.32	<0.03	<0.05	<0.01	0.28

CELL 9
SAMPLE BH4-75-80

CYCLE	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	K (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)	Na (mg/L)	Sr (mg/L)	Tl (mg/L)	Sn (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
0	0.561	<0.00005	4.57	<0.02	<0.3	36	0.0005	4.54	0.0002	39	6.63	<0.1	<0.03	<0.01	<0.03	0.073
1	0.240	<0.00005	1.13	<0.02	<0.3	13	0.0005	3.66	<0.0001	5	2.22	<0.1	<0.03	<0.01	<0.03	0.013
2	0.155	<0.00005	0.70	<0.02	<0.3	9	<0.0005	3.73	<0.0001	<2	1.38	<0.1	<0.03	<0.01	<0.03	0.005
3	0.088	<0.00005	0.52	<0.02	<0.3	7	0.0007	3.26	<0.0001	<2	0.963	<0.1	<0.03	<0.01	<0.03	0.006
4	0.061	<0.00005	0.11	<0.02	<0.3	<2	<0.0005	0.59	<0.0001	<2	0.223	<0.1	<0.03	<0.01	<0.03	<0.005
5	0.045	<0.00005	0.09	<0.02	<0.3	<2	<0.0005	0.76	<0.0001	<2	0.284	<0.1	<0.03	<0.01	<0.03	<0.005
6																
7																
8	0.053	<0.00005	0.17	<0.02	<0.3	2	<0.0005	0.79	<0.0001	<2	0.313	<0.1	<0.03	<0.01	<0.03	<0.005
9																
10																
11	0.045	<0.00005	0.21	<0.02	<0.3	<2	<0.0005	0.69	<0.0001	<2	0.265	<0.1	<0.03	<0.01	<0.03	<0.005
12																
13																
14	<0.005	<0.00005	<0.03	<0.02	<0.3	3	<0.0005	5.71	<0.0001	<2	0.195	<0.1	<0.03	<0.01	<0.03	0.018
15																
16																
17	0.040	<0.00005	0.36	<0.02	<0.3	<2	<0.0005	0.57	<0.0001	<2	0.229	<0.1	<0.03	<0.01	<0.03	<0.005
18																
19																
20	0.039	<0.00005	0.47	<0.02	<0.3	<2	<0.0005	0.60	<0.0001	<2	0.217	<0.1	<0.03	<0.01	<0.03	<0.005

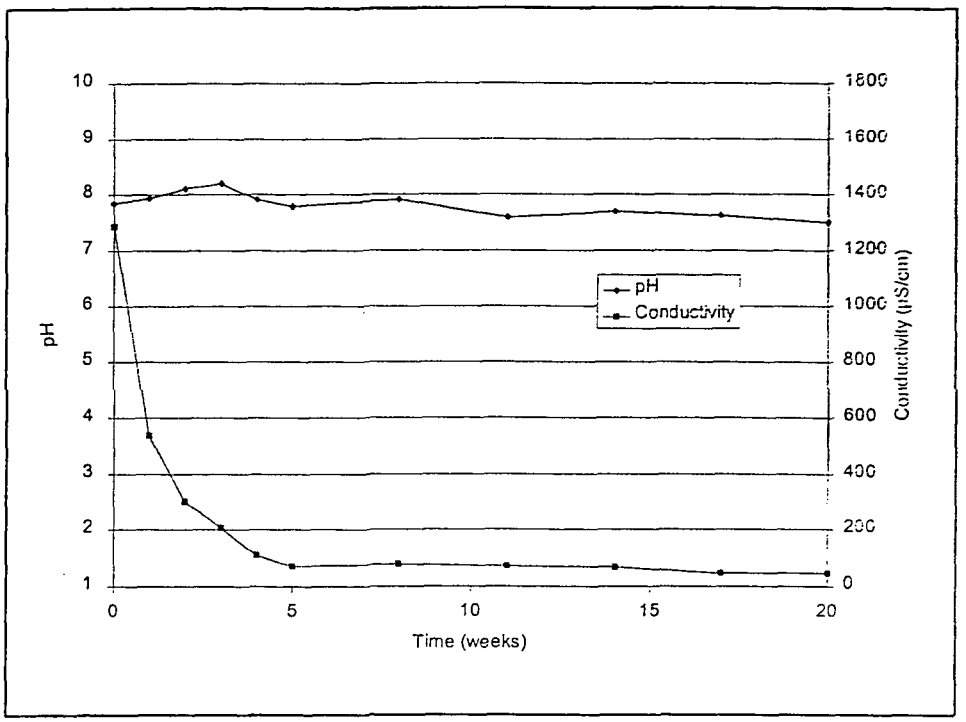
CELL 9
SAMPLE BH4-75-80

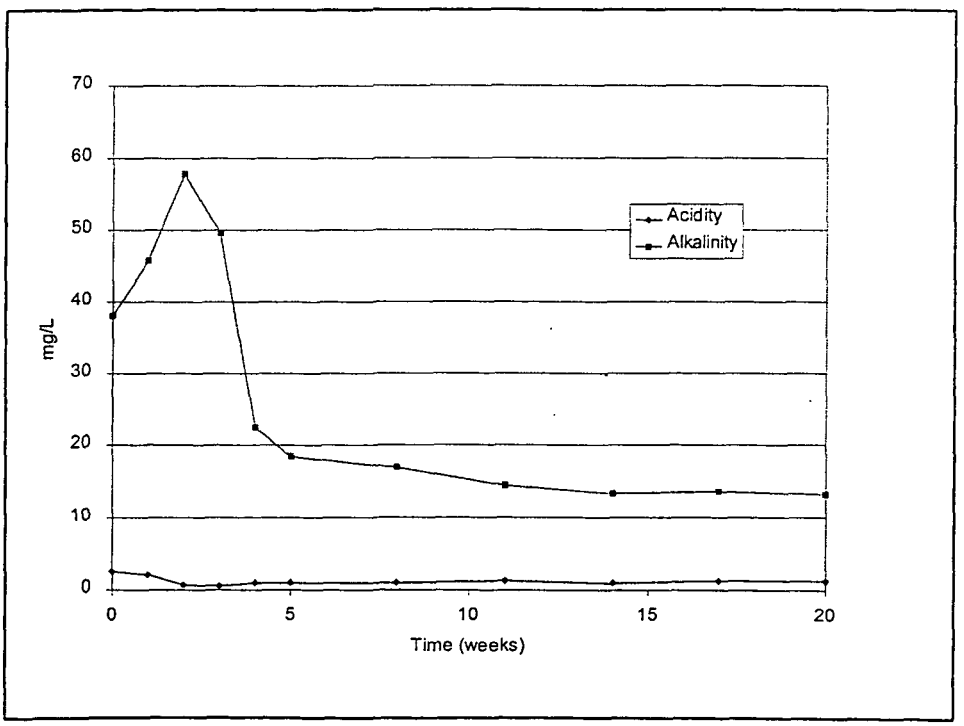
CYCLE	CALCULATIONS													
						Ca/Mg Equivalent Alklinity Release				Weekly Release Rates				
	SO4/ Ca+Mg (molar)	Weekly Sulfate (mg/kg/wk)	Weekly Acidity (pH=8.3) (mg/kg/wk)	Weekly Alkalinity (mg/kg/wk)	Cumulative NP Eq. leached	Ca (mg/kg)	Mg (mg/kg)	CaCO3 eq (mg/kg)	Cumulative NP Eq. leached	F (mg/kg/wk)	Mn (mg/kg/wk)	Mo (mg/kg/wk)	Ni (mg/kg/wk)	Zn (mg/kg/wk)
0	1.16	1344	3.9	58.5	58.5	426.58	35.1	1213	1213	5.59	35.11	7.04	0.02	0.11
1	0.83	388	4.0	91.5	150.0	177.00	10.9	488	1701	3.70	10.94	2.26	0.02	0.03
2	0.66	157	1.5	119.0	269.0	91.05	4.9	248	1949	3.50	4.88	1.44	0.02	0.01
3	0.51	75	1.0	98.0	367.0	56.43	2.8	153	2102	2.71	2.83	1.03	0.02	0.01
4	0.28	12	1.9	43.2	410.2	16.09	0.6	43	2144	0.54	0.60	0.21	0.02	0.005
5	0.33	16	2.0	36.3	446.5	18.87	0.8	50	2195	0.63	0.76	0.18	0.02	0.00
6		20	2.0	37.1	483.6				2195					
7		28	1.5	34.5	518.1				2195					
8	0.45	24	2.0	33.7	551.7	20.99	0.8	56	2250	0.67	0.77	0.34	0.02	0.005
9		22	1.5	29.4	581.1				2250					
10		20	2.0	28.0	609.1				2250					
11	0.46	22	2.5	29.0	638.1	18.66	0.7	50	2300	0.66	0.70	0.42	0.02	0.005
12		20	2.0	27.2	665.4				2300					
13		20	3.0	29.0	694.4				2300					
14	0.19	18	2.0	27.0	721.4	36.00	2.2	99	2399	0.62	2.18	0.03	0.02	0.036
15		16	2.0	26.5	747.9				2399					
16		18	3.5	26.8	774.6				2399					
17	0.48	20	2.5	27.5	802.1	16.42	0.6	44	2443	0.60	0.60	0.72	0.02	0.005
18		16	4.0	26.0	828.1				2443					
19		16	2.0	25.6	853.7				2443					
20	0.39	16	2.6	26.6	880.3	16.20	0.6	43	2485	0.00	0.56	0.94	0.02	0.005

CELL 9
SAMPLE BH4-75-80

CYCLE	INITIAL SOLIDS ANALYSIS RESULTS						CUMULATIVE PERCENT LEACHED					
	F (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	S (as SO4 eq.) (mg/kg)	F (%)	Mn (%)	Mo (%)	Ni (%)	Zn (%)	S (as SO4 eq.) (%)
0	3400	800	292	30	175	18300	0.16	4.39	2.41	0.05	0.06	7.3
1							0.27	5.76	3.18	0.12	0.08	9.5
2							0.38	6.37	3.68	0.19	0.08	10.3
3							0.46	6.72	4.03	0.25	0.09	10.7
4							0.47	6.80	4.10	0.32	0.09	10.8
5							0.49	6.89	4.16	0.38	0.10	10.9
6							0.49	6.89	4.16	0.38	0.10	11.0
7							0.49	6.89	4.16	0.38	0.10	11.1
8							0.51	6.99	4.28	0.45	0.10	11.3
9							0.51	6.99	4.28	0.45	0.10	11.4
10							0.51	6.99	4.28	0.45	0.10	11.5
11							0.53	7.07	4.42	0.51	0.10	11.6
12							0.53	7.07	4.42	0.51	0.10	11.7
13							0.53	7.07	4.42	0.51	0.10	11.8
14							0.55	7.35	4.43	0.58	0.12	11.9
15							0.55	7.35	4.43	0.58	0.12	12.0
16							0.55	7.35	4.43	0.58	0.12	12.1
17							0.57	7.42	4.68	0.65	0.13	12.2
18							0.57	7.42	4.68	0.65	0.13	12.3
19							0.57	7.42	4.68	0.65	0.13	12.4
20							0.57	7.49	5.00	0.71	0.13	12.5

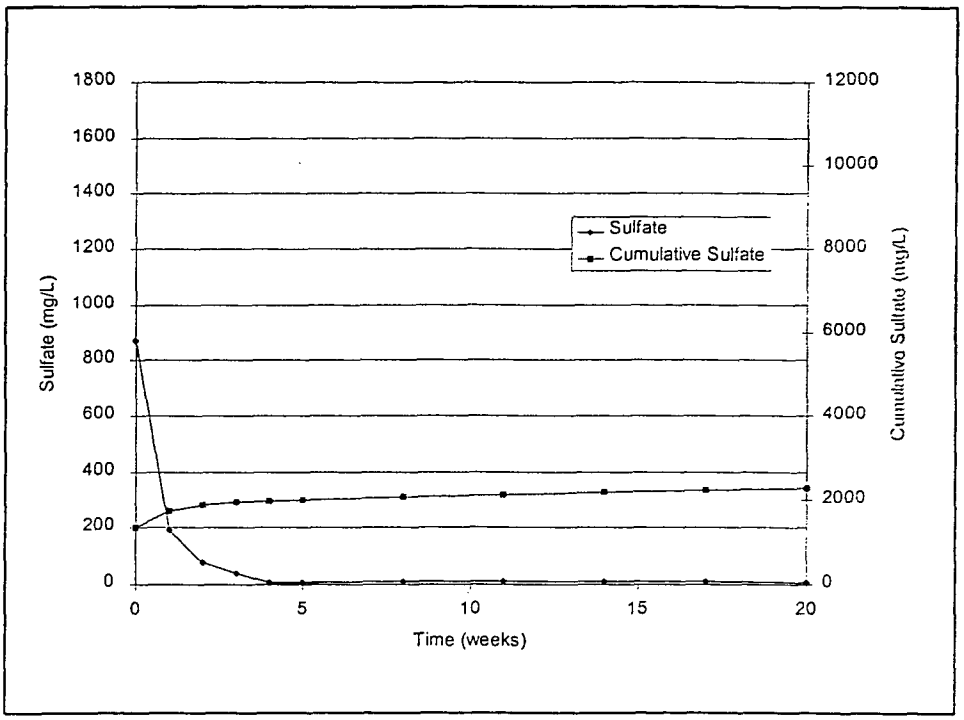
CELL 9 - Sample BH4-75-80

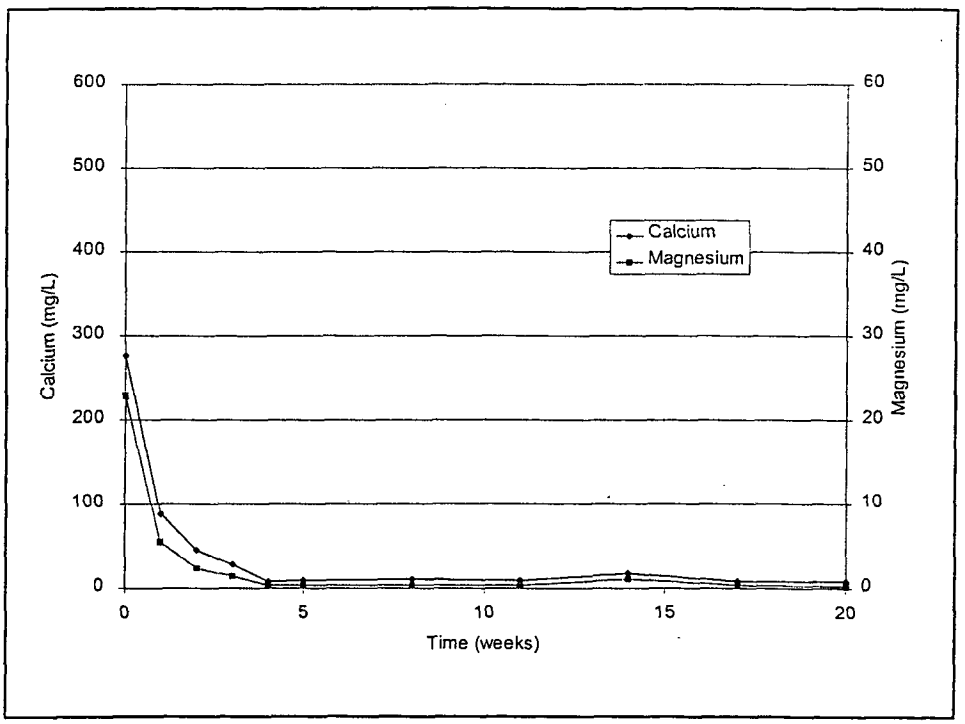




> *Tailings slimes*

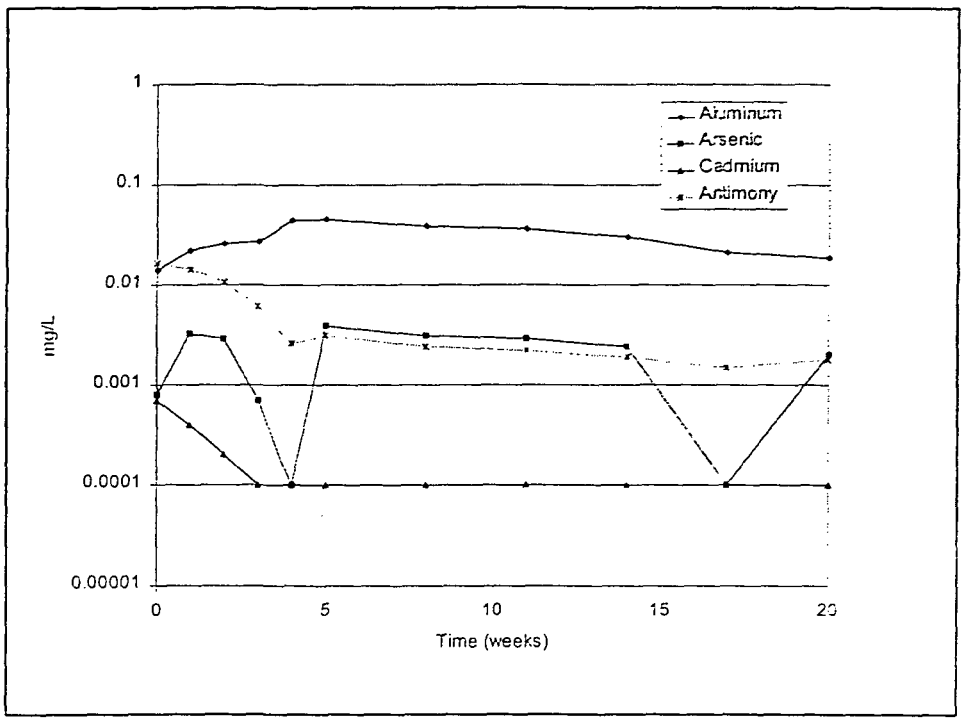
CELL 9 - Sample BH4-75-80

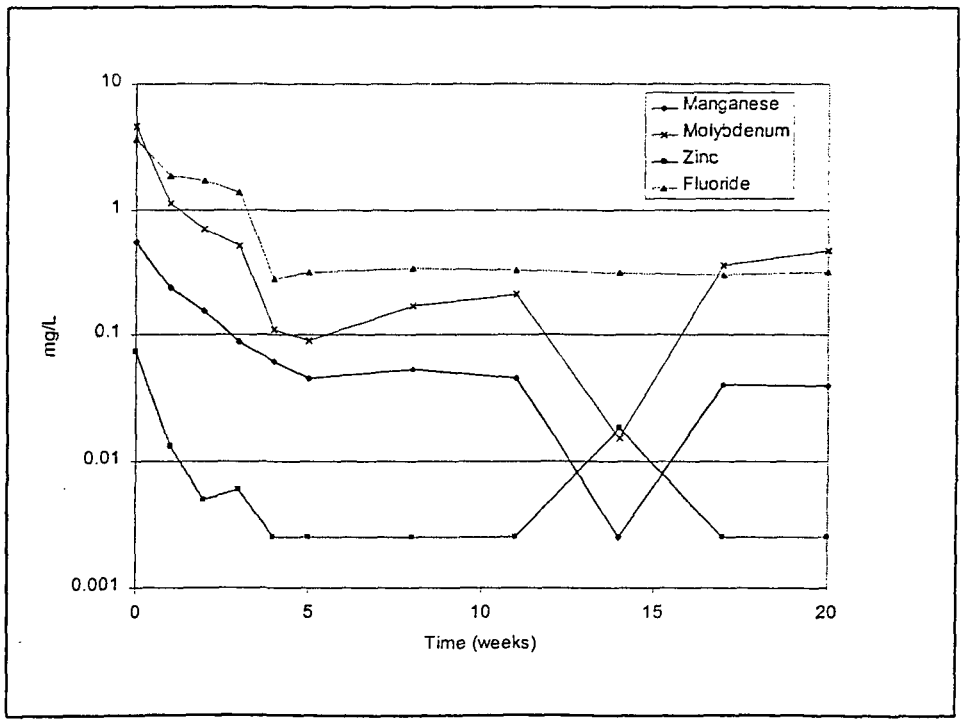




> *Tailings slimes*

CELL 9 - Sample BH4-75-80





> Tailings slimes

APPENDIX E

EXAMPLE OF MINTEQA2 CALCULATIONS FROM THE LEACH EXTRACTION RESULTS

Sample T-24B

PART 1 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 14:48: 9

LEACH EXTRACTION RESULTS FOR SAMPLE NO. T-24B
EPA 1312 method modified using MWMT leach reagent, 1:1 solid:liqui

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Temperature (Celsius): 20.00
Units of concentration: PPM
Ionic strength to be computed.
If specified, carbonate concentration represents total inorganic carbon.
Do not automatically terminate if charge imbalance exceeds 30%
Precipitation is allowed only for those solids specified as ALLOWED
in the input file (if any).
The maximum number of iterations is: 100
The method used to compute activity coefficients is: Davies equation
Intermediate output file

330	0.000E-01	-7.10	y
1	0.000E-01	-6.02	y
30	3.000E-02	-4.83	y
100	1.800E-02	-6.23	y
150	5.530E+02	-1.86	y
231	2.000E-02	-6.50	y
460	4.340E+01	-2.64	y
470	4.050E+00	-3.70	y
480	2.250E+00	-5.74	y
410	9.600E+00	-3.59	y
762	7.000E-03	-7.60	y
500	2.600E+00	-4.06	y
800	2.650E+00	-4.49	y
950	1.600E-01	-4.54	y
732	1.660E+03	-2.68	y
60	1.700E-03	-8.40	y
540	4.000E-02	-5.43	y
160	1.000E-02	-7.05	y
210	1.000E-02	-6.72	
280	1.000E-02	-6.75	y
600	5.000E-02	-6.62	y
61	0.000E-01	-21.15	
471	0.000E-01	-20.74	y
270	9.000E+00	-3.32	y
140	4.200E+01	-3.15	y
281	0.000E-01	-20.75	

H2O has been inserted as a COMPONENT

3 5		
600610	19.4440	-30.0150
4704710	25.5070	25.7600
2802810	13.0320	-10.0000
330	7.1000	0.0000

1 6.0175 0.0000

INPUT DATA BEFORE TYPE MODIFICATIONS

ID	NAME	ACTIVITY GUESS	LOG GUESS	ANAL TOTAL
330	H+1	7.943E-08	-7.100	0.000E-01
1	E-1	9.550E-07	-6.020	0.000E-01
30	Al+3	1.479E-05	-4.830	3.000E-02
100	Ba+2	5.888E-07	-6.230	1.800E-02
150	Ca+2	1.380E-02	-1.860	5.530E+02
231	Cu+2	3.162E-07	-6.500	2.000E-02
460	Mg+2	2.291E-03	-2.640	4.340E+01
470	Mn+2	1.995E-04	-3.700	4.050E+00
480	MoO4-2	1.820E-06	-5.740	2.250E+00
410	K+1	2.570E-04	-3.590	9.600E+00
762	SeO4-2	2.512E-08	-7.600	7.000E-03
500	Na+1	8.710E-05	-4.060	2.600E+00
800	Sr+2	3.236E-05	-4.490	2.650E+00
950	Zn+2	2.884E-05	-4.540	1.600E-01
732	SO4-2	2.089E-03	-2.680	1.660E+03
60	H3AsO3	3.981E-09	-8.400	1.700E-03
540	Ni+2	3.715E-06	-5.430	4.000E-02
160	Cd+2	8.913E-08	-7.050	1.000E-02
210	Cr+2	1.905E-07	-6.720	1.000E-02
280	Fe+2	1.778E-07	-6.750	1.000E-02
600	Pb+2	2.399E-07	-6.620	5.000E-02
61	H3AsO4	7.079E-22	-21.150	0.000E-01
471	Mn+3	1.820E-21	-20.740	0.000E-01
270	F-1	4.786E-04	-3.320	9.000E+00
140	CO3-2	7.079E-04	-3.150	4.200E+01
281	Fe+3	1.778E-21	-20.750	0.000E-01
2	H2O	1.000E+00	0.000	0.000E-01

Charge Balance: UNSPECIATED

Sum of CATIONS= 3.182E-02 Sum of ANIONS = 3.655E-02

PERCENT DIFFERENCE = 6.919E+00 (ANIONS - CATIONS)/(ANIONS + CATIONS)

IMPROVED ACTIVITY GUESSES PRIOR TO FIRST ITERATION:

Al+3	Log activity guess:	-11.40
Cu+2	Log activity guess:	-6.55
Mn+2	Log activity guess:	-4.13
SeO4-2	Log activity guess:	-7.31
SO4-2	Log activity guess:	-1.76
H3AsO3	Log activity guess:	-19.66
Fe+2	Log activity guess:	-8.22
H3AsO4	Log activity guess:	-13.25
Mn+3	Log activity guess:	-23.30
CO3-2	Log activity guess:	-6.50
Fe+3	Log activity guess:	-15.36

PART 3 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 14:48:10

PARAMETERS OF THE COMPONENT MOST OUT OF BALANCE:

ITER	NAME	TOTAL MOL	DIFF FXN	LOG ACTVTY	RESIDUAL
0	Pb+2	2.419E-07	4.025E-06	-6.62000	4.025E-06
1	Pb+2	2.419E-07	8.103E-07	-7.08799	8.103E-07
2	Pb+2	2.419E-07	1.016E-07	-7.57031	1.016E-07
3	Pb+2	2.419E-07	1.347E-08	-7.63478	1.345E-08
4	Pb+2	2.419E-07	6.880E-10	-7.64260	6.639E-10
5	Pb+2	2.419E-07	4.977E-11	-7.64251	2.558E-11
6	Cr+2	1.928E-07	2.496E-11	-7.05060	5.676E-12

ID	NAME	ANAL MOL	CALC MOL	LOG ACTVTY	GAMMA	DIFF FXN
270	F-1	4.748E-04	4.422E-04	-3.43827	0.824276	2.095E-09
140	CO3-2	7.015E-04	5.575E-07	-6.58943	0.461626	2.692E-09
30	Al+3	1.114E-06	9.598E-13	-12.77315	0.175652	7.815E-13
100	Ba+2	1.314E-07	1.314E-07	-7.21721	0.461626	2.332E-12
150	Ca+2	1.383E-02	9.193E-03	-2.37224	0.461626	1.604E-07
231	Cu+2	3.155E-07	8.223E-08	-7.42066	0.461626	1.387E-12
460	Mg+2	1.789E-03	1.232E-03	-3.24514	0.461626	2.160E-08
470	Mn+2	7.389E-05	5.117E-05	-4.62668	0.461626	8.952E-10
480	MoO4-2	1.410E-05	1.410E-05	-5.18646	0.461626	2.503E-10
410	K+1	2.461E-04	2.375E-04	-3.70823	0.824276	1.092E-09
762	SeO4-2	4.908E-08	4.895E-08	-7.64595	0.461626	8.689E-13
500	Na+1	1.134E-04	1.103E-04	-4.04124	0.824276	5.029E-10
800	Sr+2	3.031E-05	3.032E-05	-4.85405	0.461626	5.381E-10
950	Zn+2	2.453E-06	1.444E-06	-6.17607	0.461626	2.685E-11
732	SO4-2	1.732E-02	1.215E-02	-2.25118	0.461626	2.124E-07
60	H3AsO3	1.353E-08	1.160E-20	-19.93101	1.010664	2.030E-13
540	Ni+2	6.829E-07	2.858E-07	-6.87961	0.461626	4.877E-12
160	Cd+2	8.918E-08	4.752E-08	-7.65887	0.461626	9.110E-13
210	Cr+2	1.928E-07	1.928E-07	-7.05066	0.461626	3.422E-12
280	Fe+2	1.795E-07	1.051E-08	-8.31421	0.461626	8.261E-13
600	Pb+2	2.419E-07	4.934E-08	-7.64248	0.461626	9.179E-13
61	H3AsO4	0.000E-01	3.019E-14	-13.51550	1.010664	0.000E-01
1	E-1	0.000E-01	1.917E-07	-6.01750	0.824276	0.000E-01
330	H+1	0.000E-01	9.637E-08	-7.10000	0.824276	0.000E-01
2	H2O	0.000E-01	-9.300E-07	-0.00026	1.000000	0.000E-01
471	Mn+3	0.000E-01	9.145E-24	-23.79415	0.175652	0.000E-01
281	Fe+3	0.000E-01	2.003E-15	-15.45372	0.175652	0.000E-01

Type I - COMPONENTS AS SPECIES IN SOLUTION

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
330	H+1	9.637E-08	7.943E-08	-7.10000	0.82428	0.084
281	Fe+3	2.003E-15	3.518E-16	-15.45372	0.17565	0.755
30	Al+3	9.598E-13	1.686E-13	-12.77315	0.17565	0.755

100	Ba+2	1.314E-07	6.064E-08	-7.21721	0.46163	0.336
150	Ca+2	9.193E-03	4.244E-03	-2.37224	0.46163	0.336
231	Cu+2	8.223E-08	3.796E-08	-7.42066	0.46163	0.336
460	Mg+2	1.232E-03	5.687E-04	-3.24514	0.46163	0.336
470	Mn+2	5.117E-05	2.362E-05	-4.62668	0.46163	0.336
480	MoO4-2	1.410E-05	6.509E-06	-5.18646	0.46163	0.336
410	K+1	2.375E-04	1.958E-04	-3.70823	0.82428	0.084
762	SeO4-2	4.895E-08	2.260E-08	-7.64595	0.46163	0.336
500	Na+1	1.103E-04	9.094E-05	-4.04124	0.82428	0.084
800	Sr+2	3.032E-05	1.399E-05	-4.85405	0.46163	0.336
950	Zn+2	1.444E-06	6.667E-07	-6.17607	0.46163	0.336
732	SO4-2	1.215E-02	5.608E-03	-2.25118	0.46163	0.336
60	H3AsO3	1.160E-20	1.172E-20	-19.93101	1.01066	-0.005
540	Ni+2	2.858E-07	1.319E-07	-6.87961	0.46163	0.336
160	Cd+2	4.752E-08	2.193E-08	-7.65887	0.46163	0.336
210	Cr+2	1.928E-07	8.899E-08	-7.05066	0.46163	0.336
280	Fe+2	1.051E-08	4.851E-09	-8.31421	0.46163	0.336
600	Pb+2	4.934E-08	2.278E-08	-7.64248	0.46163	0.336
61	H3AsO4	3.019E-14	3.051E-14	-13.51550	1.01066	-0.005
471	Mn+3	9.145E-24	1.606E-24	-23.79415	0.17565	0.755
270	F-1	4.422E-04	3.645E-04	-3.43827	0.82428	0.084
140	CO3-2	5.575E-07	2.574E-07	-6.58943	0.46163	0.336

Type II - OTHER SPECIES IN SOLUTION OR ADSORBED

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
1607620	CdSeO4	8.552E-14	8.643E-14	-13.06332	1.01066	2.237
9507620	ZnSeO4	2.373E-12	2.398E-12	-11.62012	1.01066	2.197
9507621	Zn(SeO4)2-2	6.271E-22	2.895E-22	-21.53837	0.46163	0.265
3300020	OH-	1.044E-07	8.608E-08	-7.06509	0.82428	-14.081
4603300	MgOH +	9.160E-09	7.550E-09	-8.12203	0.82428	-11.893
4602700	MgF +	1.452E-05	1.197E-05	-4.92185	0.82428	1.845
4601400	MgCO3 AQ	1.280E-07	1.294E-07	-6.88819	1.01066	2.942
4601401	MgHCO3 +	3.792E-06	3.126E-06	-5.50504	0.82428	11.513
4607320	MgSO4 AQ	5.390E-04	5.447E-04	-3.26382	1.01066	2.228
1503300	CaOH +	1.076E-08	8.867E-09	-8.05221	0.82428	-12.696
1501400	CaHCO3 +	2.228E-05	1.837E-05	-4.73601	0.82428	11.410
1501401	CaCO3 AQ	1.383E-06	1.398E-06	-5.85458	1.01066	3.102
1507320	CaSO4 AQ	4.598E-03	4.647E-03	-2.33280	1.01066	2.286
1502700	CaF +	1.465E-05	1.208E-05	-4.91799	0.82428	0.976
5001400	NaCO3 -	4.072E-10	3.357E-10	-9.47407	0.82428	1.241
5001401	NaHCO3 AQ	2.212E-08	2.235E-08	-7.65067	1.01066	10.075
5007320	NaSO4 -	3.003E-06	2.475E-06	-5.60643	0.82428	0.770
5002700	NaF AQ	5.320E-09	5.376E-09	-8.26951	1.01066	-0.795
4107320	KSO4 -	8.566E-06	7.061E-06	-5.15113	0.82428	0.892
303300	AlOH +2	3.339E-11	1.541E-11	-10.81216	0.46163	-4.803
303301	Al(OH)2 +	2.572E-09	2.120E-09	-8.67366	0.82428	-10.016
303302	Al(OH)4 -	1.442E-08	1.189E-08	-7.92498	0.82428	-23.467
302700	AlF +2	1.362E-09	6.289E-10	-9.20142	0.46163	7.346
302701	AlF2 +	8.594E-08	7.084E-08	-7.14972	0.82428	12.584
302702	AlF3 AQ	7.874E-07	7.958E-07	-6.09921	1.01066	16.984
302703	AlF4 -	1.895E-07	1.562E-07	-6.80623	0.82428	19.804

307320	AlSO4 +	1.129E-12	9.307E-13	-12.03121	0.82428	3.077
307321	Al(SO4)2 -	4.931E-13	4.064E-13	-12.39102	0.82428	4.968
303303	Al(OH)3 AQ	3.323E-08	3.358E-08	-7.47391	1.01066	-16.005
2803300	FeOH +	1.601E-11	1.320E-11	-10.87947	0.82428	-9.581
2803301	FeOH3 -1	4.900E-19	4.039E-19	-18.39377	0.82428	-31.295
2807320	FeSO4 AQ	4.361E-09	4.408E-09	-8.35577	1.01066	2.205
2803302	FeOH2 AQ	8.986E-16	9.082E-16	-15.04182	1.01066	-20.932
2813300	FeOH +2	4.589E-11	2.118E-11	-10.67398	0.46163	-1.984
2817320	FeSO4 +	1.779E-14	1.466E-14	-13.83379	0.82428	3.955
2813301	FeOH2 +	1.444E-07	1.191E-07	-6.92423	0.82428	-5.586
2813302	FeOH3 AQ	1.741E-08	1.760E-08	-7.75449	1.01066	-13.605
2813303	FeOH4 -	2.686E-09	2.214E-09	-8.65474	0.82428	-21.516
2812700	FeF +2	4.064E-13	1.876E-13	-12.72673	0.46163	6.501
2812701	FeF2 +	3.116E-12	2.569E-12	-11.59027	0.82428	10.824
2812702	FeF3 AQ	1.443E-12	1.459E-12	-11.83603	1.01066	13.928
2817321	Fe(SO4)2 -	3.093E-15	2.549E-15	-14.59360	0.82428	5.446
2813304	Fe2(OH)2+4	3.282E-19	1.490E-20	-19.82672	0.04541	-1.776
2813305	Fe3(OH)4+5	4.542E-23	3.623E-25	-24.44095	0.00798	-4.381
8003300	SrOH +	9.341E-12	7.700E-12	-11.11351	0.82428	-13.275
1003300	BaOH +	2.629E-14	2.167E-14	-13.66418	0.82428	-13.463
4703300	MnOH +	6.123E-09	5.047E-09	-8.29695	0.82428	-10.686
4703301	Mn(OH)3 -1	9.046E-19	7.457E-19	-18.12745	0.82428	-34.716
4700020	MnO4 -	2.050E-48	1.690E-48	-47.77221	0.82428	-129.948
4700021	MnO4 -2	1.830E-44	8.449E-45	-44.07317	0.46163	-119.980
4702700	MnF +	7.396E-08	6.096E-08	-7.21495	0.82428	0.934
4707320	MnSO4 AQ	2.241E-05	2.265E-05	-4.64500	1.01066	2.228
4701400	MnHCO3 +	2.332E-07	1.923E-07	-6.71611	0.82428	11.684
2311400	CuCO3 AQ	5.192E-08	5.247E-08	-7.28009	1.01066	6.725
2311401	Cu(CO3)2-2	3.683E-11	1.700E-11	-10.76952	0.46163	10.166
2312700	CuF +	2.916E-10	2.403E-10	-9.61918	0.82428	1.324
2313300	CuOH +	5.794E-09	4.776E-09	-8.32091	0.82428	-7.916
2313301	Cu(OH)2 AQ	1.242E-07	1.256E-07	-6.90117	1.01066	-13.685
2313302	Cu(OH)3 -	1.157E-13	9.541E-14	-13.02042	0.82428	-26.815
2313303	Cu(OH)4 -2	5.176E-19	2.390E-19	-18.62168	0.46163	-39.264
2313304	Cu2(OH)2+2	1.307E-11	6.031E-12	-11.21960	0.46163	-10.242
2317320	CuSO4 AQ	4.152E-08	4.197E-08	-7.37709	1.01066	2.290
2311402	CuHCO3 +	9.415E-09	7.761E-09	-8.11009	0.82428	13.084
9502700	ZnF +	3.907E-09	3.220E-09	-8.49210	0.82428	1.206
9503300	ZnOH +	7.587E-09	6.254E-09	-8.20384	0.82428	-9.044
9503301	Zn(OH)2 AQ	1.318E-09	1.332E-09	-8.87558	1.01066	-16.904
9503302	Zn(OH)3 -	6.428E-14	5.299E-14	-13.27584	0.82428	-28.315
9503303	Zn(OH)4 -2	2.289E-19	1.057E-19	-18.97610	0.46163	-40.863
9507320	ZnSO4 AQ	8.339E-07	8.428E-07	-6.07426	1.01066	2.348
9507321	Zn(SO4)2-2	8.655E-08	3.995E-08	-7.39844	0.46163	3.616
9501400	ZnHCO3 +	4.154E-08	3.424E-08	-7.46550	0.82428	12.484
9501401	ZnCO3 AQ	3.388E-08	3.424E-08	-7.46550	1.01066	5.295
9501402	Zn(CO3)2-2	4.081E-10	1.884E-10	-9.72493	0.46163	9.966
1602700	CdF +	1.221E-10	1.007E-10	-9.99714	0.82428	1.184
1602701	CdF2 AQ	9.120E-14	9.217E-14	-13.03542	1.01066	1.495
1601400	Cd(CO3)3-4	1.367E-20	6.206E-22	-21.20716	0.04541	7.563
1603300	CdOH +	1.910E-11	1.574E-11	-10.80290	0.82428	-10.160
1603301	Cd(OH)2 AQ	1.535E-14	1.551E-14	-13.80938	1.01066	-20.355
1603302	Cd(OH)3 -	2.656E-20	2.190E-20	-19.65964	0.82428	-33.216
1603303	Cd(OH)4 -2	5.319E-27	2.455E-27	-26.60990	0.46163	-47.014

1603304	Cd2OH +3	1.026E-17	1.802E-18	-17.74426	0.17565	-8.771
1607320	CdSO4 AQ	3.403E-08	3.439E-08	-7.46356	1.01066	2.442
1601400	CdHCO3 +	1.367E-09	1.126E-09	-8.94830	0.82428	12.484
1601401	CdCO3 AQ	1.400E-09	1.415E-09	-8.84930	1.01066	5.394
1607321	Cd(SO4)2-2	4.726E-09	2.182E-09	-8.66124	0.46163	3.836
6001400	Pb(CO3)2-2	1.427E-10	6.587E-11	-10.18134	0.46163	10.976
6002700	PbF +	1.791E-10	1.477E-10	-9.83075	0.82428	1.334
6002701	PbF2 AQ	1.087E-12	1.099E-12	-11.95902	1.01066	2.555
6002702	PbF3 -	3.521E-15	2.902E-15	-14.53729	0.82428	3.504
6002703	PbF4 -2	1.097E-18	5.063E-19	-18.29557	0.46163	3.436
6003300	PbOH +	6.779E-09	5.588E-09	-8.25274	0.82428	-7.626
6003301	Pb(OH)2 AQ	2.706E-11	2.735E-11	-10.56299	1.01066	-17.125
6003302	Pb(OH)3 -	4.794E-15	3.951E-15	-14.40325	0.82428	-27.976
6003303	Pb2OH +3	1.622E-14	2.850E-15	-14.54522	0.17565	-5.605
6007320	PbSO4 AQ	7.108E-08	7.183E-08	-7.14366	1.01066	2.745
6003304	Pb3(OH)4+2	3.944E-19	1.821E-19	-18.73975	0.46163	-23.876
6001401	PbCO3 AQ	1.008E-07	1.019E-07	-6.99191	1.01066	7.235
6003305	Pb(OH)4 -2	2.473E-19	1.142E-19	-18.94250	0.46163	-39.363
6007321	Pb(SO4)2-2	4.580E-09	2.114E-09	-8.67485	0.46163	3.806
6001402	PbHCO3 +	8.954E-09	7.381E-09	-8.13191	0.82428	13.284
5402700	NiF +	1.164E-09	9.597E-10	-9.01789	0.82428	1.384
5403300	NiOH +	1.944E-10	1.603E-10	-9.79514	0.82428	-9.931
5403301	Ni(OH)2 AQ	2.067E-12	2.089E-12	-11.68013	1.01066	-19.005
5403302	Ni(OH)3 -	3.188E-16	2.628E-16	-15.58038	0.82428	-29.916
5407320	NiSO4 AQ	1.366E-07	1.381E-07	-6.85980	1.01066	2.266
5401400	NiHCO3 +	9.658E-09	7.961E-09	-8.09904	0.82428	12.554
5401401	NiCO3 AQ	2.491E-07	2.517E-07	-6.59904	1.01066	6.865
5401402	Ni(CO3)2-2	2.439E-10	1.126E-10	-9.94847	0.46163	10.446
5407321	Ni(SO4)2-2	9.413E-11	4.345E-11	-10.36198	0.46163	1.356
3300600	H2AsO3 -	8.768E-23	7.227E-23	-22.14102	0.82428	-9.226
3300601	HAsO3 -2	1.251E-27	5.774E-28	-27.23852	0.46163	-21.172
3300602	AsO3 -3	1.340E-33	2.354E-34	-33.62816	0.17565	-34.242
3300603	H4AsO3 +	5.597E-28	4.613E-28	-27.33601	0.82428	-0.221
3300611	H2AsO4 -	2.796E-09	2.305E-09	-8.63737	0.82428	-2.138
3300612	HAsO4 -2	1.073E-08	4.955E-09	-8.30499	0.46163	-8.654
3300613	AsO4 -3	7.943E-13	1.395E-13	-12.85538	0.17565	-19.885
3301400	HCO3 -	5.904E-04	4.866E-04	-3.31279	0.82428	10.461
3301401	H2CO3 AQ	8.223E-05	8.311E-05	-4.08034	1.01066	16.704
3307320	HSO4 -	4.571E-08	3.767E-08	-7.42395	0.82428	2.011
3302700	HF AQ	3.827E-08	3.868E-08	-7.41253	1.01066	3.121
3302701	HF2 -	6.302E-11	5.195E-11	-10.28442	0.82428	3.776
3302702	H2F2 AQ	4.862E-15	4.914E-15	-14.30854	1.01066	6.763
3307620	HSeO4-1	1.553E-13	1.280E-13	-12.89266	0.82428	1.937
4707620	MnSeO4	1.254E-10	1.267E-10	-9.89709	1.01066	2.371
5407620	NiSeO4	1.161E-12	1.173E-12	-11.93062	1.01066	2.590

Type III - SPECIES WITH FIXED ACTIVITY

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
2	H2O	-9.300E-07	-6.031	0.000	0.000
1	E-1	1.917E-07	-6.717	6.018	0.000
330	H+1	-7.805E-04	-3.108	7.100	0.000

600610	AsO3/AsO4	-1.353E-08	-7.869	19.819	-30.015
4704710	Mn+2/Mn+3	-9.145E-24	-23.039	25.185	25.760
2802810	Fe+2/Fe+3	-1.646E-07	-6.784	13.157	-10.000

Type VI - EXCLUDED SPECIES (not included in mole balance)

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
3301404	CH4 (g)	0.000E-01	-84.866	40.863	-61.000
3301403	CO2 (g)	2.385E-03	-2.623	18.167	-0.530
3300021	O2 (g)	4.747E-33	-32.324	-84.793	133.830

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 14:48:11

Saturation indices and stoichiometry of all minerals

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
2003000	ALOH3(A)	-2.192	[1.000]	30	[3.000]	2	[-3.000]	330		
6003000	ALOHSO4	-4.695	[-1.000]	330	[1.000]	30	[1.000]	732		
			[1.000]	2						
6003001	AL4(OH)10SO4	-5.046	[-10.000]	330	[4.000]	30	[1.000]	732		
			[10.000]	2						
6041000	ALUM K	-15.727	[1.000]	410	[1.000]	30	[2.000]	732		
			[12.000]	2						
6041001	ALUNITE	-2.537	[1.000]	410	[3.000]	30	[2.000]	732		
			[6.000]	2	[-6.000]	330				
6015000	ANHYDRITE	-0.034	[1.000]	150	[1.000]	732				
5015000	ARAGONITE	-0.670	[1.000]	150	[1.000]	140				
5046000	ARTINITE	-8.840	[-2.000]	330	[2.000]	460	[1.000]	140		
			[5.000]	2						
4210000	BAF2	-8.321	[1.000]	100	[2.000]	270				
6010000	BARITE	0.586	[1.000]	100	[1.000]	732				
2003001	BOEHMITE	-0.403	[-3.000]	330	[1.000]	30	[2.000]	2		
2046000	BRUCITE	-6.161	[1.000]	460	[2.000]	2	[-2.000]	330		
5015001	CALCITE	-0.516	[1.000]	150	[1.000]	140				
6080000	CELESTITE	-0.646	[1.000]	800	[1.000]	732				
2003002	DIASPORE	1.345	[-3.000]	330	[1.000]	30	[2.000]	2		
5015002	DOLOMITE	-1.900	[1.000]	150	[1.000]	460	[2.000]	140		
6046000	EPSOMITE	-3.323	[1.000]	460	[1.000]	732	[7.000]	2		
2028100	FERRIHYDRITE	0.955	[-3.000]	330	[1.000]	281	[3.000]	2		
2028101	FE3(OH)8	-2.646	[-8.000]	330	[2.000]	281	[1.000]	280		
			[8.000]	2						
6028100	FE2(SO4)3	-41.980	[2.000]	281	[3.000]	732				
4215000	FLUORITE	1.760	[1.000]	150	[2.000]	270				
2003003	GIBBSITE (C)	-0.529	[-3.000]	330	[1.000]	30	[3.000]	2		
3003000	Al2O3	-5.927	[2.000]	30	[3.000]	2	[-6.000]	330		
2028102	GOETHITE	5.165	[-3.000]	330	[1.000]	281	[2.000]	2		
6015001	GYPSUM	0.227	[1.000]	150	[1.000]	732	[2.000]	2		
3028100	HEMATITE	15.314	[-6.000]	330	[2.000]	281	[3.000]	2		
5015003	HUNTITE	-8.819	[3.000]	460	[1.000]	150	[4.000]	140		
5046001	HYDRMAGNESIT	-20.272	[5.000]	460	[4.000]	140	[-2.000]	330		
			[6.000]	2						
6050000	JAROSITE NA	-1.559	[-6.000]	330	[1.000]	500	[3.000]	281		
			[2.000]	732	[6.000]	2				
6041002	JAROSITE K	2.436	[-6.000]	330	[1.000]	410	[3.000]	281		
			[2.000]	732	[6.000]	2				
6028101	JAROSITE H	-3.955	[-5.000]	330	[3.000]	281	[2.000]	732		
			[7.000]	2						
3028101	MAGHEMITE	5.306	[-6.000]	330	[2.000]	281	[3.000]	2		
5046002	MAGNESITE	-1.883	[1.000]	460	[1.000]	140				

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
3028000	MAGNETITE	13.210	[-8.000]	330	[2.000]	281	[1.000]	280		
			[4.000]	2						
6028000	MELANTERITE	-8.061	[1.000]	280	[1.000]	732	[7.000]	2		
6050001	MIRABILITE	-8.985	[2.000]	500	[1.000]	732	[10.000]	2		
3050000	NATRON	-13.167	[2.000]	500	[1.000]	140	[10.000]	2		
5046003	NESQUEHONITE	-4.287	[1.000]	460	[1.000]	140	[3.000]	2		
5028000	SIDERITE	-4.420	[1.000]	280	[1.000]	140				
4280000	SRF2	-3.175	[1.000]	800	[2.000]	270				
5080000	STRONTIANITE	-2.202	[1.000]	800	[1.000]	140				
6050002	THENARDITE	-10.162	[2.000]	500	[1.000]	732				
5050001	THERMONATR	-14.832	[2.000]	500	[1.000]	140	[1.000]	2		
5010000	WITHERITE	-5.217	[1.000]	100	[1.000]	140				
2047000	PYROLUSITE	-5.603	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
2047001	BIRNESSITE	-7.468	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
2047002	NSUTITE	-6.881	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
3047100	BIXBYITE	-4.569	[-6.000]	330	[2.000]	471	[3.000]	2		
3047000	HAUSMANNITE	-7.588	[-8.000]	330	[-2.000]	1	[3.000]	470		
			[4.000]	2						
2047003	PYROCROITE	-5.798	[-2.000]	330	[1.000]	470	[2.000]	2		
2047100	MANGANITE	-2.257	[-3.000]	330	[1.000]	471	[2.000]	2		
5047000	RHODOCHROSIT	-0.832	[1.000]	470	[1.000]	140				
6047000	MNSO4	-9.740	[1.000]	470	[1.000]	732				
6047100	MN2(SO4)3	-49.119	[2.000]	471	[3.000]	732				
5023100	CUCO3	-4.380	[1.000]	231	[1.000]	140				
4223100	CUF2	-13.844	[1.000]	231	[2.000]	270				
4223101	CUF2, 2H2O	-9.793	[1.000]	231	[2.000]	270	[2.000]	2		
2023100	CU(OH)2	-2.052	[-2.000]	330	[1.000]	231	[2.000]	2		
6023100	ANTLERITE	-4.404	[-4.000]	330	[3.000]	231	[4.000]	2		
			[1.000]	732						
6023101	BROCHANTITE	-4.675	[-6.000]	330	[4.000]	231	[6.000]	2		
			[1.000]	732						
6023102	LANGITE	-6.621	[-6.000]	330	[4.000]	231	[7.000]	2		
			[1.000]	732						
2023101	TENORITE	-1.031	[-2.000]	330	[1.000]	231	[1.000]	2		
6023103	CUOCUSO4	-14.867	[-2.000]	330	[2.000]	231	[1.000]	2		
			[1.000]	732						
6023104	CUSO4	-12.909	[1.000]	231	[1.000]	732				
6023105	CHALCANTHITE	-7.015	[1.000]	231	[1.000]	732	[5.000]	2		
3023100	CUPRICFERIT	12.107	[-8.000]	330	[1.000]	231	[2.000]	281		
			[4.000]	2						
95000	ZN METAL	-44.428	[1.000]	950	[2.000]	1				
5095000	SMITHSONITE	-2.820	[1.000]	950	[1.000]	140				
5095001	ZNCO3, 1H2O	-2.506	[1.000]	950	[1.000]	140	[1.000]	2		
4295000	ZNF2	-11.696	[1.000]	950	[2.000]	270				
2095000	ZN(OH)2 (A)	-4.427	[-2.000]	330	[1.000]	950	[2.000]	2		
2095001	ZN(OH)2 (C)	-4.177	[-2.000]	330	[1.000]	950	[2.000]	2		
2095002	ZN(OH)2 (B)	-3.727	[-2.000]	330	[1.000]	950	[2.000]	2		
2095003	ZN(OH)2 (G)	-3.687	[-2.000]	330	[1.000]	950	[2.000]	2		

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
2095004	ZN(OH)2 (E)	-3.477	[-2.000]	330	[1.000]	950	[2.000]	2		
6095000	ZN2(OH)2SO4	-7.904	[-2.000]	330	[2.000]	950	[2.000]	2		
			[1.000]	732						
6095001	ZN4(OH)6SO4	-12.757	[-6.000]	330	[4.000]	950	[6.000]	2		
			[1.000]	732						
2095005	ZNO(ACTIVE)	-3.286	[-2.000]	330	[1.000]	950	[1.000]	2		
2095006	ZINCITE	-3.390	[-2.000]	330	[1.000]	950	[1.000]	2		
6095002	ZN3O(SO4)2	-28.626	[-2.000]	330	[3.000]	950	[2.000]	732		
			[1.000]	2						
6095003	ZINCOSITE	-11.677	[1.000]	950	[1.000]	732				
6095004	ZNSO4, 1H2O	-7.991	[1.000]	950	[1.000]	732	[1.000]	2		
6095005	BIANCHITE	-6.666	[1.000]	950	[1.000]	732	[6.000]	2		
6095006	GOSLARITE	-6.428	[1.000]	950	[1.000]	732	[7.000]	2		
16000	CD METAL	-33.409	[1.000]	160	[2.000]	1				
16001	GAMMA CD	-33.511	[1.000]	160	[2.000]	1				
5016000	OTAVITE	-0.516	[1.000]	160	[1.000]	140				
4216000	CDF2	-11.677	[1.000]	160	[2.000]	270				
2016000	CD(OH)2 (A)	-7.449	[-2.000]	330	[1.000]	160	[2.000]	2		
2016001	CD(OH)2 (C)	-7.109	[-2.000]	330	[1.000]	160	[2.000]	2		
6016000	CD3(OH)4SO4	-19.389	[-4.000]	330	[3.000]	160	[4.000]	2		
			[1.000]	732						
6016001	CD3OH2(SO4)2	-19.989	[-2.000]	330	[3.000]	160	[2.000]	2		
			[2.000]	732						
6016002	CD4(OH)6SO4	-18.688	[-6.000]	330	[4.000]	160	[6.000]	2		
			[1.000]	732						
2016002	MONTEPONITE	-8.889	[-2.000]	330	[1.000]	160	[1.000]	2		
6016003	CDSO4	-9.994	[1.000]	160	[1.000]	732				
6016004	CDSO4, 1H2O	-8.347	[1.000]	160	[1.000]	732	[1.000]	2		
6016005	CDSO4,2.7H2O	-8.091	[1.000]	160	[1.000]	732	[2.670]	2		
60000	PB METAL	-23.942	[1.000]	600	[2.000]	1				
5060000	CERRUSITE	-1.041	[1.000]	600	[1.000]	140				
4260000	PBF2	-7.088	[1.000]	600	[2.000]	270				
2060000	MASSICOT	-6.563	[-2.000]	330	[1.000]	600	[1.000]	2		
2060001	LITHARGE	-6.368	[-2.000]	330	[1.000]	600	[1.000]	2		
2060002	PBO, .3H2O	-6.423	[-2.000]	330	[1.000]	600	[1.330]	2		
5060001	PB2OCO3	-7.318	[-2.000]	330	[2.000]	600	[1.000]	2		
			[1.000]	140						
6060000	LARNAKITE	-3.137	[-2.000]	330	[2.000]	600	[1.000]	732		
			[1.000]	2						
6060001	PB3O2SO4	-7.439	[-4.000]	330	[3.000]	600	[1.000]	732		
			[2.000]	2						
6060002	PB4O3SO4	-12.760	[-6.000]	330	[4.000]	600	[1.000]	732		
			[3.000]	2						
5060002	PB3O2CO3	-12.468	[-4.000]	330	[3.000]	600	[1.000]	140		
			[2.000]	2						
6060003	ANGLESITE	-2.077	[1.000]	600	[1.000]	732				
2060003	PLATTNERITE	-17.392	[-4.000]	330	[-2.000]	1	[1.000]	600		
			[2.000]	2						
3060000	PB2O3	-21.691	[-6.000]	330	[-2.000]	1	[2.000]	600		
			[3.000]	2						
3060001	MINIUM	-29.068	[-8.000]	330	[-2.000]	1	[3.000]	600		
			[4.000]	2						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
2060004	PB(OH)2 (C)	-1.768	[-2.000]	330	[1.000]	600	[2.000]	2		
5060003	HYDCERRUSITE	-4.447	[-2.000]	330	[3.000]	600	[2.000]	140		
			[2.000]	2						
2060005	PB2O(OH)2	-13.086	[-4.000]	330	[2.000]	600	[3.000]	2		
6060004	PB4(OH)6SO4	-11.323	[-6.000]	330	[4.000]	600	[1.000]	732		
			[6.000]	2						
5054000	NICO3	-6.753	[1.000]	540	[1.000]	140				
2054000	NI(OH)2	-3.099	[-2.000]	330	[1.000]	540	[2.000]	2		
6054000	NI4(OH)6SO4	-19.171	[-6.000]	330	[4.000]	540	[1.000]	732		
			[6.000]	2						
2054001	BUNSENITE	-5.429	[-2.000]	330	[1.000]	540	[1.000]	2		
6054001	RETGERSITE	-7.079	[1.000]	540	[1.000]	732	[6.000]	2		
6054002	MORENOSITE	-6.736	[1.000]	540	[1.000]	732	[7.000]	2		
5023101	MALACHITE	-2.246	[2.000]	231	[2.000]	2	[1.000]	140		
			[-2.000]	330						
5023102	AZURITE	-4.619	[3.000]	231	[2.000]	2	[2.000]	140		
			[-2.000]	330						
3006000	ARSENOLITE	-76.742	[4.000]	60	[-6.000]	2				
3006001	CLAUDETITE	-76.491	[4.000]	60	[-6.000]	2				
3006100	AS2O5	-33.797	[2.000]	61	[-3.000]	2				
7203000	ALASO4.2W	-9.789	[1.000]	30	[1.000]	61	[2.000]	2		
			[-3.000]	330						
7215000	CA3(ASO4)26W	-13.849	[3.000]	150	[2.000]	61	[4.000]	2		
			[-6.000]	330						
7223100	CU3(ASO4)26W	-12.793	[3.000]	231	[2.000]	61	[2.000]	2		
			[-6.000]	330						
7228100	FEASO4.2W	-8.070	[1.000]	281	[1.000]	61	[2.000]	2		
			[-3.000]	330						
7247000	MN3ASO428W	-10.813	[3.000]	470	[2.000]	61	[8.000]	2		
			[-6.000]	330						
7254000	NI3(ASO4)28W	-20.772	[3.000]	540	[2.000]	61	[8.000]	2		
			[-6.000]	330						
7260000	PB3(ASO4)2	-13.158	[3.000]	600	[2.000]	61	[-6.000]	330		
7295000	ZN3ASO422.5W	-16.610	[3.000]	950	[2.000]	61	[2.500]	2		
			[-6.000]	330						
7210000	BA(ASO4)2	2.860	[3.000]	100	[2.000]	61	[-6.000]	330		
2015000	LIME	-21.548	[-2.000]	330	[1.000]	150	[1.000]	2		
2015001	PORTLANDITE	-11.231	[-2.000]	330	[1.000]	150	[2.000]	2		
2028000	WUSTITE	-5.671	[-2.000]	330	[0.947]	280	[1.000]	2		
2046001	PERICLASE	-11.007	[-2.000]	330	[1.000]	460	[1.000]	2		
3028001	HERCYNITE	-5.203	[-8.000]	330	[1.000]	280	[2.000]	30		
			[4.000]	2						
3046000	SPINEL	-9.439	[-8.000]	330	[1.000]	460	[2.000]	30		
			[4.000]	2						
3046001	MAG-FERRITE	5.048	[-8.000]	330	[1.000]	460	[2.000]	281		
			[4.000]	2						
4250000	CRYOLITE	-13.900	[1.000]	30	[3.000]	500	[6.000]	270		
3028102	LEPIDOCROCIT	4.475	[-3.000]	330	[1.000]	281	[2.000]	2		
2076200	SeO3	-43.327	[1.000]	762	[2.000]	330	[-1.000]	2		
6110001	BaSeO4	-9.649	[1.000]	762	[1.000]	100				

6115001	CaSeO4:2H2O	-7.060	[1.000]	762	[1.000]	150	[2.000]	2		

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
6160000	PbSeO4	-8.402	[1.000]	762	[1.000]	800				
6180001	SrSeO4	-5.592	[1.000]	762	[1.000]	800				
2021100	CR(OH)2	-3.776	[1.000]	210	[2.000]	2	[-2.000]	330		
21000	CR METAL	-51.758	[1.000]	210	[2.000]	1				

INITIAL WASH RESULTS

PART 1 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 16: 5: 9

Initial leachate wash from humidity cell no. 1
(leachate collected May 30, 1997)

Temperature (Celsius): 20.00
Units of concentration: MG/L
Ionic strength to be computed.
Carbonate concentration represents carbonate alkalinity.
Do not automatically terminate if charge imbalance exceeds 30%
Precipitation is allowed only for those solids specified as ALLOWED
in the input file (if any).
The maximum number of iterations is: 100
The method used to compute activity coefficients is: Davies equation
Intermediate output file

330	0.000E-01	-7.24	y
1	0.000E-01	-5.63	y
270	1.170E+01	-3.21	y
30	4.000E-01	-4.83	y
740	4.260E-01	-5.76	y
100	8.000E-02	-6.23	y
160	4.000E-02	-6.45	y
150	5.500E+02	-1.86	y
231	2.000E-02	-6.50	y
280	8.000E-03	-6.84	y
460	5.510E+01	-2.64	y
470	1.100E+01	-3.70	y
480	4.800E-01	-5.74	y
410	1.000E+01	-3.59	y
762	6.500E-03	-7.60	y
500	2.000E+00	-4.06	y
800	2.810E+00	-4.49	y
950	1.900E+00	-4.54	y
732	1.595E+03	-1.78	y
60	8.000E-04	-8.40	y
770	1.766E+01	-4.27	y
440	5.000E-02	-5.14	y
540	2.200E-01	-5.43	y
140	2.236E+01	-6.57	
471	0.000E-01	-20.74	
61	0.000E-01	-21.15	y
281	0.000E-01	-20.75	

H2O has been inserted as a COMPONENT

3 5		
4704710	25.5070	25.7600
600610	19.4440	-30.0150
2802810	13.0320	-10.0000
330	7.2400	0.0000
1	5.6292	0.0000

INPUT DATA BEFORE TYPE MODIFICATIONS

ID	NAME	ACTIVITY GUESS	LOG GUESS	ANAL TOTAL
330	H+1	5.754E-08	-7.240	0.000E-01
1	E-1	2.344E-06	-5.630	0.000E-01
270	F-1	6.166E-04	-3.210	1.170E+01
30	Al+3	1.479E-05	-4.830	4.000E-01
740	Sb(OH)3	1.738E-06	-5.760	4.260E-01
100	Ba+2	5.888E-07	-6.230	8.000E-02
160	Cd+2	3.548E-07	-6.450	4.000E-02
150	Ca+2	1.380E-02	-1.860	5.500E+02
231	Cu+2	3.162E-07	-6.500	2.000E-02
280	Fe+2	1.445E-07	-6.840	8.000E-03
460	Mg+2	2.291E-03	-2.640	5.510E+01
470	Mn+2	1.995E-04	-3.700	1.100E+01
480	MoO4-2	1.820E-06	-5.740	4.800E-01
410	K+1	2.570E-04	-3.590	1.000E+01
762	SeO4-2	2.512E-08	-7.600	6.500E-03
500	Na+1	8.710E-05	-4.060	2.000E+00
800	Sr+2	3.236E-05	-4.490	2.810E+00
950	Zn+2	2.884E-05	-4.540	1.900E+00
732	SO4-2	1.660E-02	-1.780	1.595E+03
60	H3AsO3	3.981E-09	-8.400	8.000E-04
770	H4SiO4	5.370E-05	-4.270	1.766E+01
440	Li+1	7.244E-06	-5.140	5.000E-02
540	Ni+2	3.715E-06	-5.430	2.200E-01
140	CO3-2	2.692E-07	-6.570	2.236E+01
471	Mn+3	1.820E-21	-20.740	0.000E-01
61	H3AsO4	7.079E-22	-21.150	0.000E-01
281	Fe+3	1.778E-21	-20.750	0.000E-01
2	H2O	1.000E+00	0.000	0.000E-01

Charge Balance: UNSPECIATED

Sum of CATIONS= 3.298E-02 Sum of ANIONS = 3.465E-02

PERCENT DIFFERENCE = 2.474E+00 (ANIONS - CATIONS)/(ANIONS + CATIONS)

IMPROVED ACTIVITY GUESSES PRIOR TO FIRST ITERATION:

Al+3	Log activity guess:	-10.73
Sb(OH)3	Log activity guess:	-5.90
Cu+2	Log activity guess:	-6.57
Fe+2	Log activity guess:	-8.24
Mn+2	Log activity guess:	-3.70
SeO4-2	Log activity guess:	-7.34
SO4-2	Log activity guess:	-1.78
H3AsO3	Log activity guess:	-19.73
H4SiO4	Log activity guess:	-3.74
CO3-2	Log activity guess:	-6.62
Mn+3	Log activity guess:	-23.25
H3AsO4	Log activity guess:	-13.81
Fe+3	Log activity guess:	-15.76

PART 3 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 16: 5:10

PARAMETERS OF THE COMPONENT MOST OUT OF BALANCE:

ITER	NAME	TOTAL MOL	DIFF FXN	LOG ACTVTY	RESIDUAL
0	Li+1	7.222E-06	5.485E-07	-5.14000	5.478E-07
1	Li+1	7.222E-06	9.330E-09	-5.15863	8.607E-09
2	Li+1	7.222E-06	1.282E-06	-5.15531	1.281E-06
3	Li+1	7.222E-06	2.061E-07	-5.22259	2.054E-07
4	Li+1	7.222E-06	1.795E-08	-5.23403	1.723E-08
5	Li+1	7.222E-06	1.722E-09	-5.23505	9.993E-10
6	Sr+2	3.214E-05	4.092E-09	-4.82835	8.770E-10

ID	NAME	ANAL MOL	CALC MOL	LOG ACTVTY	GAMMA	DIFF FXN
61	H3AsO4	0.000E-01	7.910E-15	-14.09724	1.010647	9.741E-14
140	CO3-2	8.115E-04	9.131E-07	-6.37499	0.461843	7.239E-09
270	F-1	6.172E-04	5.331E-04	-3.35709	0.824372	2.531E-09
30	Al+3	1.486E-05	6.946E-12	-11.91314	0.175837	1.169E-11
740	Sb(OH)3	2.471E-06	1.245E-06	-5.90011	1.010647	-1.579E-12
100	Ba+2	5.838E-07	5.838E-07	-6.56921	0.461843	1.014E-11
160	Cd+2	3.567E-07	1.924E-07	-7.05124	0.461843	3.583E-12
150	Ca+2	1.375E-02	9.301E-03	-2.36700	0.461843	1.589E-07
231	Cu+2	3.155E-07	5.601E-08	-7.58726	0.461843	8.748E-13
280	Fe+2	1.436E-07	1.006E-08	-8.33308	0.461843	6.457E-13
460	Mg+2	2.272E-03	1.586E-03	-3.13528	0.461843	2.725E-08
470	Mn+2	2.007E-04	1.411E-04	-4.18593	0.461843	2.418E-09
480	MoO4-2	3.008E-06	3.008E-06	-5.85722	0.461843	5.224E-11
410	K+1	2.563E-04	2.479E-04	-3.68966	0.824372	1.113E-09
762	SeO4-2	4.557E-08	4.522E-08	-7.68017	0.461843	7.851E-13
500	Na+1	8.719E-05	8.498E-05	-4.15456	0.824372	3.785E-10
800	Sr+2	3.214E-05	3.214E-05	-4.82840	0.461843	5.583E-10
950	Zn+2	2.913E-05	1.728E-05	-5.09807	0.461843	3.133E-10
732	SO4-2	1.664E-02	1.150E-02	-2.27493	0.461843	1.965E-07
540	Ni+2	3.756E-06	1.282E-06	-6.22767	0.461843	2.103E-11
770	H4SiO4	1.842E-04	1.838E-04	-3.73105	1.010647	-1.159E-10
440	Li+1	7.222E-06	7.059E-06	-5.23516	0.824372	3.136E-11
60	H3AsO3	6.367E-09	9.533E-21	-20.01616	1.010647	0.000E-01
1	E-1	0.000E-01	1.423E-07	-5.62920	0.824372	0.000E-01
330	H+1	0.000E-01	6.980E-08	-7.24000	0.824372	0.000E-01
471	Mn+3	0.000E-01	1.031E-23	-23.74169	0.175837	0.000E-01
2	H2O	0.000E-01	-3.266E-06	-0.00025	1.000000	0.000E-01
281	Fe+3	0.000E-01	7.834E-16	-15.86090	0.175837	0.000E-01

Type I - COMPONENTS AS SPECIES IN SOLUTION

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
330	H+1	6.980E-08	5.754E-08	-7.24000	0.82437	0.084
281	Fe+3	7.834E-16	1.378E-16	-15.86090	0.17584	0.755

270	F-1	5.331E-04	4.395E-04	-3.35709	0.82437	0.084
30	Al+3	6.946E-12	1.221E-12	-11.91314	0.17584	0.755
740	Sb(OH)3	1.245E-06	1.259E-06	-5.90011	1.01065	-0.005
100	Ba+2	5.838E-07	2.696E-07	-6.56921	0.46184	0.336
160	Cd+2	1.924E-07	8.887E-08	-7.05124	0.46184	0.336
150	Ca+2	9.301E-03	4.295E-03	-2.36700	0.46184	0.336
231	Cu+2	5.601E-08	2.587E-08	-7.58726	0.46184	0.336
280	Fe+2	1.006E-08	4.644E-09	-8.33308	0.46184	0.336
460	Mg+2	1.586E-03	7.324E-04	-3.13528	0.46184	0.336
470	Mn+2	1.411E-04	6.517E-05	-4.18593	0.46184	0.336
480	MoO4-2	3.008E-06	1.389E-06	-5.85722	0.46184	0.336
410	K+1	2.479E-04	2.043E-04	-3.68966	0.82437	0.084
762	SeO4-2	4.522E-08	2.088E-08	-7.68017	0.46184	0.336
500	Na+1	8.498E-05	7.005E-05	-4.15456	0.82437	0.084
800	Sr+2	3.214E-05	1.485E-05	-4.82840	0.46184	0.336
950	Zn+2	1.728E-05	7.979E-06	-5.09807	0.46184	0.336
732	SO4-2	1.150E-02	5.310E-03	-2.27493	0.46184	0.336
60	H3AsO3	9.533E-21	9.635E-21	-20.01616	1.01065	-0.005
770	H4SiO4	1.838E-04	1.858E-04	-3.73105	1.01065	-0.005
440	Li+1	7.059E-06	5.819E-06	-5.23516	0.82437	0.084
540	Ni+2	1.282E-06	5.920E-07	-6.22767	0.46184	0.336
140	CO3-2	9.131E-07	4.217E-07	-6.37499	0.46184	0.336
471	Mn+3	1.031E-23	1.813E-24	-23.74169	0.17584	0.755
61	H3AsO4	7.910E-15	7.994E-15	-14.09724	1.01065	-0.005

Type II - OTHER SPECIES IN SOLUTION OR ADSORBED

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
1607620	CdSeO4	3.203E-13	3.237E-13	-12.48990	1.01065	2.237
9507620	ZnSeO4	2.625E-11	2.653E-11	-10.57634	1.01065	2.197
9507621	Zn(SeO4)2-2	6.408E-21	2.959E-21	-20.52881	0.46184	0.265
3300020	OH-	1.441E-07	1.188E-07	-6.92509	0.82437	-14.081
3307700	H3SiO4 -	3.556E-07	2.931E-07	-6.53293	0.82437	-9.958
3307701	H2SiO4 -2	1.232E-11	5.691E-12	-11.24477	0.46184	-21.658
7702700	SiF6 -2	7.695E-23	3.554E-23	-22.44928	0.46184	30.719
4603300	MgOH +	1.628E-08	1.342E-08	-7.87216	0.82437	-11.893
4602700	MgF +	2.255E-05	1.859E-05	-4.73079	0.82437	1.845
4601400	MgCO3 AQ	2.701E-07	2.730E-07	-6.56388	1.01065	2.942
4601401	MgHCO3 +	5.796E-06	4.778E-06	-5.32073	0.82437	11.513
4607320	MgSO4 AQ	6.572E-04	6.642E-04	-3.17769	1.01065	2.228
1503300	CaOH +	1.503E-08	1.239E-08	-7.90696	0.82437	-12.696
1501400	CaHCO3 +	2.676E-05	2.206E-05	-4.65632	0.82437	11.410
1501401	CaCO3 AQ	2.294E-06	2.318E-06	-5.63489	1.01065	3.102
1507320	CaSO4 AQ	4.407E-03	4.453E-03	-2.35130	1.01065	2.286
1502700	CaF +	1.788E-05	1.474E-05	-4.83156	0.82437	0.976
5001400	NaCO3 -	5.140E-10	4.237E-10	-9.37295	0.82437	1.240
5001401	NaHCO3 AQ	2.022E-08	2.044E-08	-7.68955	1.01065	10.075
5007320	NaSO4 -	2.190E-06	1.805E-06	-5.74349	0.82437	0.770
5002700	NaF AQ	4.940E-09	4.993E-09	-8.30165	1.01065	-0.795
4107320	KSO4 -	8.464E-06	6.977E-06	-5.15631	0.82437	0.892
303300	AlOH +2	3.337E-10	1.541E-10	-9.81215	0.46184	-4.803
303301	Al(OH)2 +	3.550E-08	2.927E-08	-7.53365	0.82437	-10.016

303302	Al(OH)4 -	3.792E-07	3.126E-07	-6.50497	0.82437	-23.467
302700	AlF +2	1.189E-08	5.493E-09	-8.26023	0.46184	7.346
302701	AlF2 +	9.048E-07	7.459E-07	-6.12735	0.82437	12.584
302702	AlF3 AQ	9.994E-06	1.010E-05	-4.99566	1.01065	16.984
302703	AlF4 -	2.900E-06	2.391E-06	-5.62149	0.82437	19.804
307320	AlSO4 +	7.743E-12	6.383E-12	-11.19495	0.82437	3.077
307321	Al(SO4)2 -	3.202E-12	2.639E-12	-11.57850	0.82437	4.968
303303	Al(OH)3 AQ	6.331E-07	6.399E-07	-6.19391	1.01065	-16.005
2803300	FeOH +	2.116E-11	1.744E-11	-10.75835	0.82437	-9.581
2803301	FeOH3 -1	1.234E-18	1.017E-18	-17.99264	0.82437	-31.295
2807320	FeSO4 AQ	3.954E-09	3.996E-09	-8.39839	1.01065	2.205
2803302	FeOH2 AQ	1.639E-15	1.657E-15	-14.78070	1.01065	-20.932
2813300	FeOH +2	2.479E-11	1.145E-11	-10.94116	0.46184	-1.984
2817320	FeSO4 +	6.594E-15	5.436E-15	-14.26471	0.82437	3.955
2813301	FeOH2 +	1.078E-07	8.884E-08	-7.05141	0.82437	-5.586
2813302	FeOH3 AQ	1.794E-08	1.813E-08	-7.74166	1.01065	-13.605
2813303	FeOH4 -	3.819E-09	3.148E-09	-8.50192	0.82437	-21.516
2812700	FeF +2	1.918E-13	8.857E-14	-13.05273	0.46184	6.501
2812701	FeF2 +	1.773E-12	1.462E-12	-11.83508	0.82437	10.824
2812702	FeF3 AQ	9.902E-13	1.001E-12	-11.99966	1.01065	13.928
2817321	Fe(SO4)2 -	1.085E-15	8.948E-16	-15.04826	0.82437	5.446
2813304	Fe2(OH)2+4	9.571E-20	4.354E-21	-20.36108	0.04550	-1.777
2813305	Fe3(OH)4+5	9.872E-24	7.898E-26	-25.10249	0.00800	-4.382
4407320	LiSO4 -	1.636E-07	1.349E-07	-6.87009	0.82437	0.724
8003300	SrOH +	1.368E-11	1.128E-11	-10.94787	0.82437	-13.275
1003300	BaOH +	1.613E-13	1.330E-13	-12.87618	0.82437	-13.463
4703300	MnOH +	2.332E-08	1.922E-08	-7.71619	0.82437	-10.686
4703301	Mn(OH)3 -1	6.564E-18	5.411E-18	-17.26669	0.82437	-34.716
4700020	MnO4 -	8.529E-49	7.031E-49	-48.15295	0.82437	-129.948
4700021	MnO4 -2	1.862E-44	8.598E-45	-44.06561	0.46184	-119.980
4702700	MnF +	2.460E-07	2.028E-07	-6.69301	0.82437	0.934
4707320	MnSO4 AQ	5.854E-05	5.916E-05	-4.22798	1.01065	2.228
4701400	MnHCO3 +	7.638E-07	6.296E-07	-6.20091	0.82437	11.684
2311400	CuCO3 AQ	5.796E-08	5.858E-08	-7.23225	1.01065	6.725
2311401	Cu(CO3)2-2	6.734E-11	3.110E-11	-10.50723	0.46184	10.166
2312700	CuF +	2.395E-10	1.974E-10	-9.70460	0.82437	1.324
2313300	CuOH +	5.450E-09	4.492E-09	-8.34751	0.82437	-7.916
2313301	Cu(OH)2 AQ	1.613E-07	1.630E-07	-6.78777	1.01065	-13.685
2313302	Cu(OH)3 -	2.074E-13	1.710E-13	-12.76702	0.82437	-26.815
2313303	Cu(OH)4 -2	1.280E-18	5.912E-19	-18.22828	0.46184	-39.264
2313304	Cu2(OH)2+2	1.155E-11	5.336E-12	-11.27280	0.46184	-10.242
2317320	CuSO4 AQ	2.679E-08	2.707E-08	-7.56744	1.01065	2.290
2311402	CuHCO3 +	7.614E-09	6.277E-09	-8.20225	0.82437	13.084
9502700	ZnF +	5.636E-08	4.646E-08	-7.33291	0.82437	1.206
9503300	ZnOH +	1.253E-07	1.033E-07	-6.98583	0.82437	-9.044
9503301	Zn(OH)2 AQ	3.005E-08	3.037E-08	-7.51758	1.01065	-16.904
9503302	Zn(OH)3 -	2.023E-12	1.668E-12	-11.77784	0.82437	-28.315
9503303	Zn(OH)4 -2	9.941E-18	4.591E-18	-17.33809	0.46184	-40.863
9507320	ZnSO4 AQ	9.449E-06	9.550E-06	-5.02000	1.01065	2.348
9507321	Zn(SO4)2-2	9.281E-07	4.286E-07	-6.36793	0.46184	3.616
9501400	ZnHCO3 +	5.900E-07	4.863E-07	-6.31306	0.82437	12.484
9501401	ZnCO3 AQ	6.643E-07	6.713E-07	-6.17306	1.01065	5.295
9501402	Zn(CO3)2-2	1.311E-08	6.053E-09	-8.21804	0.46184	9.966
1602700	CdF +	5.964E-10	4.917E-10	-9.30832	0.82437	1.184

1602701	CdF2 AQ	5.370E-13	5.427E-13	-12.26541	1.01065	1.495
1601400	Cd(CO3)3-4	2.431E-19	1.106E-20	-19.95620	0.04550	7.562
1603300	CdOH +	1.068E-10	8.805E-11	-10.05526	0.82437	-10.160
1603301	Cd(OH)2 AQ	1.185E-13	1.197E-13	-12.92175	1.01065	-20.355
1603302	Cd(OH)3 -	2.831E-19	2.333E-19	-18.63200	0.82437	-33.216
1603303	Cd(OH)4 -2	7.821E-26	3.612E-26	-25.44226	0.46184	-47.014
1603304	Cd2OH +3	2.322E-16	4.083E-17	-16.38898	0.17584	-8.771
1607320	CdSO4 AQ	1.305E-07	1.319E-07	-6.87967	1.01065	2.442
1601400	CdHCO3 +	6.571E-09	5.417E-09	-8.26622	0.82437	12.484
1601401	CdCO3 AQ	9.293E-09	9.392E-09	-8.02722	1.01065	5.394
1607321	Cd(SO4)2-2	1.716E-08	7.923E-09	-8.10109	0.46184	3.836
5402700	NiF +	6.297E-09	5.191E-09	-8.28476	0.82437	1.384
5403300	NiOH +	1.204E-09	9.927E-10	-9.00320	0.82437	-9.931
5403301	Ni(OH)2 AQ	1.767E-11	1.786E-11	-10.74818	1.01065	-19.005
5403302	Ni(OH)3 -	3.762E-15	3.101E-15	-14.50844	0.82437	-29.916
5407320	NiSO4 AQ	5.805E-07	5.867E-07	-6.23160	1.01065	2.266
5401400	NiHCO3 +	5.143E-08	4.240E-08	-7.37266	0.82437	12.554
5401401	NiCO3 AQ	1.831E-06	1.851E-06	-5.73266	1.01065	6.865
5401402	Ni(CO3)2-2	2.937E-09	1.356E-09	-8.86765	0.46184	10.446
5407321	Ni(SO4)2-2	3.784E-10	1.748E-10	-9.75753	0.46184	1.356
3300600	H2AsO3 -	9.947E-23	8.200E-23	-22.08616	0.82437	-9.226
3300601	HAsO3 -2	1.958E-27	9.044E-28	-27.04366	0.46184	-21.172
3300602	AsO3 -3	2.895E-33	5.090E-34	-33.29331	0.17584	-34.242
3300603	H4AsO3 +	3.332E-28	2.747E-28	-27.56116	0.82437	-0.221
3300611	H2AsO4 -	1.011E-09	8.335E-10	-9.07911	0.82437	-2.138
3300612	HAsO4 -2	5.355E-09	2.473E-09	-8.60674	0.46184	-8.654
3300613	AsO4 -3	5.467E-13	9.613E-14	-13.01712	0.17584	-19.885
7400021	HSbO2	1.226E-06	1.239E-06	-5.90697	1.01065	-0.012
7402700	SbOF (aq)	4.843E-11	4.895E-11	-10.31029	1.01065	6.182
7402702	Sb(OH)2F aq	4.922E-11	4.975E-11	-10.30324	1.01065	6.189
7403300	SbO+	6.957E-13	5.735E-13	-12.24143	0.82437	0.982
7403301	SbO2-	2.589E-11	2.135E-11	-10.67067	0.82437	-11.927
7403302	Sb(OH)2+	2.135E-12	1.760E-12	-11.75456	0.82437	1.469
7400020	Sb(OH)4-1	1.486E-11	1.225E-11	-10.91198	0.82437	-12.168
3301400	HCO3 -	7.007E-04	5.776E-04	-3.23835	0.82437	10.461
3301401	H2CO3 AQ	7.071E-05	7.147E-05	-4.14590	1.01065	16.704
3307320	HSO4 -	3.135E-08	2.584E-08	-7.58770	0.82437	2.011
3302700	HF AQ	3.342E-08	3.378E-08	-7.47134	1.01065	3.121
3302701	HF2 -	6.635E-11	5.469E-11	-10.26206	0.82437	3.776
3302702	H2F2 AQ	3.709E-15	3.748E-15	-14.42617	1.01065	6.763
3307620	HSeO4-1	1.040E-13	8.573E-14	-13.06687	0.82437	1.937
4707620	MnSeO4	3.198E-10	3.232E-10	-9.49055	1.01065	2.371
5407620	NiSeO4	4.814E-12	4.865E-12	-11.31290	1.01065	2.590

Type III - SPECIES WITH FIXED ACTIVITY

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
2	H2O	-3.266E-06	-5.486	0.000	0.000
1	E-1	1.423E-07	-6.847	5.629	0.000
330	H+1	-8.714E-04	-3.060	7.240	0.000
4704710	Mn+2/Mn+3	-1.031E-23	-22.987	25.185	25.760
600610	AsO3/AsO4	-6.367E-09	-8.196	19.819	-30.015

2802810	Fe+2/Fe+3	-1.295E-07	-6.888	13.157	-10.000

Type VI - EXCLUDED SPECIES (not included in mole balance)

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
3301404	CH4 (g)	0.000E-01	-82.945	40.863	-61.000
3301403	CO2 (g)	2.051E-03	-2.688	18.167	-0.530
3300021	O2 (g)	4.822E-34	-33.317	-84.793	133.830

PART 6 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 14-OCT-97 TIME: 16: 5:10

Saturation indices and stoichiometry of all minerals

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
2003000	ALOH3(A)	-0.912	[1.000]	30	[3.000]	2	[-3.000]	330		
6003000	ALOHSO4	-3.718	[-1.000]	330	[1.000]	30	[1.000]	732		
			[1.000]	2						
6003001	AL4(OH)10SO4	-0.230	[-10.000]	330	[4.000]	30	[1.000]	732		
			[10.000]	2						
6041000	ALUM K	-14.895	[1.000]	410	[1.000]	30	[2.000]	732		
			[12.000]	2						
6041001	ALUNITE	0.855	[1.000]	410	[3.000]	30	[2.000]	732		
			[6.000]	2	[-6.000]	330				
6015000	ANHYDRITE	-0.052	[1.000]	150	[1.000]	732				
5015000	ARAGONITE	-0.450	[1.000]	150	[1.000]	140				
5046000	ARTINITE	-8.126	[-2.000]	330	[2.000]	460	[1.000]	140		
			[5.000]	2						
4210000	BAF2	-7.511	[1.000]	100	[2.000]	270				
6010000	BARITE	1.210	[1.000]	100	[1.000]	732				
2003001	BOEHMITE	0.877	[-3.000]	330	[1.000]	30	[2.000]	2		
2046000	BRUCITE	-5.771	[1.000]	460	[2.000]	2	[-2.000]	330		
5015001	CALCITE	-0.296	[1.000]	150	[1.000]	140				
6080000	CELESTITE	-0.644	[1.000]	800	[1.000]	732				
2077000	CHALCEDONY	-0.150	[-2.000]	2	[1.000]	770				
8646000	CHRYSOTILE	-6.272	[-6.000]	330	[3.000]	460	[2.000]	770		
			[1.000]	2						
8246000	CLINOENSTITE	-3.974	[-1.000]	2	[1.000]	460	[1.000]	770		
			[-2.000]	330						
2077001	CRISTOBALITE	-0.075	[-2.000]	2	[1.000]	770				
2003002	DIASPORE	2.625	[-3.000]	330	[1.000]	30	[2.000]	2		
8215000	DIOPSIDE	-4.293	[-2.000]	2	[1.000]	150	[1.000]	460		
			[2.000]	770	[-4.000]	330				
5015002	DOLOMITE	-1.356	[1.000]	150	[1.000]	460	[2.000]	140		
6046000	EPSOMITE	-3.237	[1.000]	460	[1.000]	732	[7.000]	2		
8646003	SEPIOLITE(C)	-4.757	[-0.500]	2	[2.000]	460	[3.000]	770		
			[-4.000]	330						
2028100	FERRIHYDRITE	0.967	[-3.000]	330	[1.000]	281	[3.000]	2		
2028101	FE3(OH)8	-2.359	[-8.000]	330	[2.000]	281	[1.000]	280		
			[8.000]	2						
6028100	FE2(SO4)3	-42.866	[2.000]	281	[3.000]	732				
4215000	FLUORITE	1.928	[1.000]	150	[2.000]	270				
8046000	FORSTERITE	-9.946	[-4.000]	330	[2.000]	460	[1.000]	770		
2003003	GIBBSITE (C)	0.751	[-3.000]	330	[1.000]	30	[3.000]	2		
3003000	Al2O3	-3.367	[2.000]	30	[3.000]	2	[-6.000]	330		
2028102	GOETHITE	5.178	[-3.000]	330	[1.000]	281	[2.000]	2		
8628000	GREENALITE	-9.832	[-6.000]	330	[3.000]	280	[2.000]	770		
			[1.000]	2						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]					
6015001	GYPSUM	0.209	[1.000]	150	[1.000]	732	[2.000]	2
3028100	HEMATITE	15.340	[-6.000]	330	[2.000]	281	[3.000]	2
5015003	HUNTITE	-7.627	[3.000]	460	[1.000]	150	[4.000]	140
5046001	HYDRMAGNESIT	-18.585	[5.000]	460	[4.000]	140	[-2.000]	330
			[6.000]	2				
6050000	JAROSITE NA	-2.101	[-6.000]	330	[1.000]	500	[3.000]	281
			[2.000]	732	[6.000]	2		
6041002	JAROSITE K	2.025	[-6.000]	330	[1.000]	410	[3.000]	281
			[2.000]	732	[6.000]	2		
6028101	JAROSITE H	-4.524	[-5.000]	330	[3.000]	281	[2.000]	732
			[7.000]	2				
8450000	MAGADIITE	-8.730	[-1.000]	330	[-9.000]	2	[1.000]	500
			[7.000]	770				
3028101	MAGHEMITE	5.331	[-6.000]	330	[2.000]	281	[3.000]	2
5046002	MAGNESITE	-1.558	[1.000]	460	[1.000]	140		
3028000	MAGNETITE	13.496	[-8.000]	330	[2.000]	281	[1.000]	280
			[4.000]	2				
6028000	MELANTERITE	-8.104	[1.000]	280	[1.000]	732	[7.000]	2
6050001	MIRABILITE	-9.235	[2.000]	500	[1.000]	732	[10.000]	2
3050000	NATRON	-13.179	[2.000]	500	[1.000]	140	[10.000]	2
5046003	NESQUEHONITE	-3.962	[1.000]	460	[1.000]	140	[3.000]	2
8646001	PHLOGOPITE	-31.181	[-10.000]	330	[1.000]	410	[3.000]	460
			[1.000]	30	[3.000]	770		
2077002	QUARTZ	0.353	[-2.000]	2	[1.000]	770		
8646004	SEPIOLITE(A)	-7.284	[-0.500]	2	[2.000]	460	[3.000]	770
			[-4.000]	330				
5028000	SIDERITE	-4.225	[1.000]	280	[1.000]	140		
2077003	SIO2(A,GL)	-0.657	[-2.000]	2	[1.000]	770		
2077004	SIO2(A,PT)	-0.972	[-2.000]	2	[1.000]	770		
4280000	SRF2	-2.987	[1.000]	800	[2.000]	270		
5080000	STRONTIANITE	-1.962	[1.000]	800	[1.000]	140		
8646002	TALC	-4.382	[-4.000]	2	[3.000]	460	[4.000]	770
			[-6.000]	330				
6050002	THENARDITE	-10.412	[2.000]	500	[1.000]	732		
5050001	THERMONATR	-14.844	[2.000]	500	[1.000]	140	[1.000]	2
8215001	TREMOLITE	-6.651	[-8.000]	2	[2.000]	150	[5.000]	460
			[8.000]	770	[-14.000]	330		
5010000	WITHERITE	-4.355	[1.000]	100	[1.000]	140		
2047000	PYROLUSITE	-5.379	[-4.000]	330	[-1.000]	1	[1.000]	471
			[2.000]	2				
2047001	BIRNESSITE	-7.244	[-4.000]	330	[-1.000]	1	[1.000]	471
			[2.000]	2				
2047002	NSUTITE	-6.657	[-4.000]	330	[-1.000]	1	[1.000]	471
			[2.000]	2				
3047100	BIXBYITE	-3.624	[-6.000]	330	[2.000]	471	[3.000]	2
3047000	HAUSMANNITE	-5.922	[-8.000]	330	[-2.000]	1	[3.000]	470
			[4.000]	2				
2047003	PYROCROITE	-5.077	[-2.000]	330	[1.000]	470	[2.000]	2
2047100	MANGANITE	-1.784	[-3.000]	330	[1.000]	471	[2.000]	2
5047000	RHODOCHROSIT	-0.177	[1.000]	470	[1.000]	140		
6047000	MNSO4	-9.323	[1.000]	470	[1.000]	732		

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
6047100	MN2(SO4)3	-49.085	[2.000]	471	[3.000]	732				
5023100	CUCO3	-4.332	[1.000]	231	[1.000]	140				
4223100	CUF2	-13.848	[1.000]	231	[2.000]	270				
4223101	CUF2, 2H2O	-9.798	[1.000]	231	[2.000]	270	[2.000]	2		
2023100	CU(OH)2	-1.938	[-2.000]	330	[1.000]	231	[2.000]	2		
6023100	ANTLERITE	-4.368	[-4.000]	330	[3.000]	231	[4.000]	2		
			[1.000]	732						
6023101	BROCHANTITE	-4.525	[-6.000]	330	[4.000]	231	[6.000]	2		
			[1.000]	732						
6023102	LANGITE	-6.471	[-6.000]	330	[4.000]	231	[7.000]	2		
			[1.000]	732						
2023101	TENORITE	-0.918	[-2.000]	330	[1.000]	231	[1.000]	2		
6023103	CUOCUSO4	-14.944	[-2.000]	330	[2.000]	231	[1.000]	2		
			[1.000]	732						
6023104	CUSO4	-13.099	[1.000]	231	[1.000]	732				
6023105	CHALCANTHITE	-7.205	[1.000]	231	[1.000]	732	[5.000]	2		
2023102	DIOPTASE	-3.450	[-2.000]	330	[1.000]	231	[1.000]	770		
3023100	CUPRICFERIT	12.246	[-8.000]	330	[1.000]	231	[2.000]	281		
			[4.000]	2						
95000	ZN METAL	-42.573	[1.000]	950	[2.000]	1				
5095000	SMITHSONITE	-1.528	[1.000]	950	[1.000]	140				
5095001	ZNCO3, 1H2O	-1.213	[1.000]	950	[1.000]	140	[1.000]	2		
4295000	ZNF2	-10.456	[1.000]	950	[2.000]	270				
2095000	ZN(OH)2 (A)	-3.069	[-2.000]	330	[1.000]	950	[2.000]	2		
2095001	ZN(OH)2 (C)	-2.819	[-2.000]	330	[1.000]	950	[2.000]	2		
2095002	ZN(OH)2 (B)	-2.369	[-2.000]	330	[1.000]	950	[2.000]	2		
2095003	ZN(OH)2 (G)	-2.329	[-2.000]	330	[1.000]	950	[2.000]	2		
2095004	ZN(OH)2 (E)	-2.119	[-2.000]	330	[1.000]	950	[2.000]	2		
6095000	ZN2(OH)2SO4	-5.492	[-2.000]	330	[2.000]	950	[2.000]	2		
			[1.000]	732						
6095001	ZN4(OH)6SO4	-7.629	[-6.000]	330	[4.000]	950	[6.000]	2		
			[1.000]	732						
2095005	ZNO(ACTIVE)	-1.928	[-2.000]	330	[1.000]	950	[1.000]	2		
2095006	ZINCITE	-2.032	[-2.000]	330	[1.000]	950	[1.000]	2		
6095002	ZN3O(SO4)2	-25.159	[-2.000]	330	[3.000]	950	[2.000]	732		
			[1.000]	2						
8295000	ZNSIO3	2.493	[-2.000]	330	[-1.000]	2	[1.000]	950		
			[1.000]	770						
8095000	WILLEMITE	-0.714	[-4.000]	330	[2.000]	950	[1.000]	770		
6095003	ZINCOSITE	-10.623	[1.000]	950	[1.000]	732				
6095004	ZNSO4, 1H2O	-6.936	[1.000]	950	[1.000]	732	[1.000]	2		
6095005	BIANCHITE	-5.612	[1.000]	950	[1.000]	732	[6.000]	2		
6095006	GOSLARITE	-5.374	[1.000]	950	[1.000]	732	[7.000]	2		
16000	CD METAL	-32.025	[1.000]	160	[2.000]	1				
16001	GAMMA CD	-32.126	[1.000]	160	[2.000]	1				
5016000	OTAVITE	0.307	[1.000]	160	[1.000]	140				
4216000	CDF2	-10.907	[1.000]	160	[2.000]	270				
2016000	CD(OH)2 (A)	-6.561	[-2.000]	330	[1.000]	160	[2.000]	2		
2016001	CD(OH)2 (C)	-6.222	[-2.000]	330	[1.000]	160	[2.000]	2		
6016000	CD3(OH)4SO4	-17.030	[-4.000]	330	[3.000]	160	[4.000]	2		
			[1.000]	732						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
6016001	CD3OH2(SO4)2	-17.934	[-2.000]	330	[3.000]	160	[2.000]	2		
			[2.000]	732						
6016002	CD4(OH)6SO4	-15.441	[-6.000]	330	[4.000]	160	[6.000]	2		
			[1.000]	732						
2016002	MONTEPONITE	-8.001	[-2.000]	330	[1.000]	160	[1.000]	2		
8216000	CDSIO3	-5.570	[-1.000]	2	[1.000]	160	[1.000]	770		
			[-2.000]	330						
6016003	CDSO4	-9.410	[1.000]	160	[1.000]	732				
6016004	CDSO4, 1H2O	-7.763	[1.000]	160	[1.000]	732	[1.000]	2		
6016005	CDSO4,2.7H2O	-7.508	[1.000]	160	[1.000]	732	[2.670]	2		
5054000	NICO3	-5.887	[1.000]	540	[1.000]	140				
2054000	NI(OH)2	-2.168	[-2.000]	330	[1.000]	540	[2.000]	2		
6054000	NI4(OH)6SO4	-15.747	[-6.000]	330	[4.000]	540	[1.000]	732		
			[6.000]	2						
2054001	BUNSENITE	-4.497	[-2.000]	330	[1.000]	540	[1.000]	2		
6054001	RETGERSITE	-6.450	[1.000]	540	[1.000]	732	[6.000]	2		
6054002	MORENOSITE	-6.108	[1.000]	540	[1.000]	732	[7.000]	2		
8054000	NI2SIO4	-2.183	[-4.000]	330	[2.000]	540	[1.000]	770		
8450001	ANALCIME	-1.574	[1.000]	500	[1.000]	30	[2.000]	770		
			[-1.000]	2	[-4.000]	330				
8603000	HALLOYSITE	2.661	[2.000]	30	[2.000]	770	[1.000]	2		
			[-6.000]	330						
8603001	KAOLINITE	5.984	[2.000]	30	[2.000]	770	[1.000]	2		
			[-6.000]	330						
8415000	LEONHARDITE	16.048	[-1.000]	2	[-16.000]	330	[2.000]	150		
			[8.000]	770	[4.000]	30				
8450002	LOW ALBITE	-1.109	[1.000]	500	[1.000]	30	[3.000]	770		
			[-4.000]	330	[-4.000]	2				
8450003	ANALBITE	-2.056	[1.000]	500	[1.000]	30	[3.000]	770		
			[-4.000]	330	[-4.000]	2				
8641000	MUSCOVITE	8.046	[1.000]	410	[3.000]	30	[3.000]	770		
			[-10.000]	330						
8641001	ANNITE	-3.507	[1.000]	410	[3.000]	280	[1.000]	30		
			[3.000]	770	[-10.000]	330				
8415001	ANORTHITE	-2.049	[1.000]	150	[2.000]	30	[2.000]	770		
			[-8.000]	330						
8603002	PYROPHYLLITE	6.289	[2.000]	30	[4.000]	770	[-4.000]	2		
			[-6.000]	330						
8415002	LAUMONTITE	1.712	[1.000]	150	[2.000]	30	[4.000]	770		
			[-8.000]	330						
8415003	WAIRAKITE	-2.856	[1.000]	150	[2.000]	30	[4.000]	770		
			[-8.000]	330	[-2.000]	2				
5023101	MALACHITE	-2.085	[2.000]	231	[2.000]	2	[1.000]	140		
			[-2.000]	330						
5023102	AZURITE	-4.409	[3.000]	231	[2.000]	2	[2.000]	140		
			[-2.000]	330						
3006000	ARSENOLITE	-77.083	[4.000]	60	[-6.000]	2				
3006001	CLAUDETITE	-76.832	[4.000]	60	[-6.000]	2				
3006100	AS2O5	-34.960	[2.000]	61	[-3.000]	2				
74001	Sb	-32.551	[1.000]	740	[3.000]	330	[3.000]	1		
			[-3.000]	2						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
1474001	NiSb Breitha	-43.184	[1.000]	740	[5.000]	1	[3.000]	330		
			[1.000]	540	[-3.000]	2				
1474002	ZnSb	-72.041	[1.000]	740	[5.000]	1	[1.000]	950		
			[3.000]	330	[-3.000]	2				
1474003	AlSb	-138.932	[1.000]	740	[6.000]	1	[1.000]	30		
			[3.000]	330	[-3.000]	2				
1474004	CdSb	-62.355	[1.000]	740	[5.000]	1	[3.000]	330		
			[1.000]	160	[-3.000]	2				
1474005	Mg2Sb3	-236.992	[2.000]	460	[3.000]	740	[9.000]	330		
			[13.000]	1	[-9.000]	2				
1474007	Na3Sb	-169.557	[3.000]	500	[1.000]	740	[3.000]	330		
			[6.000]	1	[-3.000]	2				
1474008	NaSb	-77.748	[1.000]	500	[1.000]	740	[3.000]	330		
			[4.000]	1	[-3.000]	2				
1474009	Mn2Sb	-136.475	[2.000]	470	[1.000]	740	[7.000]	1		
			[3.000]	330	[-3.000]	2				
1474010	Ca3Sb2	-275.053	[3.000]	150	[2.000]	740	[6.000]	330		
			[12.000]	1	[-6.000]	2				
1474013	MnSb	-82.163	[1.000]	471	[1.000]	740	[6.000]	1		
			[3.000]	330	[-3.000]	2				
2074001	Sb2O4	10.276	[2.000]	740	[-2.000]	2	[-2.000]	330		
			[-2.000]	1						
2074002	Sb4O6 II,CUB	-3.758	[4.000]	740	[-6.000]	2				
2074003	Sb4O6 I,ORTH	-6.452	[4.000]	740	[-6.000]	2				
2074004	Sb(OH)3 (s)	1.300	[1.000]	740						
2074005	Cu(SbO3)2	1.359	[2.000]	740	[1.000]	231	[-6.000]	330		
			[-4.000]	1						
2074006	Sb2O3 SENARM	0.658	[2.000]	740	[-3.000]	2				
2074007	Sb2O3 VALENT	-3.262	[2.000]	740	[-3.000]	2				
4274000	SbF3	-27.486	[1.000]	740	[3.000]	330	[3.000]	270		
			[-3.000]	2						
7203000	ALASO4.2W	-9.091	[1.000]	30	[1.000]	61	[2.000]	2		
			[-3.000]	330						
7215000	CA3(ASO4)26W	-14.156	[3.000]	150	[2.000]	61	[4.000]	2		
			[-6.000]	330						
7223100	CU3(ASO4)26W	-13.617	[3.000]	231	[2.000]	61	[2.000]	2		
			[-6.000]	330						
7228100	FEASO4.2W	-8.639	[1.000]	281	[1.000]	61	[2.000]	2		
			[-3.000]	330						
7247000	MN3ASO428W	-9.814	[3.000]	470	[2.000]	61	[8.000]	2		
			[-6.000]	330						
7254000	NI3(ASO4)28W	-19.140	[3.000]	540	[2.000]	61	[8.000]	2		
			[-6.000]	330						
7295000	ZN3ASO422.5W	-13.699	[3.000]	950	[2.000]	61	[2.500]	2		
			[-6.000]	330						
7210000	BA(ASO4)2	4.481	[3.000]	100	[2.000]	61	[-6.000]	330		
2015000	LIME	-21.263	[-2.000]	330	[1.000]	150	[1.000]	2		
2015001	PORTLANDITE	-10.946	[-2.000]	330	[1.000]	150	[2.000]	2		
2028000	WUSTITE	-5.409	[-2.000]	330	[0.947]	280	[1.000]	2		
2046001	PERICLASE	-10.617	[-2.000]	330	[1.000]	460	[1.000]	2		
3028001	HERCYNITE	-2.382	[-8.000]	330	[1.000]	280	[2.000]	30		
			[4.000]	2						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
3046000	SPINEL	-6.489	[-8.000]	330	[1.000]	460	[2.000]	30
			[4.000]	2				
3046001	MAG-FERRITE	5.464	[-8.000]	330	[1.000]	460	[2.000]	281
			[4.000]	2				
4250000	CRYOLITE	-12.893	[1.000]	30	[3.000]	500	[6.000]	270
8215002	WOLLASTONITE	-4.858	[-1.000]	2	[-2.000]	330	[1.000]	770
			[1.000]	150				
8215003	P-WOLLSTANIT	-5.727	[-1.000]	2	[-2.000]	330	[1.000]	770
			[1.000]	150				
8015001	CA-OLIVINE	-17.838	[-4.000]	330	[1.000]	770	[2.000]	150
8015002	LARNITE	-19.362	[-4.000]	330	[1.000]	770	[2.000]	150
8015007	CA3SIO5	-42.589	[-6.000]	330	[1.000]	770	[3.000]	150
			[1.000]	2				
8015003	MONTICELLITE	-11.163	[-4.000]	330	[1.000]	770	[1.000]	150
			[1.000]	460				
8015005	AKERMINITE	-20.319	[-1.000]	2	[-6.000]	330	[2.000]	770
			[2.000]	150	[1.000]	460		
8015004	MERWINITE	-29.660	[-8.000]	330	[2.000]	770	[1.000]	460
			[3.000]	150				
8441000	KALSILITE	-3.573	[-4.000]	330	[1.000]	770	[1.000]	30
			[1.000]	410				
8441001	LEUCITE	-0.803	[-2.000]	2	[-4.000]	330	[2.000]	770
			[1.000]	30	[1.000]	410		
8441002	MICROCLINE	1.395	[-4.000]	2	[-4.000]	330	[3.000]	770
			[1.000]	30	[1.000]	410		
8441003	H SANIDINE	0.925	[-4.000]	2	[-4.000]	330	[3.000]	770
			[1.000]	30	[1.000]	410		
8450004	NEPHELINE	-5.472	[-4.000]	330	[1.000]	770	[1.000]	30
			[1.000]	500				
8015006	GEHLENITE	-18.166	[-10.000]	330	[2.000]	30	[1.000]	770
			[2.000]	150	[3.000]	2		
3028102	LEPIDOCROCIT	4.488	[-3.000]	330	[1.000]	281	[2.000]	2
8650000	NA-NONTRONIT	16.784	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.330]	500	[3.670]	770
8641002	K-NONTRONITE	17.983	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.330]	410	[3.670]	770
8615000	CA-NONTRONIT	24.145	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.167]	150	[3.670]	770
8646005	MG-NONTRONIT	23.717	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.167]	460	[3.670]	770
8646006	Montmorillon	6.661	[3.810]	770	[0.490]	460	[-6.760]	330
			[-3.240]	2	[0.220]	281	[1.710]	30
2076200	SeO3	-43.641	[1.000]	762	[2.000]	330	[-1.000]	2
6110001	BaSeO4	-9.035	[1.000]	762	[1.000]	100		
6115001	CaSeO4:2H2O	-7.089	[1.000]	762	[1.000]	150	[2.000]	2
6180001	SrSeO4	-5.600	[1.000]	762	[1.000]	800		

STEADY STATE RESULTS

PART 1 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 31-OCT-97 TIME: 12: 5:22

STEADY STATE LEACHATE WASH FROM HUMIDITY CELL NO. 1 (SAMPLE T-24B)
(Cycle 20 - leachate collected Oct. 14, 1997)

Temperature (Celsius): 20.00
Units of concentration: MG/L
Ionic strength to be computed.
Carbonate concentration represents carbonate alkalinity.
Do not automatically terminate if charge imbalance exceeds 30%
Precipitation is allowed only for those solids specified as ALLOWED
in the input file (if any).
The maximum number of iterations is: 100
The method used to compute activity coefficients is: Davies equation
Intermediate output file

330	0.000E-01	-7.61	y
1	0.000E-01	-6.02	y
30	6.000E-03	-4.83	y
740	3.400E-03	-5.76	y
100	3.000E-02	-6.23	y
160	3.000E-04	-6.45	y
150	2.000E+01	-1.86	y
231	8.000E-03	-6.50	y
280	2.400E-02	-6.75	y
460	4.000E-02	-2.64	y
470	1.470E-01	-3.70	y
480	2.050E+00	-5.74	y
410	1.600E+00	-3.59	y
500	2.000E+00	-4.06	y
800	1.700E-01	-4.49	y
950	6.000E-03	-4.54	y
732	1.000E+01	-1.78	y
60	3.000E-03	-8.40	y
770	5.660E+00	-4.27	y
540	1.600E-02	-5.43	y
140	1.380E+00	-6.57	y
471	0.000E-01	-20.74	y
61	0.000E-01	-21.15	y
281	0.000E-01	-20.75	

H2O has been inserted as a COMPONENT

3 5		
4704710	25.5070	25.7600
600610	19.4440	-30.0150
2802810	13.0320	-10.0000
1	6.0175	0.0000
330	7.6100	0.0000

INPUT DATA BEFORE TYPE MODIFICATIONS

ID	NAME	ACTIVITY GUESS	LOG GUESS	ANAL TOTAL
330	H+1	2.455E-08	-7.610	0.000E-01
1	E-1	9.550E-07	-6.020	0.000E-01
30	Al+3	1.479E-05	-4.830	6.000E-03

740	Sb(OH)3	1.738E-06	-5.760	3.400E-03
100	Ba+2	5.888E-07	-6.230	3.000E-02
160	Cd+2	3.548E-07	-6.450	3.000E-04
150	Ca+2	1.380E-02	-1.860	2.000E+01
231	Cu+2	3.162E-07	-6.500	8.000E-03
280	Fe+2	1.778E-07	-6.750	2.400E-02
460	Mg+2	2.291E-03	-2.640	4.000E-02
470	Mn+2	1.995E-04	-3.700	1.470E-01
480	MoO4-2	1.820E-06	-5.740	2.050E+00
410	K+1	2.570E-04	-3.590	1.600E+00
500	Na+1	8.710E-05	-4.060	2.000E+00
800	Sr+2	3.236E-05	-4.490	1.700E-01
950	Zn+2	2.884E-05	-4.540	6.000E-03
732	SO4-2	1.660E-02	-1.780	1.000E+01
60	H3AsO3	3.981E-09	-8.400	3.000E-03
770	H4SiO4	5.370E-05	-4.270	5.660E+00
540	Ni+2	3.715E-06	-5.430	1.600E-02
140	CO3-2	2.692E-07	-6.570	1.380E+00
471	Mn+3	1.820E-21	-20.740	0.000E-01
61	H3AsO4	7.079E-22	-21.150	0.000E-01
281	Fe+3	1.778E-21	-20.750	0.000E-01
2	H2O	1.000E+00	0.000	0.000E-01

Charge Balance: UNSPECIATED

Sum of CATIONS= 1.141E-03 Sum of ANIONS = 2.798E-04

PERCENT DIFFERENCE = 6.062E+01 (ANIONS - CATIONS)/(ANIONS + CATIONS)

IMPROVED ACTIVITY GUESSES PRIOR TO FIRST ITERATION:

Al+3	Log activity guess:	-13.82
Sb(OH)3	Log activity guess:	-8.00
Cu+2	Log activity guess:	-7.05
Fe+2	Log activity guess:	-9.00
Mn+2	Log activity guess:	-5.57
SO4-2	Log activity guess:	-3.98
H3AsO3	Log activity guess:	-21.35
H4SiO4	Log activity guess:	-4.23
CO3-2	Log activity guess:	-7.43
Mn+3	Log activity guess:	-24.74
H3AsO4	Log activity guess:	-13.91
Fe+3	Log activity guess:	-16.14

PART 3 of OUTPUT FILE

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 31-OCT-97 TIME: 12: 5:23

PARAMETERS OF THE COMPONENT MOST OUT OF BALANCE:

ITER	NAME	TOTAL MOL	DIFF FXN	LOG ACTVTY	RESIDUAL
0	Ni+2	2.725E-07	4.568E-06	-5.43000	4.568E-06
1	Ni+2	2.725E-07	2.911E-07	-6.43000	2.911E-07
2	H4SiO4	5.889E-05	-8.599E-09	-4.23156	2.710E-09
3	Ni+2	2.725E-07	2.043E-10	-6.80748	1.770E-10

ID	NAME	ANAL MOL	CALC MOL	LOG ACTVTY	GAMMA	DIFF FXN
140	CO3-2	4.780E-05	8.716E-08	-7.12972	0.851096	1.995E-09
61	H3AsO4	0.000E-01	1.057E-14	-13.97569	1.000301	-7.830E-13
30	Al+3	2.224E-07	2.136E-14	-13.82790	0.695748	-1.081E-12
740	Sb(OH)3	1.968E-08	9.920E-09	-8.00335	1.000301	2.750E-15
100	Ba+2	2.184E-07	2.184E-07	-6.73069	0.851096	-7.844E-12
160	Cd+2	2.669E-09	2.562E-09	-8.66138	0.851096	-9.197E-14
150	Ca+2	4.990E-04	4.920E-04	-3.37803	0.851096	-1.765E-08
231	Cu+2	1.259E-07	4.031E-09	-8.46459	0.851096	-1.416E-13
280	Fe+2	4.298E-07	1.136E-09	-9.01462	0.851096	-2.803E-12
460	Mg+2	1.645E-06	1.625E-06	-5.85920	0.851096	-5.831E-11
470	Mn+2	2.676E-06	2.641E-06	-5.64831	0.851096	-9.478E-11
480	MoO4-2	1.282E-05	1.282E-05	-4.96221	0.851096	-4.602E-10
410	K+1	4.092E-05	4.090E-05	-4.40580	0.960494	-3.673E-10
500	Na+1	8.700E-05	8.696E-05	-4.07818	0.960494	-7.809E-10
800	Sr+2	1.940E-06	1.940E-06	-5.78217	0.851096	-6.967E-11
950	Zn+2	9.179E-08	8.520E-08	-7.13957	0.851096	-3.079E-12
732	SO4-2	1.041E-04	9.722E-05	-4.08225	0.851096	-3.478E-09
540	Ni+2	2.725E-07	1.830E-07	-6.80764	0.851096	-6.534E-12
770	H4SiO4	5.889E-05	5.866E-05	-4.23150	1.000301	6.186E-12
60	H3AsO3	2.382E-08	3.876E-22	-21.41145	1.000301	0.000E-01
330	H+1	0.000E-01	2.556E-08	-7.61000	0.960494	0.000E-01
1	E-1	0.000E-01	4.762E-07	-6.01750	0.960494	0.000E-01
471	Mn+3	0.000E-01	2.197E-25	-24.81577	0.695748	0.000E-01
2	H2O	0.000E-01	-2.416E-06	-0.00001	1.000000	0.000E-01
281	Fe+3	0.000E-01	1.008E-16	-16.15414	0.695748	0.000E-01

Type I - COMPONENTS AS SPECIES IN SOLUTION

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
330	H+1	2.556E-08	2.455E-08	-7.61000	0.96049	0.018
281	Fe+3	1.008E-16	7.012E-17	-16.15414	0.69575	0.158
30	Al+3	2.136E-14	1.486E-14	-13.82790	0.69575	0.158
740	Sb(OH)3	9.920E-09	9.923E-09	-8.00335	1.00030	0.000
100	Ba+2	2.184E-07	1.859E-07	-6.73069	0.85110	0.070
160	Cd+2	2.562E-09	2.181E-09	-8.66138	0.85110	0.070
150	Ca+2	4.920E-04	4.188E-04	-3.37803	0.85110	0.070
231	Cu+2	4.031E-09	3.431E-09	-8.46459	0.85110	0.070
280	Fe+2	1.136E-09	9.669E-10	-9.01462	0.85110	0.070
460	Mg+2	1.625E-06	1.383E-06	-5.85920	0.85110	0.070
470	Mn+2	2.641E-06	2.247E-06	-5.64831	0.85110	0.070
480	MoO4-2	1.282E-05	1.091E-05	-4.96221	0.85110	0.070
410	K+1	4.090E-05	3.928E-05	-4.40580	0.96049	0.018
500	Na+1	8.696E-05	8.353E-05	-4.07818	0.96049	0.018

800	Sr+2	1.940E-06	1.651E-06	-5.78217	0.85110	0.070
950	Zn+2	8.520E-08	7.251E-08	-7.13957	0.85110	0.070
732	SO4-2	9.722E-05	8.275E-05	-4.08225	0.85110	0.070
60	H3AsO3	3.876E-22	3.877E-22	-21.41145	1.00030	0.000
770	H4SiO4	5.866E-05	5.868E-05	-4.23150	1.00030	0.000
540	Ni+2	1.830E-07	1.557E-07	-6.80764	0.85110	0.070
140	CO3-2	8.716E-08	7.418E-08	-7.12972	0.85110	0.070
471	Mn+3	2.197E-25	1.528E-25	-24.81577	0.69575	0.158
61	H3AsO4	1.057E-14	1.058E-14	-13.97569	1.00030	0.000

Type II - OTHER SPECIES IN SOLUTION OR ADSORBED

ID	NAME	CALC MOL	ACTIVITY	LOG ACTVTY	GAMMA	NEW LOGK
3301400	HCO3 -	4.513E-05	4.334E-05	-4.36309	0.96049	10.394
3301401	H2CO3 AQ	2.287E-06	2.288E-06	-5.64063	1.00030	16.709
3307320	HSO4 -	1.789E-10	1.718E-10	-9.76501	0.96049	1.945
3300020	OH-	2.902E-07	2.787E-07	-6.55484	0.96049	-14.147
3307700	H3SiO4 -	2.260E-07	2.171E-07	-6.66338	0.96049	-10.024
3307701	H2SiO4 -2	1.161E-11	9.881E-12	-11.00522	0.85110	-21.924
4603300	MgOH +	6.190E-11	5.945E-11	-10.22583	0.96049	-11.959
4601400	MgCO3 AQ	9.064E-11	9.067E-11	-10.04254	1.00030	2.946
4601401	MgHCO3 +	7.049E-10	6.770E-10	-9.16939	0.96049	11.447
4607320	MgSO4 AQ	1.954E-08	1.955E-08	-7.70893	1.00030	2.232
1503300	CaOH +	2.950E-09	2.833E-09	-8.54774	0.96049	-12.762
1501400	CaHCO3 +	1.680E-07	1.614E-07	-6.79209	0.96049	11.343
1501401	CaCO3 AQ	3.974E-08	3.975E-08	-7.40066	1.00030	3.107
1507320	CaSO4 AQ	6.764E-06	6.766E-06	-5.16965	1.00030	2.290
5001400	NaCO3 -	9.251E-11	8.886E-11	-10.05130	0.96049	1.174
5001401	NaHCO3 AQ	1.828E-09	1.829E-09	-8.73790	1.00030	10.080
5007320	NaSO4 -	3.492E-08	3.354E-08	-7.47443	0.96049	0.704
4107320	KSO4 -	2.176E-08	2.090E-08	-7.67977	0.96049	0.826
303300	AlOH +2	5.169E-12	4.399E-12	-11.35666	0.85110	-5.069
303301	Al(OH)2 +	2.040E-09	1.959E-09	-8.70791	0.96049	-10.082
303302	Al(OH)4 -	1.199E-07	1.152E-07	-6.93873	0.96049	-23.533
307320	AlSO4 +	1.260E-15	1.211E-15	-14.91702	0.96049	3.011
307321	Al(SO4)2 -	8.121E-18	7.800E-18	-17.10789	0.96049	4.902
303303	Al(OH)3 AQ	1.005E-07	1.005E-07	-6.99791	1.00030	-16.000
2803300	FeOH +	8.869E-12	8.519E-12	-11.06963	0.96049	-9.648
2803301	FeOH3 -1	2.845E-18	2.733E-18	-17.56343	0.96049	-31.361
2807320	FeSO4 AQ	1.296E-11	1.296E-11	-10.88725	1.00030	2.209
2803302	FeOH2 AQ	1.897E-15	1.898E-15	-14.72174	1.00030	-20.927
2813300	FeOH +2	1.606E-11	1.367E-11	-10.86414	0.85110	-2.250
2817320	FeSO4 +	4.490E-17	4.313E-17	-16.36526	0.96049	3.889
2813301	FeOH2 +	2.590E-07	2.488E-07	-6.60415	0.96049	-5.652
2813302	FeOH3 AQ	1.190E-07	1.191E-07	-6.92415	1.00030	-13.600
2813303	FeOH4 -	5.051E-08	4.851E-08	-7.31416	0.96049	-21.582
2817321	Fe(SO4)2 -	1.152E-19	1.106E-19	-18.95613	0.96049	5.380
2813304	Fe2(OH)2+4	1.183E-20	6.208E-21	-20.20705	0.52470	-2.839
2813305	Fe3(OH)4+5	8.638E-25	3.154E-25	-24.50120	0.36506	-6.041
8003300	SrOH +	3.063E-12	2.942E-12	-11.53139	0.96049	-13.342
1003300	BaOH +	2.239E-13	2.151E-13	-12.66741	0.96049	-13.529
4703300	MnOH +	1.619E-09	1.555E-09	-8.80832	0.96049	-10.753
4703301	Mn(OH)3 -1	2.507E-18	2.408E-18	-17.61833	0.96049	-34.782
4700020	MnO4 -	2.017E-45	1.937E-45	-44.71284	0.96049	-130.015
4700021	MnO4 -2	1.138E-41	9.687E-42	-41.01380	0.85110	-120.245
4707320	MnSO4 AQ	3.178E-08	3.179E-08	-7.49768	1.00030	2.233
4701400	MnHCO3 +	1.696E-09	1.629E-09	-8.78803	0.96049	11.618
2311400	CuCO3 AQ	1.366E-09	1.367E-09	-8.86431	1.00030	6.730

2311401	Cu(CO3)2-2	1.500E-13	1.276E-13	-12.89404	0.85110	9.900
2313300	CuOH +	1.455E-09	1.398E-09	-8.85460	0.96049	-7.982
2313301	Cu(OH)2 AQ	1.189E-07	1.190E-07	-6.92460	1.00030	-13.680
2313302	Cu(OH)3 -	3.047E-13	2.927E-13	-12.53361	0.96049	-26.881
2313303	Cu(OH)4 -2	2.789E-18	2.373E-18	-17.62462	0.85110	-39.530
2313304	Cu2(OH)2+2	6.068E-13	5.165E-13	-12.28697	0.85110	-10.508
2317320	CuSO4 AQ	5.595E-11	5.596E-11	-10.25209	1.00030	2.295
2311402	CuHCO3 +	6.504E-11	6.247E-11	-10.20431	0.96049	13.018
9503300	ZnOH +	2.293E-09	2.202E-09	-8.65709	0.96049	-9.110
9503301	Zn(OH)2 AQ	1.518E-09	1.518E-09	-8.81859	1.00030	-16.899
9503302	Zn(OH)3 -	2.037E-13	1.956E-13	-12.70859	0.96049	-28.381
9503303	Zn(OH)4 -2	1.484E-18	1.263E-18	-17.89860	0.85110	-41.129
9507320	ZnSO4 AQ	1.352E-09	1.353E-09	-8.86882	1.00030	2.353
9507321	Zn(SO4)2-2	1.112E-12	9.461E-13	-12.02407	0.85110	3.350
9501400	ZnHCO3 +	3.453E-10	3.317E-10	-9.47930	0.96049	12.418
9501401	ZnCO3 AQ	1.073E-09	1.073E-09	-8.96930	1.00030	5.300
9501402	Zn(CO3)2-2	2.000E-12	1.702E-12	-11.76902	0.85110	9.700
1601400	Cd(CO3)3-4	2.815E-24	1.477E-24	-23.83055	0.52470	6.500
1603300	CdOH +	5.277E-12	5.068E-12	-11.29515	0.96049	-10.226
1603301	Cd(OH)2 AQ	1.616E-14	1.617E-14	-13.79139	1.00030	-20.350
1603302	Cd(OH)3 -	7.693E-20	7.389E-20	-19.13140	0.96049	-33.282
1603303	Cd(OH)4 -2	3.152E-26	2.683E-26	-25.57140	0.85110	-47.280
1603304	Cd2OH +3	8.290E-20	5.767E-20	-19.23902	0.69575	-9.369
1607320	CdSO4 AQ	5.044E-11	5.045E-11	-10.29712	1.00030	2.446
1601400	CdHCO3 +	1.038E-11	9.975E-12	-11.00110	0.96049	12.418
1601401	CdCO3 AQ	4.053E-11	4.054E-11	-10.39210	1.00030	5.399
1607321	Cd(SO4)2-2	5.548E-14	4.722E-14	-13.32587	0.85110	3.570
5403300	NiOH +	6.377E-10	6.125E-10	-9.21291	0.96049	-9.998
5403301	Ni(OH)2 AQ	2.584E-11	2.584E-11	-10.58765	1.00030	-19.000
5403302	Ni(OH)3 -	1.096E-14	1.053E-14	-13.97765	0.96049	-29.982
5407320	NiSO4 AQ	2.404E-09	2.405E-09	-8.61888	1.00030	2.271
5401400	NiHCO3 +	8.713E-10	8.368E-10	-9.07736	0.96049	12.488
5401401	NiCO3 AQ	8.561E-08	8.563E-08	-7.06736	1.00030	6.870
5401402	Ni(CO3)2-2	1.297E-11	1.104E-11	-10.95708	0.85110	10.180
5407321	Ni(SO4)2-2	1.312E-14	1.117E-14	-13.95213	0.85110	1.090
3300600	H2AsO3 -	8.055E-24	7.736E-24	-23.11146	0.96049	-9.293
3300601	HAsO3 -2	2.350E-28	2.000E-28	-27.69896	0.85110	-21.437
3300602	AsO3 -3	3.793E-34	2.639E-34	-33.57860	0.69575	-34.840
3300603	H4AsO3 +	4.910E-30	4.716E-30	-29.32645	0.96049	-0.287
3300611	H2AsO4 -	2.691E-09	2.585E-09	-8.58756	0.96049	-2.204
3300612	HAsO4 -2	2.113E-08	1.798E-08	-7.74519	0.85110	-8.919
3300613	AsO4 -3	2.355E-12	1.638E-12	-11.78557	0.69575	-20.482
7400021	HSbO2	9.759E-09	9.762E-09	-8.01046	1.00030	-0.007
7403300	SbO+	2.006E-15	1.927E-15	-14.71517	0.96049	0.916
7403301	SbO2-	4.105E-13	3.943E-13	-12.40416	0.96049	-11.993
7403302	Sb(OH)2+	6.158E-15	5.915E-15	-14.22804	0.96049	1.403
7400020	Sb(OH)4-1	2.358E-13	2.265E-13	-12.64497	0.96049	-12.234

Type III - SPECIES WITH FIXED ACTIVITY

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
2	H2O	-2.416E-06	-5.617	0.000	0.000
330	H+1	-4.718E-05	-4.326	7.610	0.000
1	E-1	4.762E-07	-6.322	6.018	0.000
4704710	Mn+2/Mn+3	-2.197E-25	-24.658	25.185	25.760
600610	AsO3/AsO4	-2.382E-08	-7.623	19.819	-30.015
2802810	Fe+2/Fe+3	-4.286E-07	-6.368	13.157	-10.000

Type VI - EXCLUDED SPECIES (not included in mole balance)

ID	NAME	CALC MOL	LOG MOL	NEW LOGK	DH
3301404	CH4 (g)	0.000E-01	-90.507	40.863	-61.000
3301403	CO2 (g)	6.560E-05	-4.183	18.167	-0.530
3300021	O2 (g)	5.211E-31	-30.283	-84.793	133.830

PC MINTEQA2 v3.10 DATE OF CALCULATIONS: 31-OCT-97 TIME: 12: 5:23

Saturation indices and stoichiometry of all minerals

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
2003000	ALOH3(A)	-1.716	[1.000]	30	[3.000]	2	[-3.000]	330		
6003000	ALOHSO4	-7.070	[-1.000]	330	[1.000]	30	[1.000]	732		
			[1.000]	2						
6003001	AL4(OH)10SO4	-5.994	[-10.000]	330	[4.000]	30	[1.000]	732		
			[10.000]	2						
6041000	ALUM K	-21.138	[1.000]	410	[1.000]	30	[2.000]	732		
			[12.000]	2						
6041001	ALUNITE	-6.999	[1.000]	410	[3.000]	30	[2.000]	732		
			[6.000]	2	[-6.000]	330				
6015000	ANHYDRITE	-2.870	[1.000]	150	[1.000]	732				
5015000	ARAGONITE	-2.216	[1.000]	150	[1.000]	140				
5046000	ARTINITE	-13.587	[-2.000]	330	[2.000]	460	[1.000]	140		
			[5.000]	2						
6010000	BARITE	-0.758	[1.000]	100	[1.000]	732				
2003001	BOEHMITE	0.072	[-3.000]	330	[1.000]	30	[2.000]	2		
2046000	BRUCITE	-7.754	[1.000]	460	[2.000]	2	[-2.000]	330		
5015001	CALCITE	-2.062	[1.000]	150	[1.000]	140				
6080000	CELESTITE	-3.405	[1.000]	800	[1.000]	732				
2077000	CHALCEDONY	-0.651	[-2.000]	2	[1.000]	770				
8646000	CHRYSOTILE	-13.225	[-6.000]	330	[3.000]	460	[2.000]	770		
			[1.000]	2						
8246000	CLINOENSTITE	-6.459	[-1.000]	2	[1.000]	460	[1.000]	770		
			[-2.000]	330						
2077001	CRISTOBALITE	-0.576	[-2.000]	2	[1.000]	770				
2003002	DIASPORE	1.821	[-3.000]	330	[1.000]	30	[2.000]	2		
8215000	DIOPSIDE	-7.550	[-2.000]	2	[1.000]	150	[1.000]	460		
			[2.000]	770	[-4.000]	330				
5015002	DOLOMITE	-6.600	[1.000]	150	[1.000]	460	[2.000]	140		
6046000	EPSOMITE	-7.766	[1.000]	460	[1.000]	732	[7.000]	2		
8646003	SEPIOLITE(C)	-10.227	[-0.500]	2	[2.000]	460	[3.000]	770		
			[-4.000]	330						
2028100	FERRIHYDRITE	1.785	[-3.000]	330	[1.000]	281	[3.000]	2		
2028101	FE3(OH)8	-0.665	[-8.000]	330	[2.000]	281	[1.000]	280		
			[8.000]	2						
6028100	FE2(SO4)3	-48.874	[2.000]	281	[3.000]	732				
8046000	FORSTERITE	-14.414	[-4.000]	330	[2.000]	460	[1.000]	770		
2003003	GIBBSITE (C)	-0.053	[-3.000]	330	[1.000]	30	[3.000]	2		
3003000	Al2O3	-4.976	[2.000]	30	[3.000]	2	[-6.000]	330		
2028102	GOETHITE	5.995	[-3.000]	330	[1.000]	281	[2.000]	2		
8628000	GREENALITE	-10.657	[-6.000]	330	[3.000]	280	[2.000]	770		
			[1.000]	2						
6015001	GYPSUM	-2.609	[1.000]	150	[1.000]	732	[2.000]	2		
3028100	HEMATITE	16.974	[-6.000]	330	[2.000]	281	[3.000]	2		

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
5015003	HUNTITE	-19.829	[3.000]	460	[1.000]	150	[4.000]	140		
5046001	HYDRMAGNESIT	-34.482	[5.000]	460	[4.000]	140	[-2.000]	330		
			[6.000]	2						
6050000	JAROSITE NA	-4.297	[-6.000]	330	[1.000]	500	[3.000]	281		
			[2.000]	732	[6.000]	2				
6041002	JAROSITE K	-0.964	[-6.000]	330	[1.000]	410	[3.000]	281		
			[2.000]	732	[6.000]	2				
6028101	JAROSITE H	-7.166	[-5.000]	330	[3.000]	281	[2.000]	732		
			[7.000]	2						
8450000	MAGADIITE	-11.789	[-1.000]	330	[-9.000]	2	[1.000]	500		
			[7.000]	770						
3028101	MAGHEMITE	6.966	[-6.000]	330	[2.000]	281	[3.000]	2		
5046002	MAGNESITE	-5.037	[1.000]	460	[1.000]	140				
3028000	MAGNETITE	15.189	[-8.000]	330	[2.000]	281	[1.000]	280		
			[4.000]	2						
6028000	MELANTERITE	-10.591	[1.000]	280	[1.000]	732	[7.000]	2		
6050001	MIRABILITE	-10.887	[2.000]	500	[1.000]	732	[10.000]	2		
3050000	NATRON	-13.778	[2.000]	500	[1.000]	140	[10.000]	2		
5046003	NESQUEHONITE	-7.440	[1.000]	460	[1.000]	140	[3.000]	2		
8646001	PHLOGOPITE	-39.785	[-10.000]	330	[1.000]	410	[3.000]	460		
			[1.000]	30	[3.000]	770				
2077002	QUARTZ	-0.148	[-2.000]	2	[1.000]	770				
8646004	SEPIOLITE(A)	-12.753	[-0.500]	2	[2.000]	460	[3.000]	770		
			[-4.000]	330						
5028000	SIDERITE	-5.661	[1.000]	280	[1.000]	140				
2077003	SIO2(A,GL)	-1.158	[-2.000]	2	[1.000]	770				
2077004	SIO2(A,PT)	-1.473	[-2.000]	2	[1.000]	770				
5080000	STRONTIANITE	-3.671	[1.000]	800	[1.000]	140				
8646002	TALC	-12.336	[-4.000]	2	[3.000]	460	[4.000]	770		
			[-6.000]	330						
6050002	THENARDITE	-12.067	[2.000]	500	[1.000]	732				
5050001	THERMONATR	-15.446	[2.000]	500	[1.000]	140	[1.000]	2		
8215001	TREMOLITE	-21.118	[-8.000]	2	[2.000]	150	[5.000]	460		
			[8.000]	770	[-14.000]	330				
5010000	WITHERITE	-5.271	[1.000]	100	[1.000]	140				
2047000	PYROLUSITE	-4.584	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
2047001	BIRNESSITE	-6.449	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
2047002	NSUTITE	-5.862	[-4.000]	330	[-1.000]	1	[1.000]	471		
			[2.000]	2						
3047100	BIXBYITE	-3.551	[-6.000]	330	[2.000]	471	[3.000]	2		
3047000	HAUSMANNITE	-6.572	[-8.000]	330	[-2.000]	1	[3.000]	470		
			[4.000]	2						
2047003	PYROCROITE	-5.799	[-2.000]	330	[1.000]	470	[2.000]	2		
2047100	MANGANITE	-1.748	[-3.000]	330	[1.000]	471	[2.000]	2		
5047000	RHODOCHROSIT	-2.394	[1.000]	470	[1.000]	140				
6047000	MNSO4	-12.593	[1.000]	470	[1.000]	732				
6047100	MN2(SO4)3	-56.656	[2.000]	471	[3.000]	732				
5023100	CUCO3	-5.964	[1.000]	231	[1.000]	140				
2023100	CU(OH)2	-2.075	[-2.000]	330	[1.000]	231	[2.000]	2		

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
6023100	ANTLERITE	-7.326	[-4.000]	330	[3.000]	231	[4.000]	2		
			[1.000]	732						
6023101	BROCHANTITE	-7.621	[-6.000]	330	[4.000]	231	[6.000]	2		
			[1.000]	732						
6023102	LANGITE	-9.566	[-6.000]	330	[4.000]	231	[7.000]	2		
			[1.000]	732						
2023101	TENORITE	-1.055	[-2.000]	330	[1.000]	231	[1.000]	2		
6023103	CUOCUSO4	-17.766	[-2.000]	330	[2.000]	231	[1.000]	2		
			[1.000]	732						
6023104	CUSO4	-15.784	[1.000]	231	[1.000]	732				
6023105	CHALCANTHITE	-9.889	[1.000]	231	[1.000]	732	[5.000]	2		
2023102	DIOPTASE	-4.088	[-2.000]	330	[1.000]	231	[1.000]	770		
3023100	CUPRICFERIT	13.743	[-8.000]	330	[1.000]	231	[2.000]	281		
			[4.000]	2						
95000	ZN METAL	-45.391	[1.000]	950	[2.000]	1				
5095000	SMITHSONITE	-4.324	[1.000]	950	[1.000]	140				
5095001	ZNCO3, 1H2O	-4.009	[1.000]	950	[1.000]	140	[1.000]	2		
2095000	ZN(OH)2 (A)	-4.370	[-2.000]	330	[1.000]	950	[2.000]	2		
2095001	ZN(OH)2 (C)	-4.120	[-2.000]	330	[1.000]	950	[2.000]	2		
2095002	ZN(OH)2 (B)	-3.670	[-2.000]	330	[1.000]	950	[2.000]	2		
2095003	ZN(OH)2 (G)	-3.630	[-2.000]	330	[1.000]	950	[2.000]	2		
2095004	ZN(OH)2 (E)	-3.420	[-2.000]	330	[1.000]	950	[2.000]	2		
6095000	ZN2(OH)2SO4	-10.641	[-2.000]	330	[2.000]	950	[2.000]	2		
			[1.000]	732						
6095001	ZN4(OH)6SO4	-15.381	[-6.000]	330	[4.000]	950	[6.000]	2		
			[1.000]	732						
2095005	ZNO(ACTIVE)	-3.230	[-2.000]	330	[1.000]	950	[1.000]	2		
2095006	ZINCITE	-3.333	[-2.000]	330	[1.000]	950	[1.000]	2		
6095002	ZN3O(SO4)2	-34.158	[-2.000]	330	[3.000]	950	[2.000]	732		
			[1.000]	2						
8295000	ZNSIO3	0.691	[-2.000]	330	[-1.000]	2	[1.000]	950		
			[1.000]	770						
8095000	WILLEMITE	-3.818	[-4.000]	330	[2.000]	950	[1.000]	770		
6095003	ZINCOSITE	-14.472	[1.000]	950	[1.000]	732				
6095004	ZNSO4, 1H2O	-10.785	[1.000]	950	[1.000]	732	[1.000]	2		
6095005	BIANCHITE	-9.459	[1.000]	950	[1.000]	732	[6.000]	2		
6095006	GOSLARITE	-9.221	[1.000]	950	[1.000]	732	[7.000]	2		
16000	CD METAL	-34.411	[1.000]	160	[2.000]	1				
16001	GAMMA CD	-34.513	[1.000]	160	[2.000]	1				
5016000	OTAVITE	-2.058	[1.000]	160	[1.000]	140				
2016000	CD(OH)2 (A)	-7.431	[-2.000]	330	[1.000]	160	[2.000]	2		
2016001	CD(OH)2 (C)	-7.091	[-2.000]	330	[1.000]	160	[2.000]	2		
6016000	CD3(OH)4SO4	-22.186	[-4.000]	330	[3.000]	160	[4.000]	2		
			[1.000]	732						
6016001	CD3OH2(SO4)2	-25.639	[-2.000]	330	[3.000]	160	[2.000]	2		
			[2.000]	732						
6016002	CD4(OH)6SO4	-21.468	[-6.000]	330	[4.000]	160	[6.000]	2		
			[1.000]	732						
2016002	MONTEPONITE	-8.871	[-2.000]	330	[1.000]	160	[1.000]	2		
8216000	CDSIO3	-6.941	[-1.000]	2	[1.000]	160	[1.000]	770		
			[-2.000]	330						

ID #	NAME	Sat. Index	Stoichiometry in [brackets]							
6016003	CDSO4	-12.828	[1.000]	160	[1.000]	732				
6016004	CDSO4, 1H2O	-11.181	[1.000]	160	[1.000]	732	[1.000]	2		
6016005	CDSO4,2.7H2O	-10.924	[1.000]	160	[1.000]	732	[2.670]	2		
5054000	NICO3	-7.222	[1.000]	540	[1.000]	140				
2054000	NI(OH)2	-2.007	[-2.000]	330	[1.000]	540	[2.000]	2		
6054000	NI4(OH)6SO4	-17.653	[-6.000]	330	[4.000]	540	[1.000]	732		
			[6.000]	2						
2054001	BUNSENITE	-4.337	[-2.000]	330	[1.000]	540	[1.000]	2		
6054001	RETGERSITE	-8.836	[1.000]	540	[1.000]	732	[6.000]	2		
6054002	MORENOSITE	-8.493	[1.000]	540	[1.000]	732	[7.000]	2		
8054000	NI2SIO4	-2.364	[-4.000]	330	[2.000]	540	[1.000]	770		
8450001	ANALCIME	-2.934	[1.000]	500	[1.000]	30	[2.000]	770		
			[-1.000]	2	[-4.000]	330				
8603000	HALLOYSITE	0.051	[2.000]	30	[2.000]	770	[1.000]	2		
			[-6.000]	330						
8603001	KAOLINITE	3.374	[2.000]	30	[2.000]	770	[1.000]	2		
			[-6.000]	330						
8415000	LEONHARDITE	8.283	[-1.000]	2	[-16.000]	330	[2.000]	150		
			[8.000]	770	[4.000]	30				
8450002	LOW ALBITE	-2.970	[1.000]	500	[1.000]	30	[3.000]	770		
			[-4.000]	330	[-4.000]	2				
8450003	ANALBITE	-3.917	[1.000]	500	[1.000]	30	[3.000]	770		
			[-4.000]	330	[-4.000]	2				
8641000	MUSCOVITE	3.784	[1.000]	410	[3.000]	30	[3.000]	770		
			[-10.000]	330						
8641001	ANNITE	-5.984	[1.000]	410	[3.000]	280	[1.000]	30		
			[3.000]	770	[-10.000]	330				
8415001	ANORTHITE	-4.930	[1.000]	150	[2.000]	30	[2.000]	770		
			[-8.000]	330						
8603002	PYROPHYLLITE	2.676	[2.000]	30	[4.000]	770	[-4.000]	2		
			[-6.000]	330						
8415002	LAUMONTITE	-2.171	[1.000]	150	[2.000]	30	[4.000]	770		
			[-8.000]	330						
8415003	WAIRAKITE	-6.739	[1.000]	150	[2.000]	30	[4.000]	770		
			[-8.000]	330	[-2.000]	2				
5023101	MALACHITE	-3.854	[2.000]	231	[2.000]	2	[1.000]	140		
			[-2.000]	330						
5023102	AZURITE	-7.810	[3.000]	231	[2.000]	2	[2.000]	140		
			[-2.000]	330						
3006000	ARSENOLITE	-82.666	[4.000]	60	[-6.000]	2				
3006001	CLAUDETITE	-82.415	[4.000]	60	[-6.000]	2				
3006100	AS2O5	-34.718	[2.000]	61	[-3.000]	2				
74001	Sb	-36.929	[1.000]	740	[3.000]	330	[3.000]	1		
			[-3.000]	2						
1474001	NiSb Breitha	-48.919	[1.000]	740	[5.000]	1	[3.000]	330		
			[1.000]	540	[-3.000]	2				
1474002	ZnSb	-79.238	[1.000]	740	[5.000]	1	[1.000]	950		
			[3.000]	330	[-3.000]	2				
1474003	AlSb	-146.390	[1.000]	740	[6.000]	1	[1.000]	30		
			[3.000]	330	[-3.000]	2				
1474004	CdSb	-69.121	[1.000]	740	[5.000]	1	[3.000]	330		
			[1.000]	160	[-3.000]	2				

ID #	NAME	Sat. Index	Stoichiometry in [brackets]					
1474005	Mg2Sb3	-257.130	[2.000]	460	[3.000]	740	[9.000]	330
			[13.000]	1	[-9.000]	2		
1474007	Na3Sb	-174.872	[3.000]	500	[1.000]	740	[3.000]	330
			[6.000]	1	[-3.000]	2		
1474008	NaSb	-82.438	[1.000]	500	[1.000]	740	[3.000]	330
			[4.000]	1	[-3.000]	2		
1474009	Mn2Sb	-145.332	[2.000]	470	[1.000]	740	[7.000]	1
			[3.000]	330	[-3.000]	2		
1474010	Ca3Sb2	-289.174	[3.000]	150	[2.000]	740	[6.000]	330
			[12.000]	1	[-6.000]	2		
1474013	MnSb	-88.781	[1.000]	471	[1.000]	740	[6.000]	1
			[3.000]	330	[-3.000]	2		
2074001	Sb2O4	7.585	[2.000]	740	[-2.000]	2	[-2.000]	330
			[-2.000]	1				
2074002	Sb4O6 II,CUB	-12.172	[4.000]	740	[-6.000]	2		
2074003	Sb4O6 I,ORTH	-14.866	[4.000]	740	[-6.000]	2		
2074004	Sb(OH)3 (s)	-0.803	[1.000]	740				
2074005	Cu(SbO3)2	0.048	[2.000]	740	[1.000]	231	[-6.000]	330
			[-4.000]	1				
2074006	Sb2O3 SENARM	-3.550	[2.000]	740	[-3.000]	2		
2074007	Sb2O3 VALENT	-7.469	[2.000]	740	[-3.000]	2		
7203000	ALASO4.2W	-9.774	[1.000]	30	[1.000]	61	[2.000]	2
			[-3.000]	330				
7215000	CA3(ASO4)26W	-14.725	[3.000]	150	[2.000]	61	[4.000]	2
			[-6.000]	330				
7223100	CU3(ASO4)26W	-13.785	[3.000]	231	[2.000]	61	[2.000]	2
			[-6.000]	330				
7228100	FEASO4.2W	-7.700	[1.000]	281	[1.000]	61	[2.000]	2
			[-3.000]	330				
7247000	MN3ASO428W	-11.736	[3.000]	470	[2.000]	61	[8.000]	2
			[-6.000]	330				
7254000	NI3(ASO4)28W	-18.414	[3.000]	540	[2.000]	61	[8.000]	2
			[-6.000]	330				
7295000	ZN3ASO422.5W	-17.360	[3.000]	950	[2.000]	61	[2.500]	2
			[-6.000]	330				
7210000	BA(ASO4)2	6.460	[3.000]	100	[2.000]	61	[-6.000]	330
2015000	LIME	-21.533	[-2.000]	330	[1.000]	150	[1.000]	2
2015001	PORTLANDITE	-11.217	[-2.000]	330	[1.000]	150	[2.000]	2
2028000	WUSTITE	-5.314	[-2.000]	330	[0.947]	280	[1.000]	2
2046001	PERICLASE	-12.601	[-2.000]	330	[1.000]	460	[1.000]	2
3028001	HERCYNITE	-3.932	[-8.000]	330	[1.000]	280	[2.000]	30
			[4.000]	2				
3046000	SPINEL	-10.082	[-8.000]	330	[1.000]	460	[2.000]	30
			[4.000]	2				
3046001	MAG-FERRITE	5.114	[-8.000]	330	[1.000]	460	[2.000]	281
			[4.000]	2				
8215002	WOLLASTONITE	-5.629	[-1.000]	2	[-2.000]	330	[1.000]	770
			[1.000]	150				
8215003	P-WOLLSTANIT	-6.499	[-1.000]	2	[-2.000]	330	[1.000]	770
			[1.000]	150				
8015001	CA-OLIVINE	-18.880	[-4.000]	330	[1.000]	770	[2.000]	150

ID #	NAME	Sat. Index	Stoichiometry in [brackets]					
8015002	LARNITE	-20.404	[-4.000]	330	[1.000]	770	[2.000]	150
8015007	CA3SIO5	-43.902	[-6.000]	330	[1.000]	770	[3.000]	150
			[1.000]	2				
8015003	MONTICELLITE	-13.919	[-4.000]	330	[1.000]	770	[1.000]	150
			[1.000]	460				
8015005	AKERMINITE	-23.846	[-1.000]	2	[-6.000]	330	[2.000]	770
			[2.000]	150	[1.000]	460		
8015004	MERWINITE	-33.458	[-8.000]	330	[2.000]	770	[1.000]	460
			[3.000]	150				
8441000	KALSILITE	-5.225	[-4.000]	330	[1.000]	770	[1.000]	30
			[1.000]	410				
8441001	LEUCITE	-2.956	[-2.000]	2	[-4.000]	330	[2.000]	770
			[1.000]	30	[1.000]	410		
8441002	MICROCLINE	-1.258	[-4.000]	2	[-4.000]	330	[3.000]	770
			[1.000]	30	[1.000]	410		
8441003	H SANIDINE	-1.728	[-4.000]	2	[-4.000]	330	[3.000]	770
			[1.000]	30	[1.000]	410		
8450004	NEPHELINE	-6.331	[-4.000]	330	[1.000]	770	[1.000]	30
			[1.000]	500				
8015006	GEHLENITE	-20.817	[-10.000]	330	[2.000]	30	[1.000]	770
			[2.000]	150	[3.000]	2		
3028102	LEPIDOCROCIT	5.305	[-3.000]	330	[1.000]	281	[2.000]	2
8650000	NA-NONTRONIT	16.462	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.330]	500	[3.670]	770
8641002	K-NONTRONITE	17.399	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.330]	410	[3.670]	770
8615000	CA-NONTRONIT	23.629	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.167]	150	[3.670]	770
8646005	MG-NONTRONIT	22.915	[-7.320]	330	[-2.680]	2	[0.330]	30
			[2.000]	281	[0.167]	460	[3.670]	770
8646006	Montmorillon	2.581	[3.810]	770	[0.490]	460	[-6.760]	330
			[-3.240]	2	[0.220]	281	[1.710]	30

Report No. 052002/1

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Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico

Appendices A-E

Received
JAN 18 2000
6WQ-PP

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UNOCAL 76
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October 1997

APPENDIX A

Results of Sensitivity Analysis for Regional Flow Model

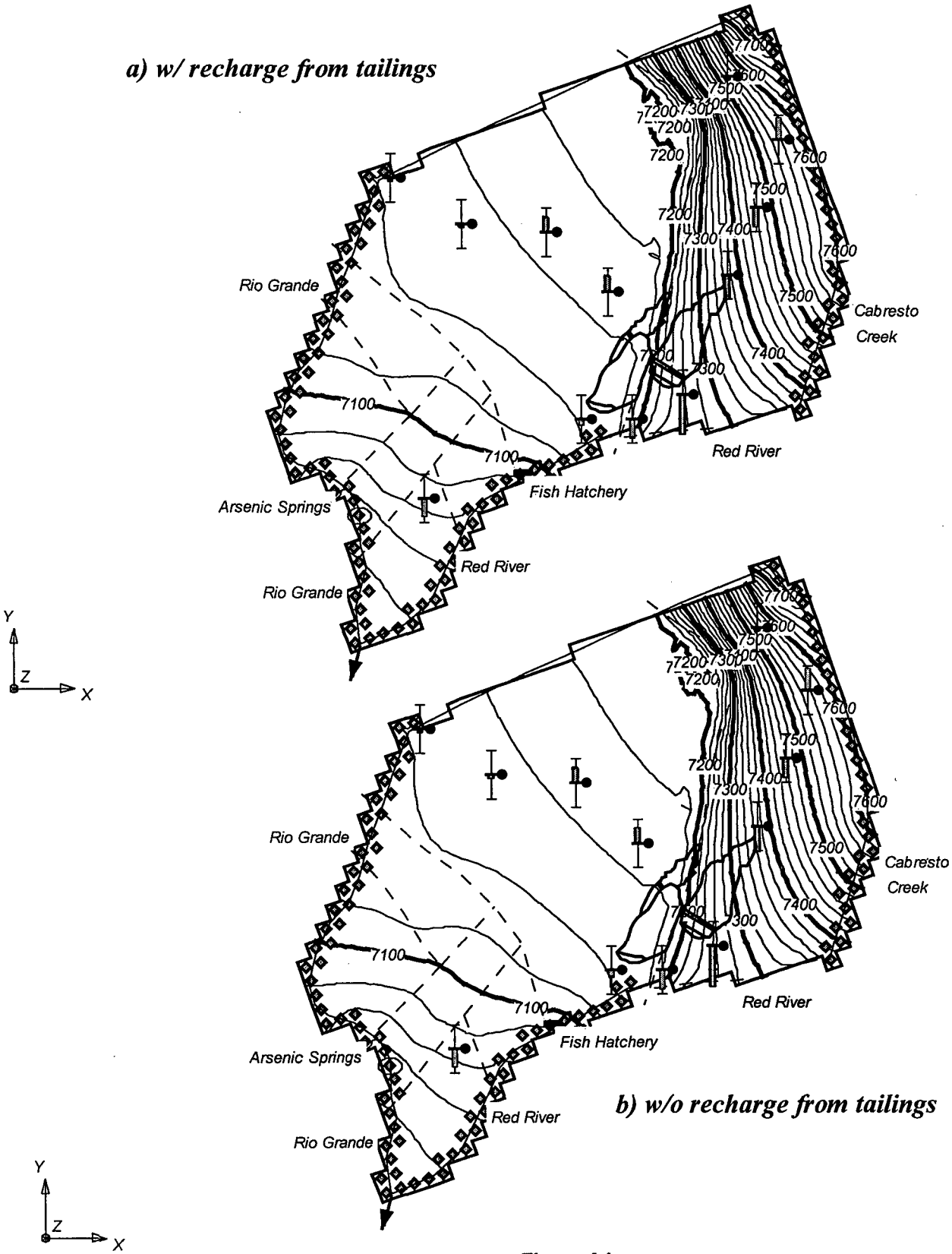


Figure A1.
Simulated heads in model layer 2 for scenario "Region 1".

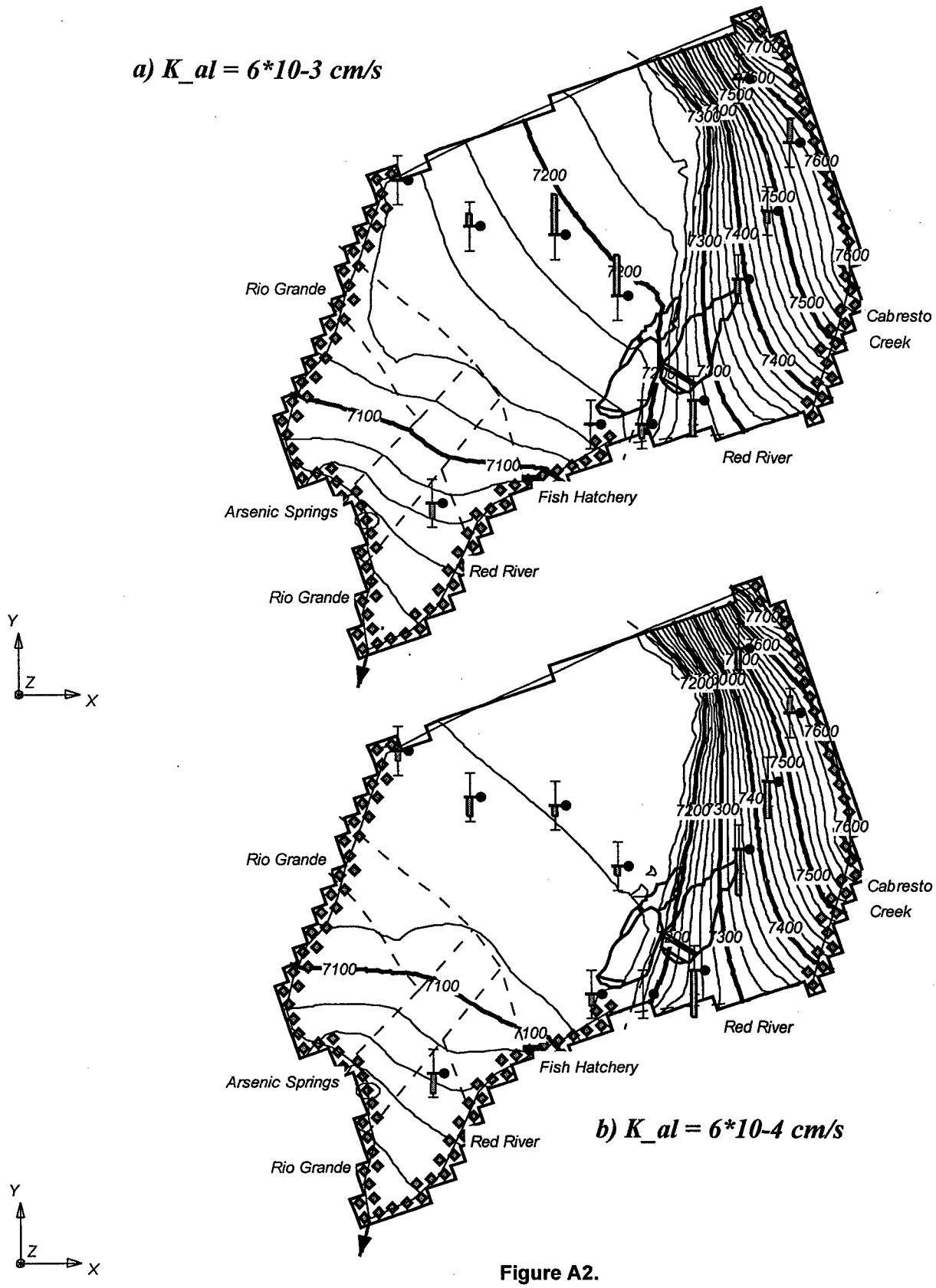


Figure A2.
Simulated heads in model layer 2 for scenario "Region 2".

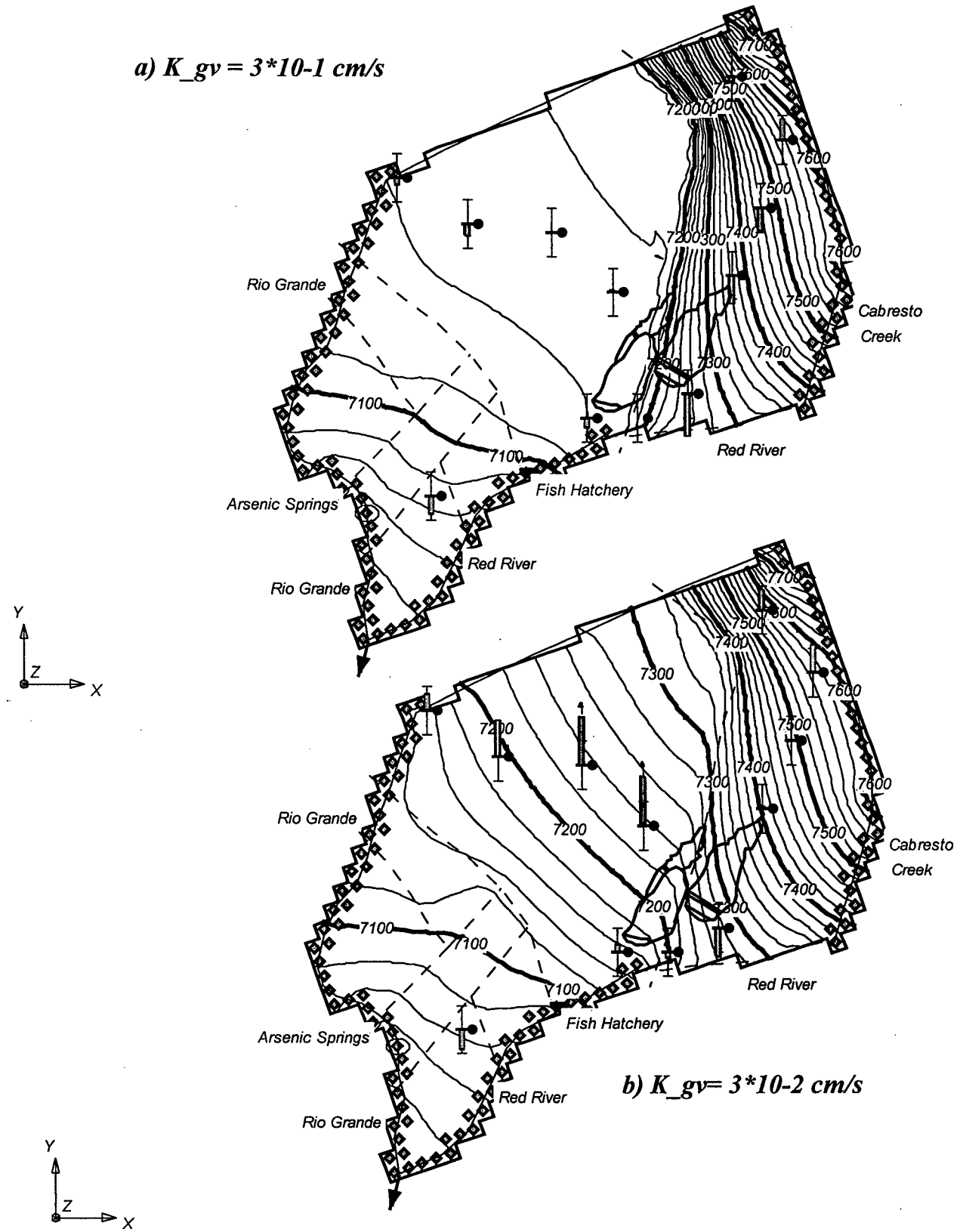


Figure A3.
Simulated heads in model layer 2 for scenario "Region 3".

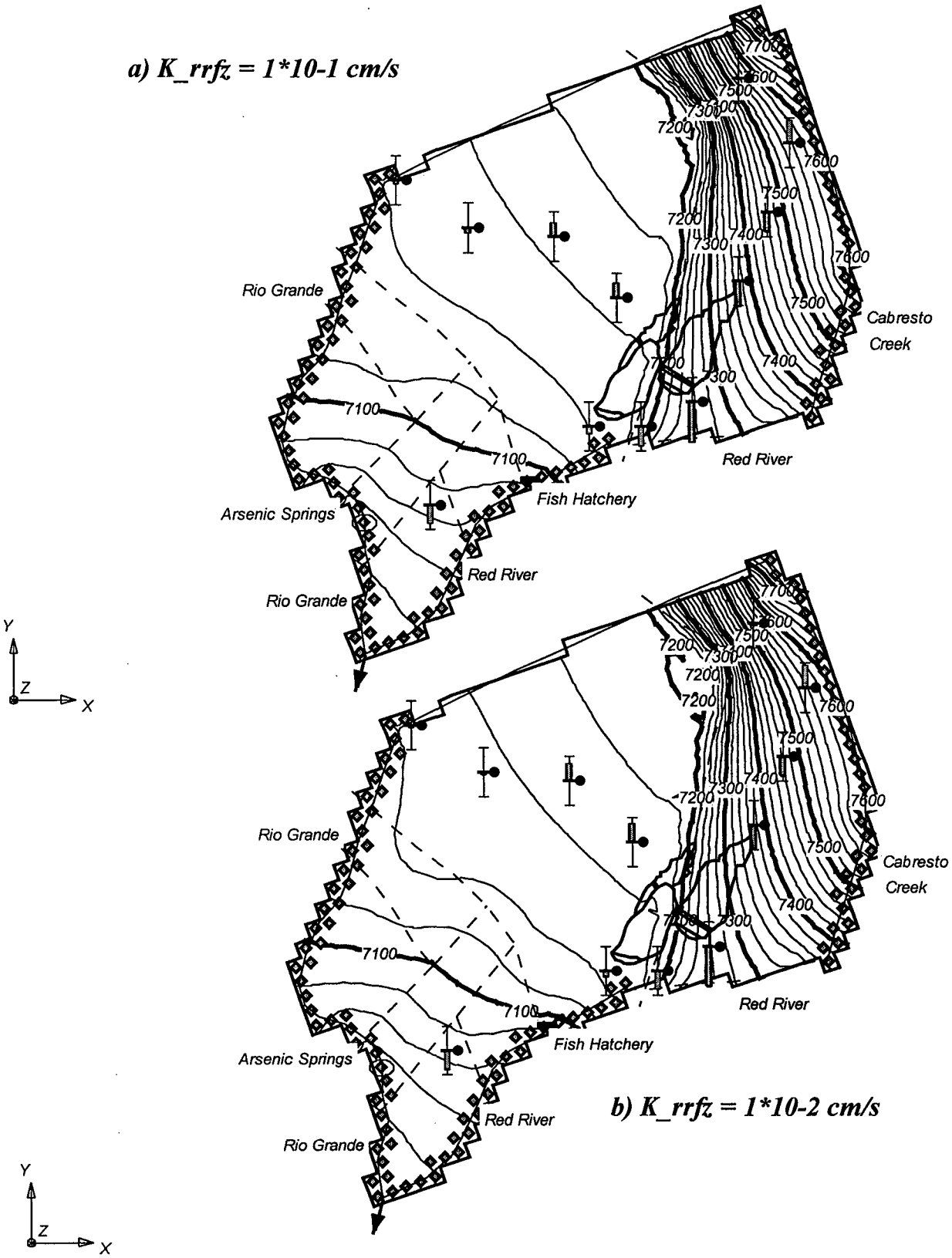


Figure A4.
Simulated heads in model layer 2 for scenario "Region 4".

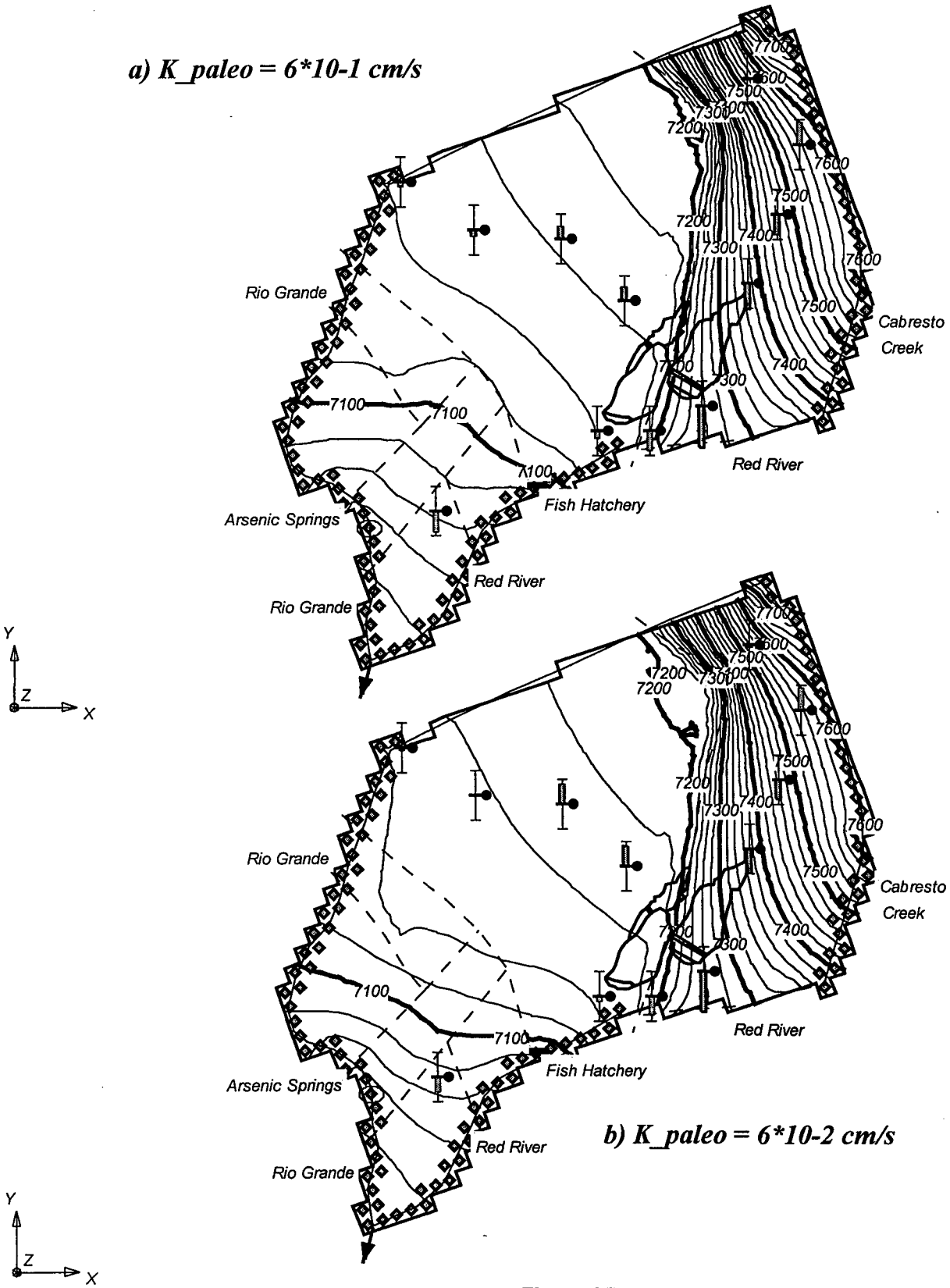


Figure A5.
Simulated heads in model layer 2 for scenario "Region 5".

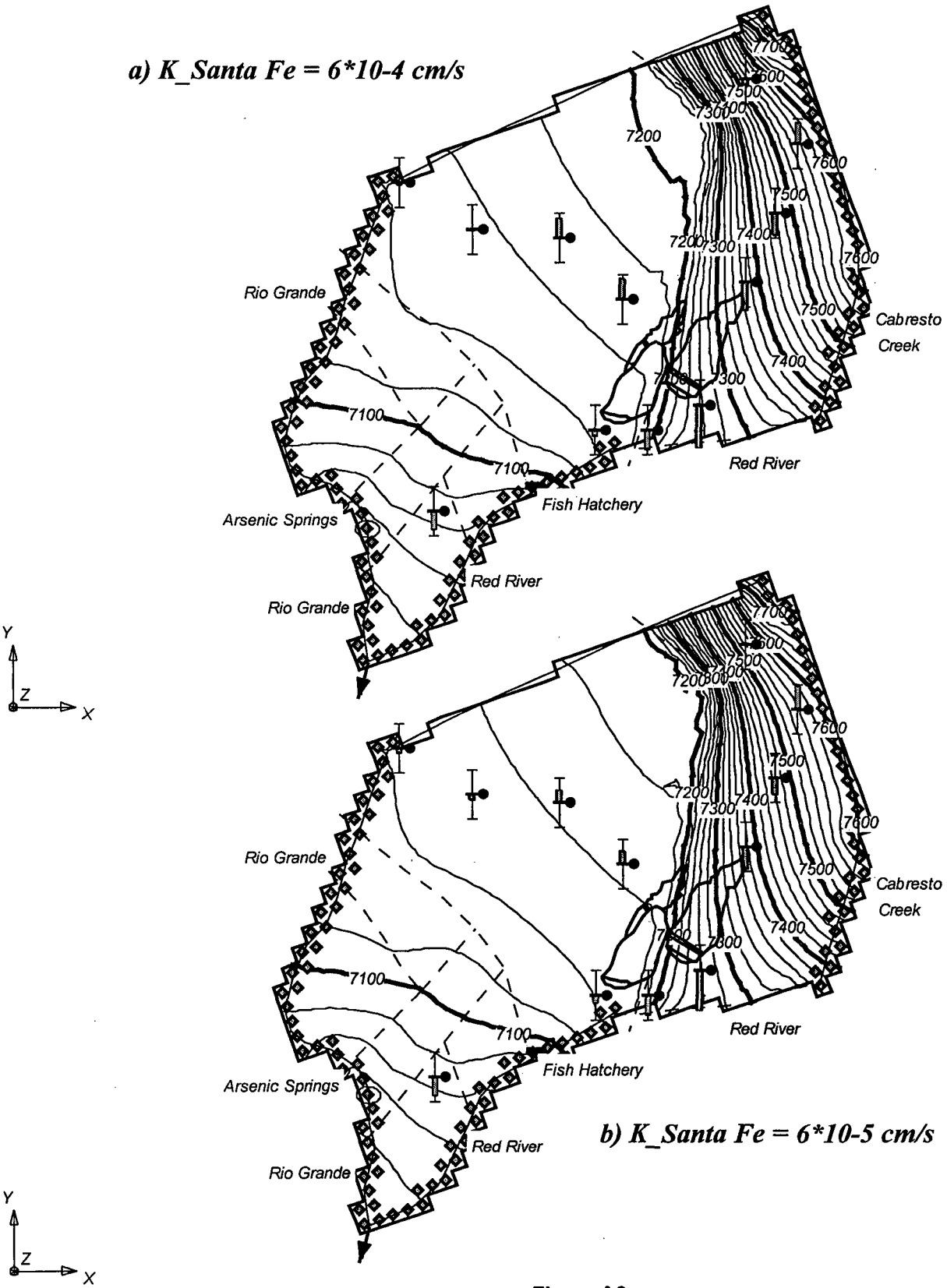


Figure A6.
Simulated heads in model layer 2 for scenario "Region 6".

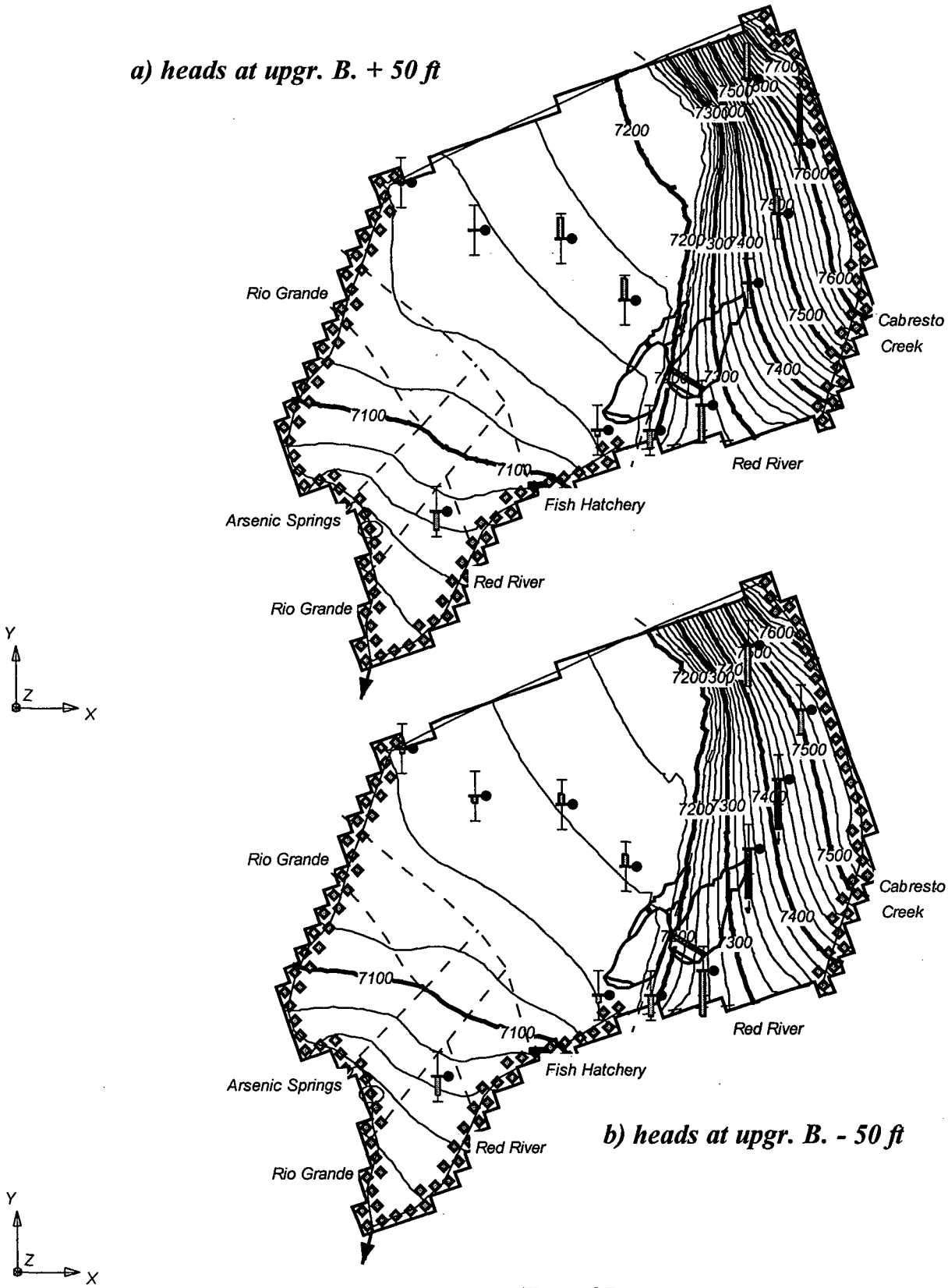


Figure A7.
Simulated heads in model layer 2 for scenario "Region 7".

Appendix B

APPENDIX B

Results of Sensitivity Analysis for Local Flow Model

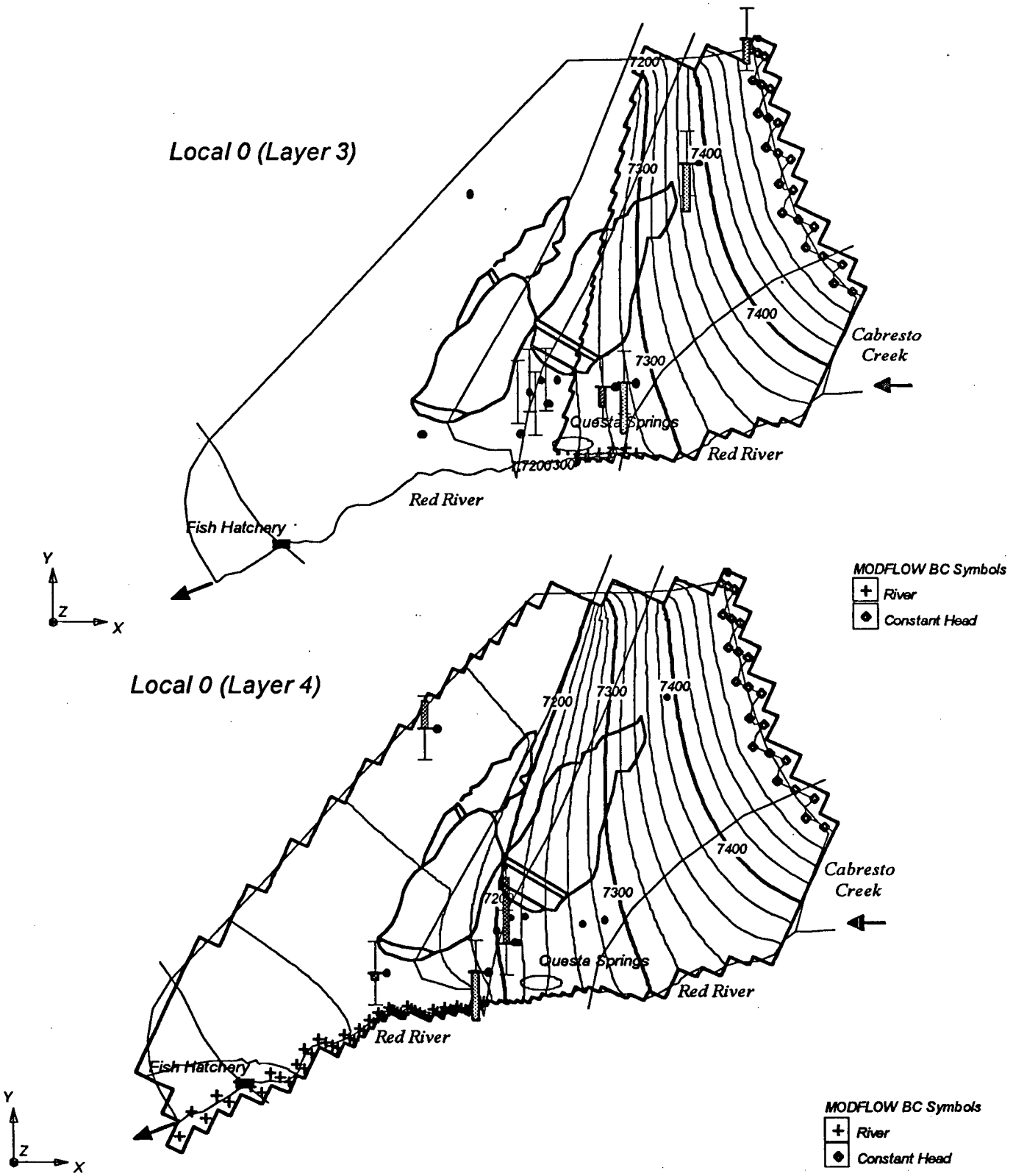
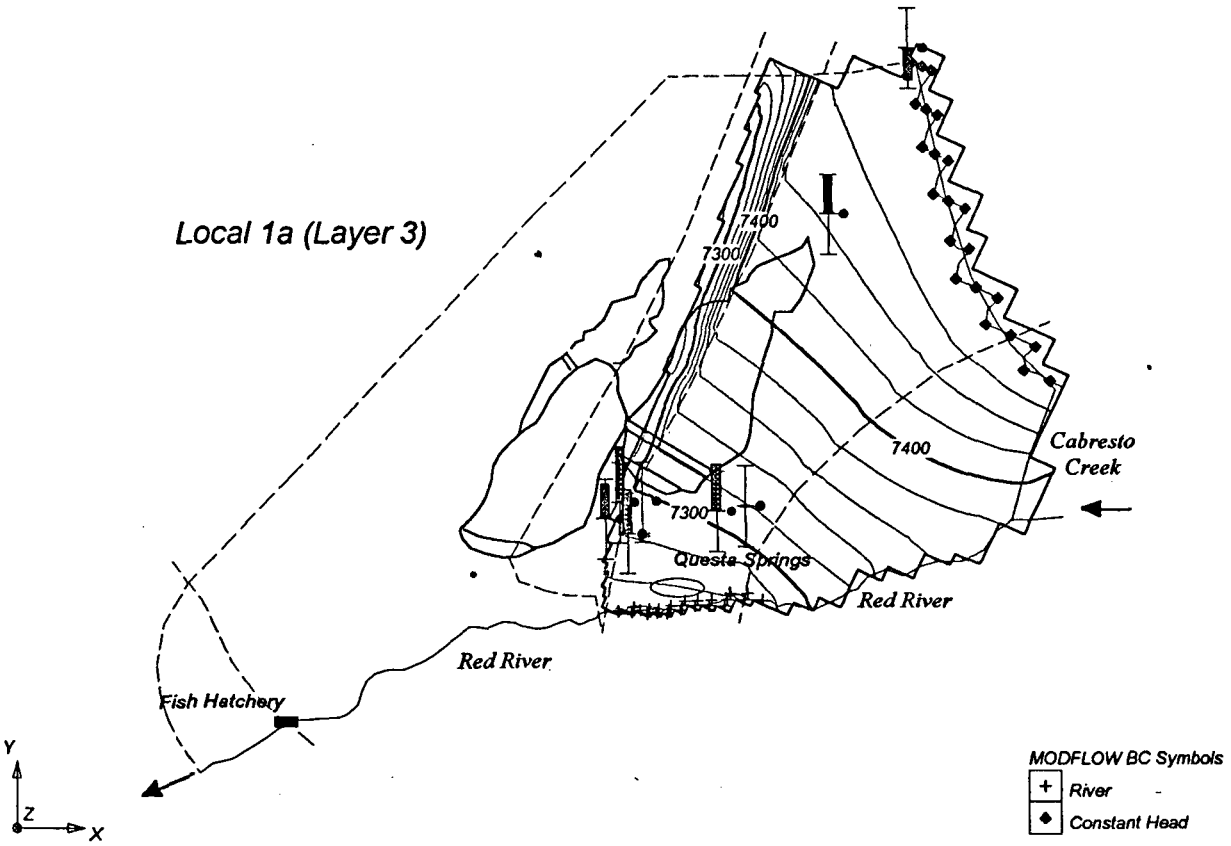


Figure B1.
Simulated heads for scenario "local 0".



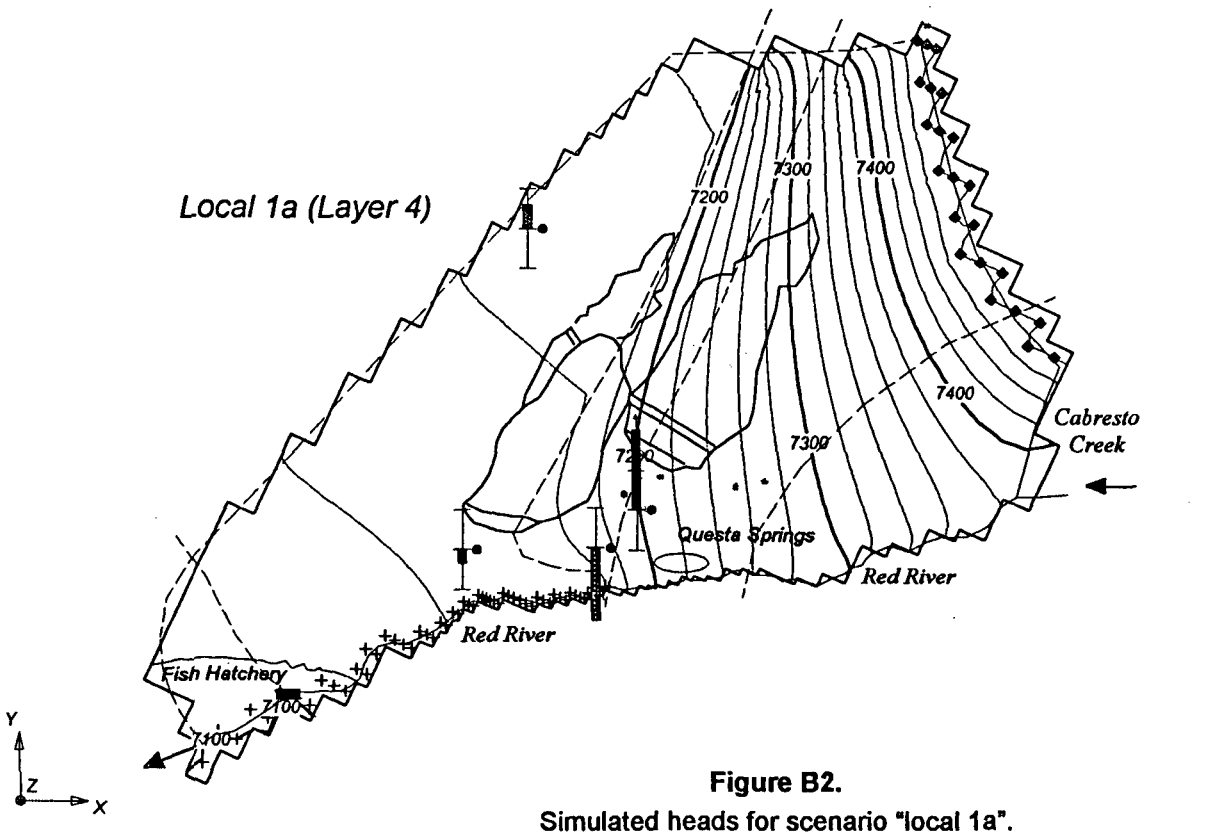
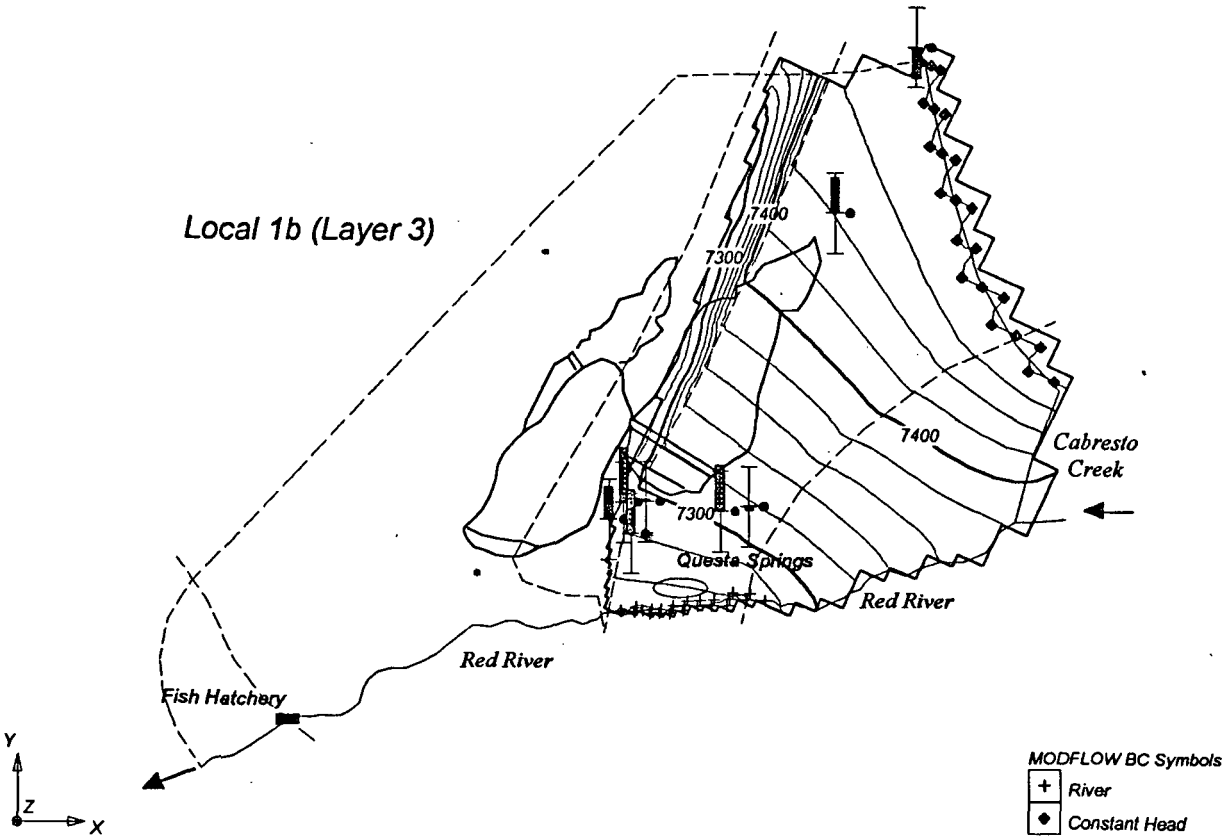


Figure B2.
Simulated heads for scenario "local 1a".



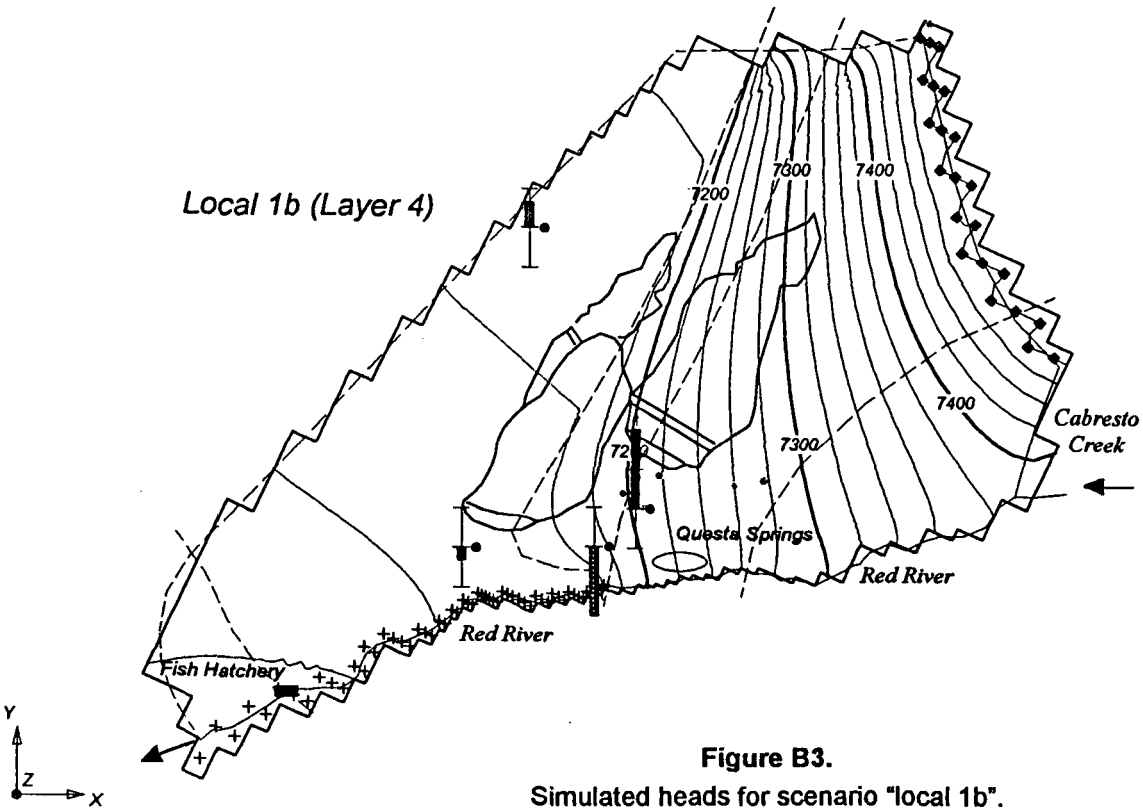
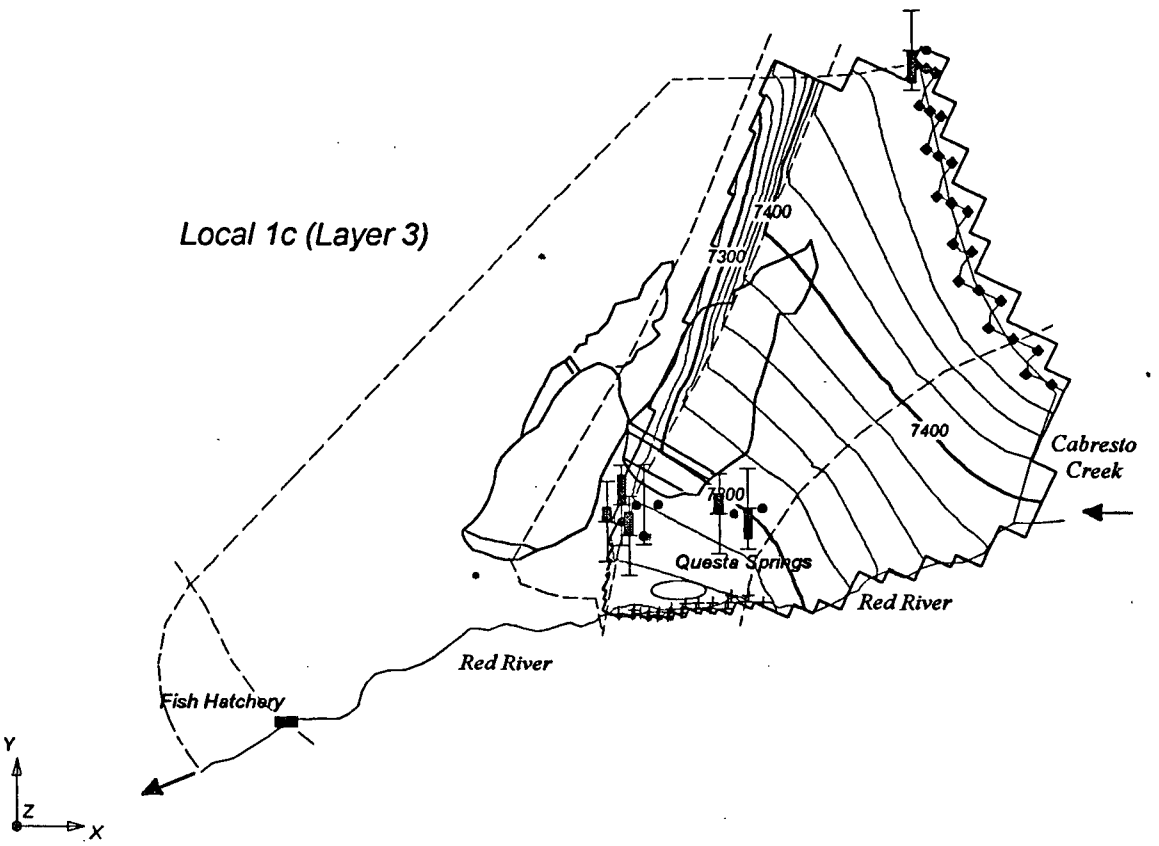


Figure B3.
Simulated heads for scenario "local 1b".



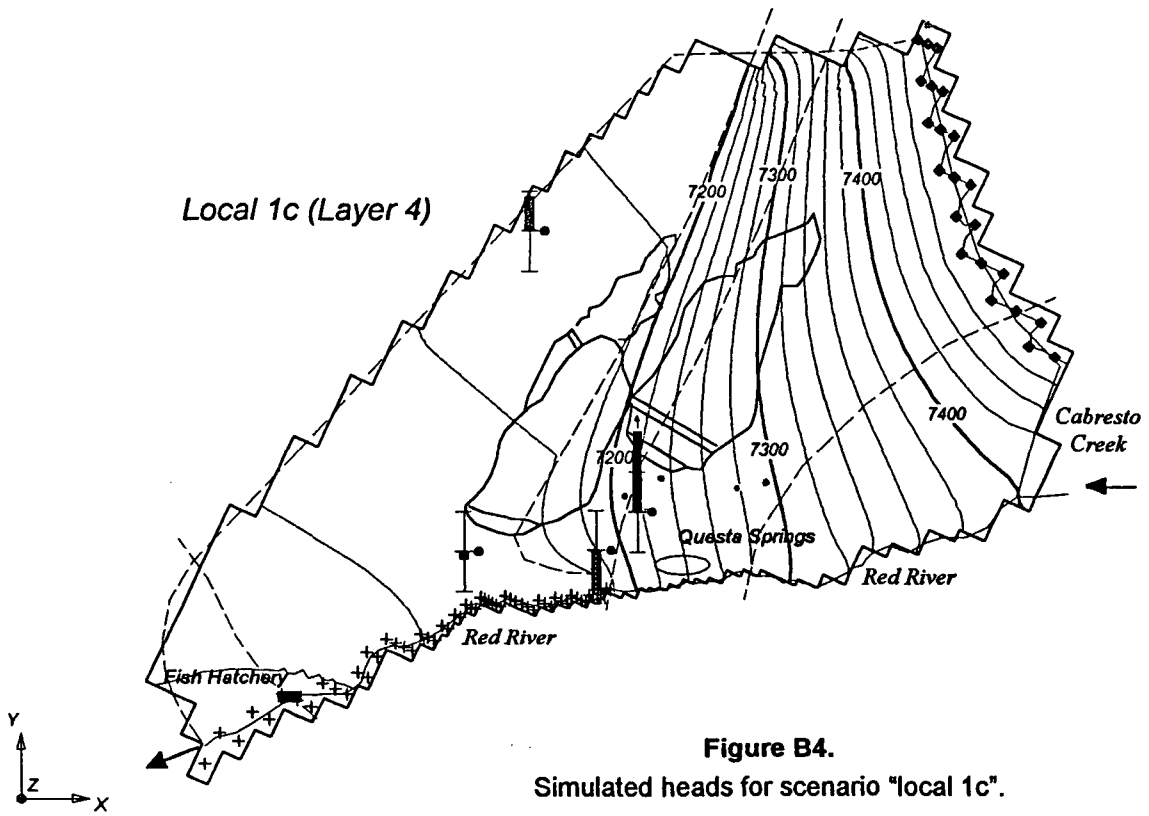
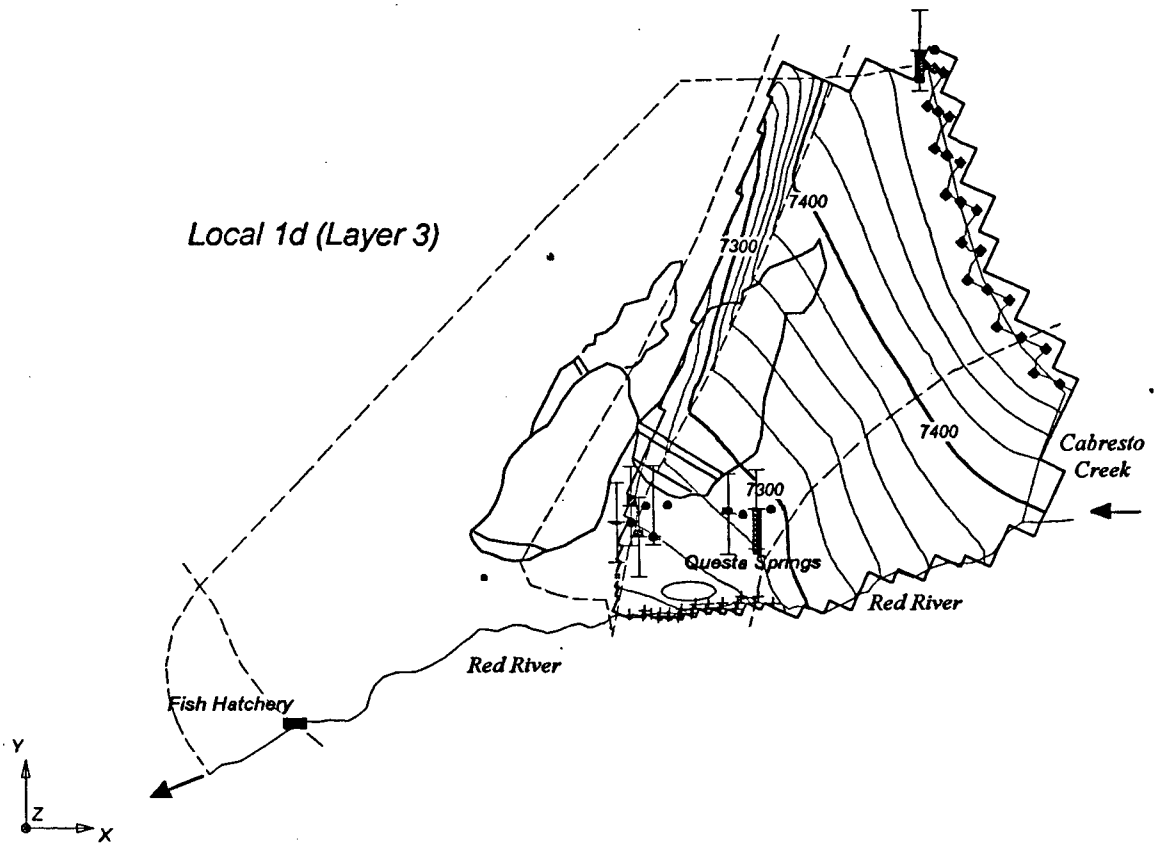


Figure B4.
Simulated heads for scenario "local 1c".



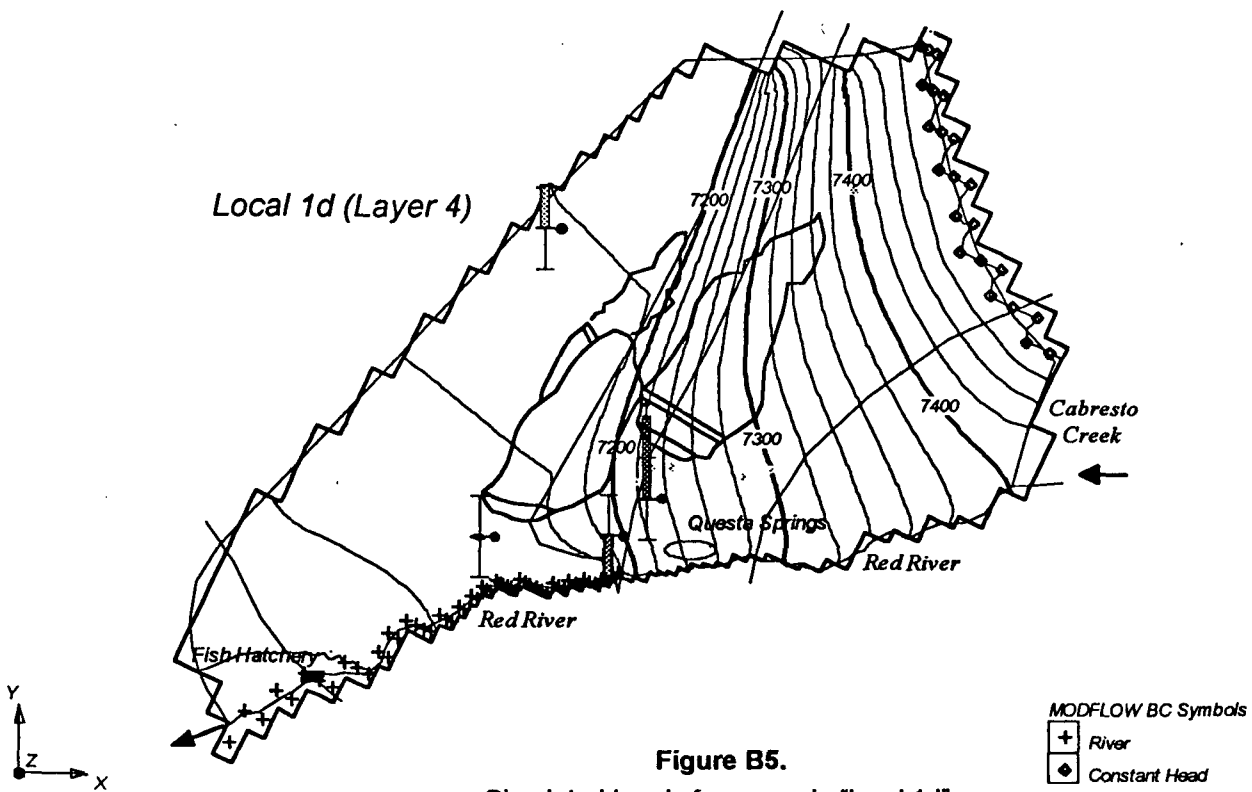
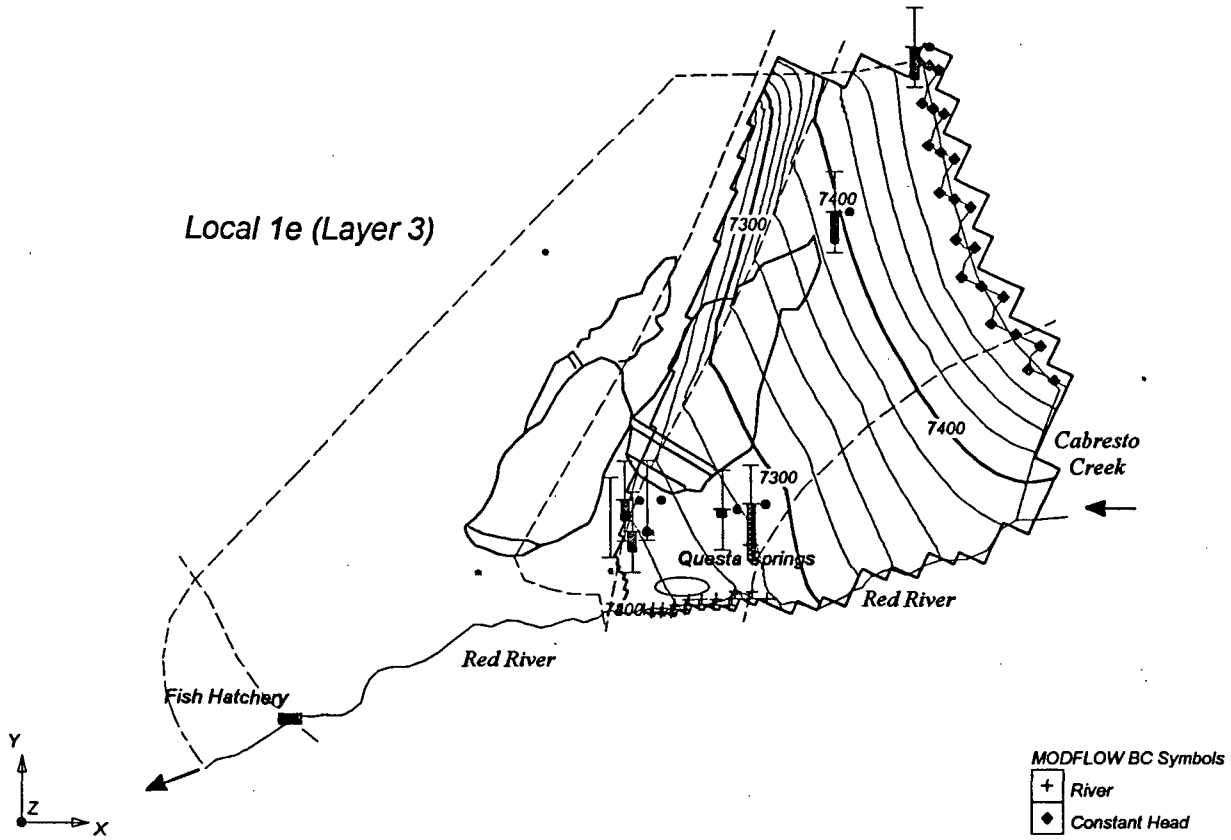


Figure B5.
Simulated heads for scenario "local 1d".



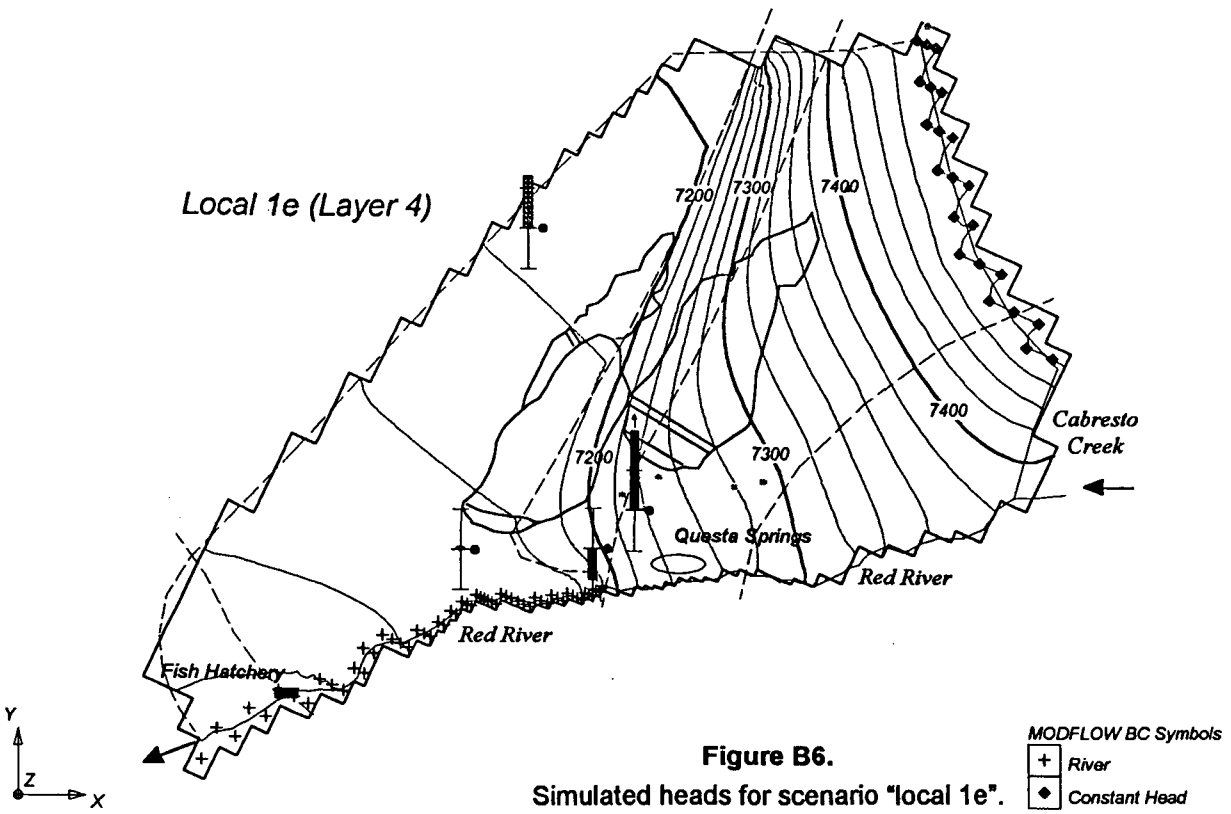
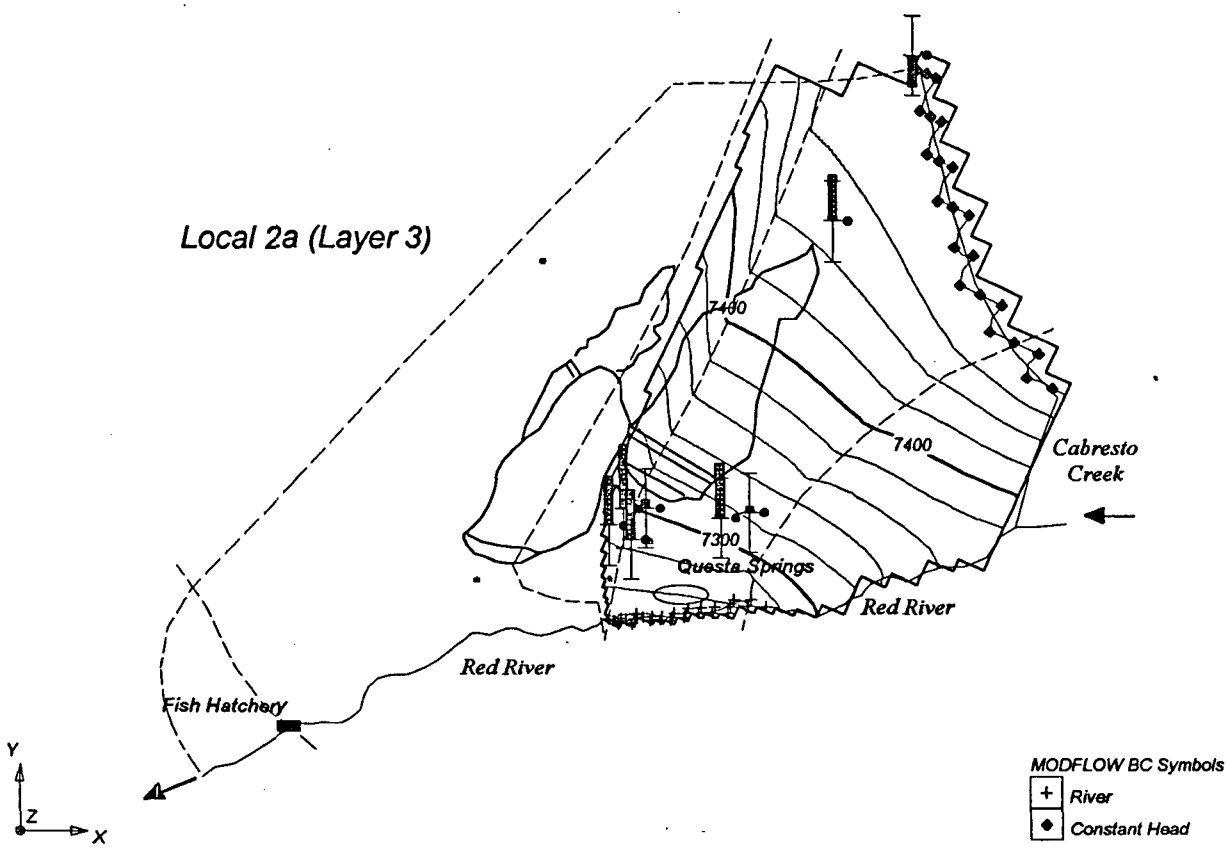


Figure B6.
Simulated heads for scenario "local 1e".



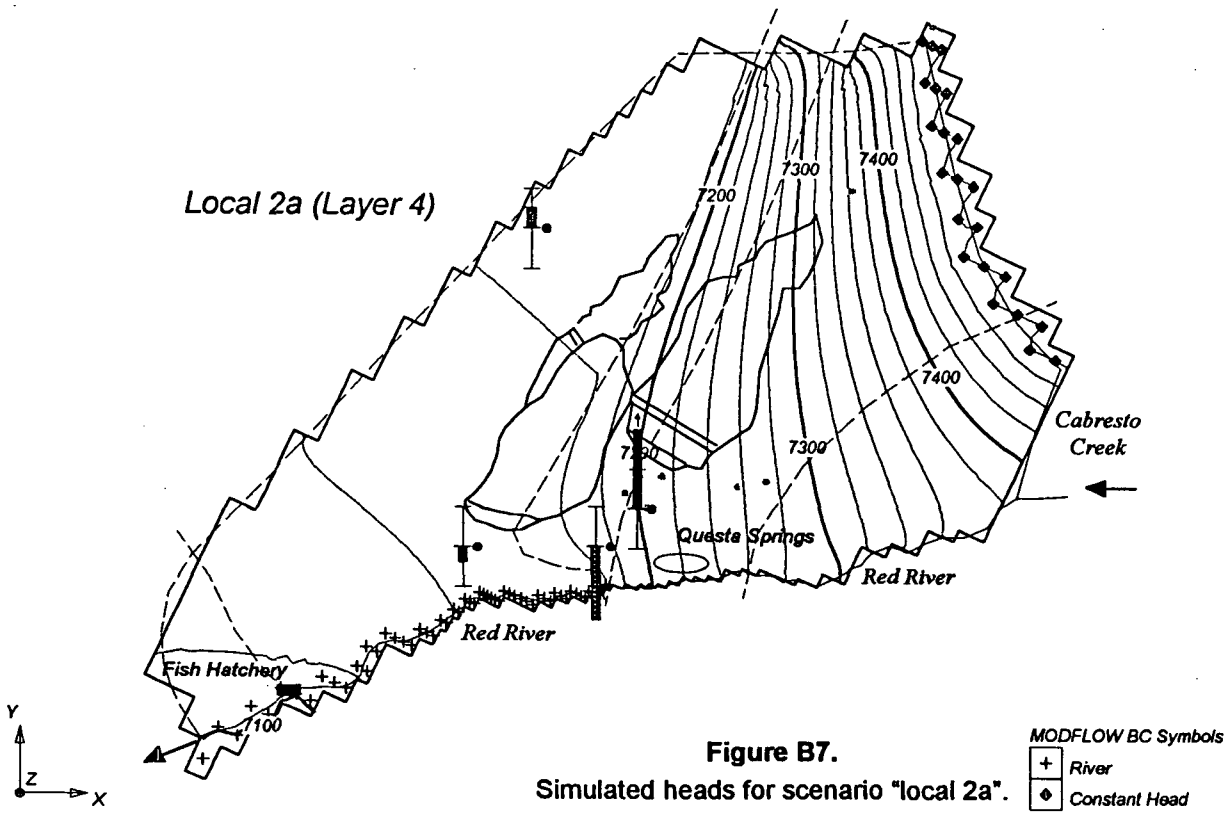
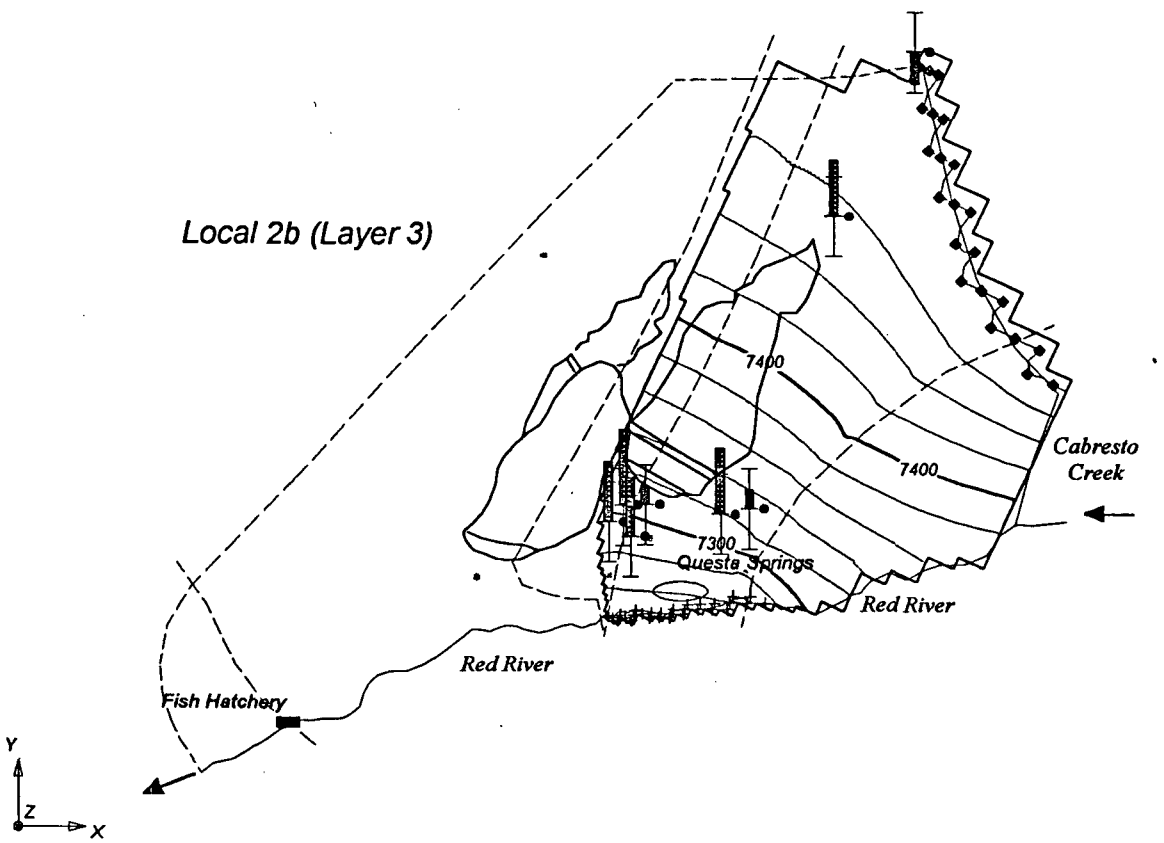


Figure B7.
Simulated heads for scenario "local 2a".



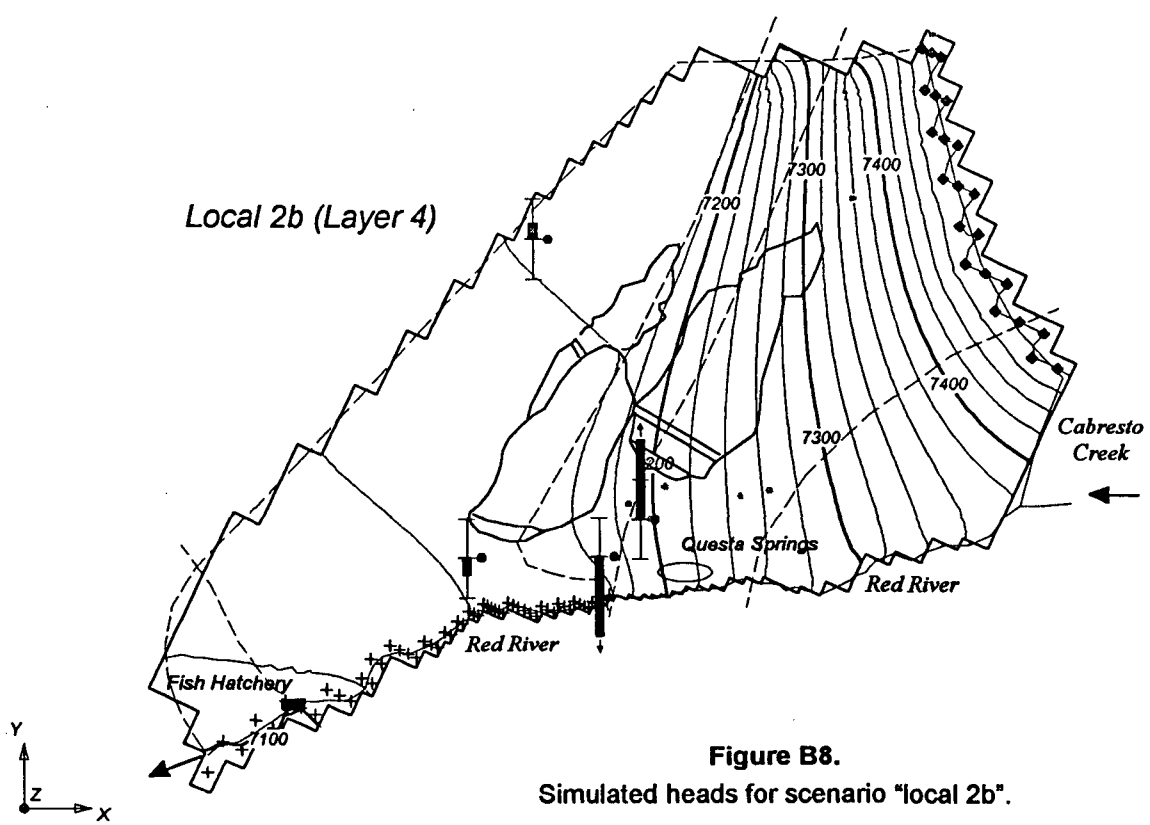


Figure B8.
Simulated heads for scenario "local 2b".

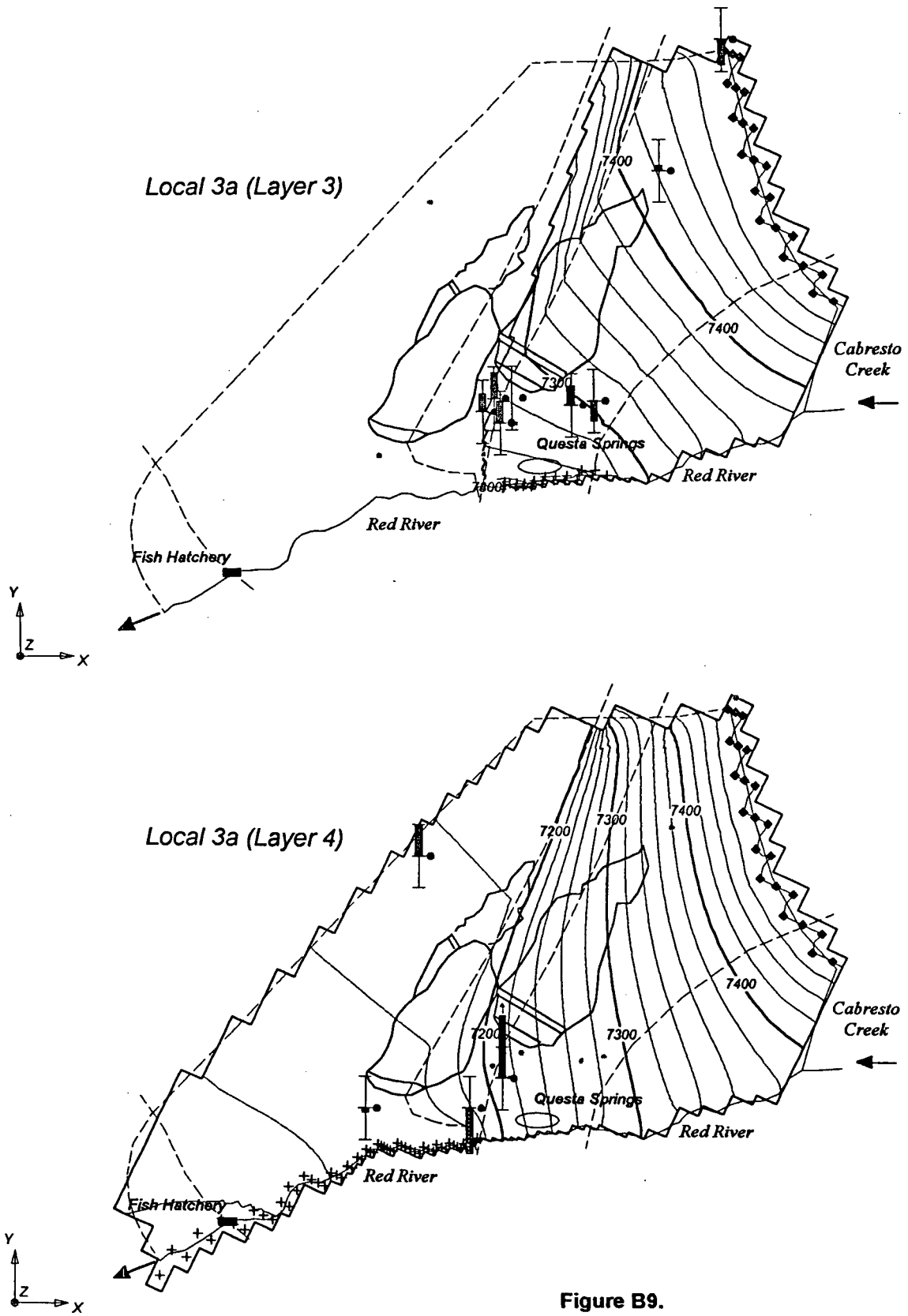


Figure B9.
Simulated heads for scenario "local 3a".

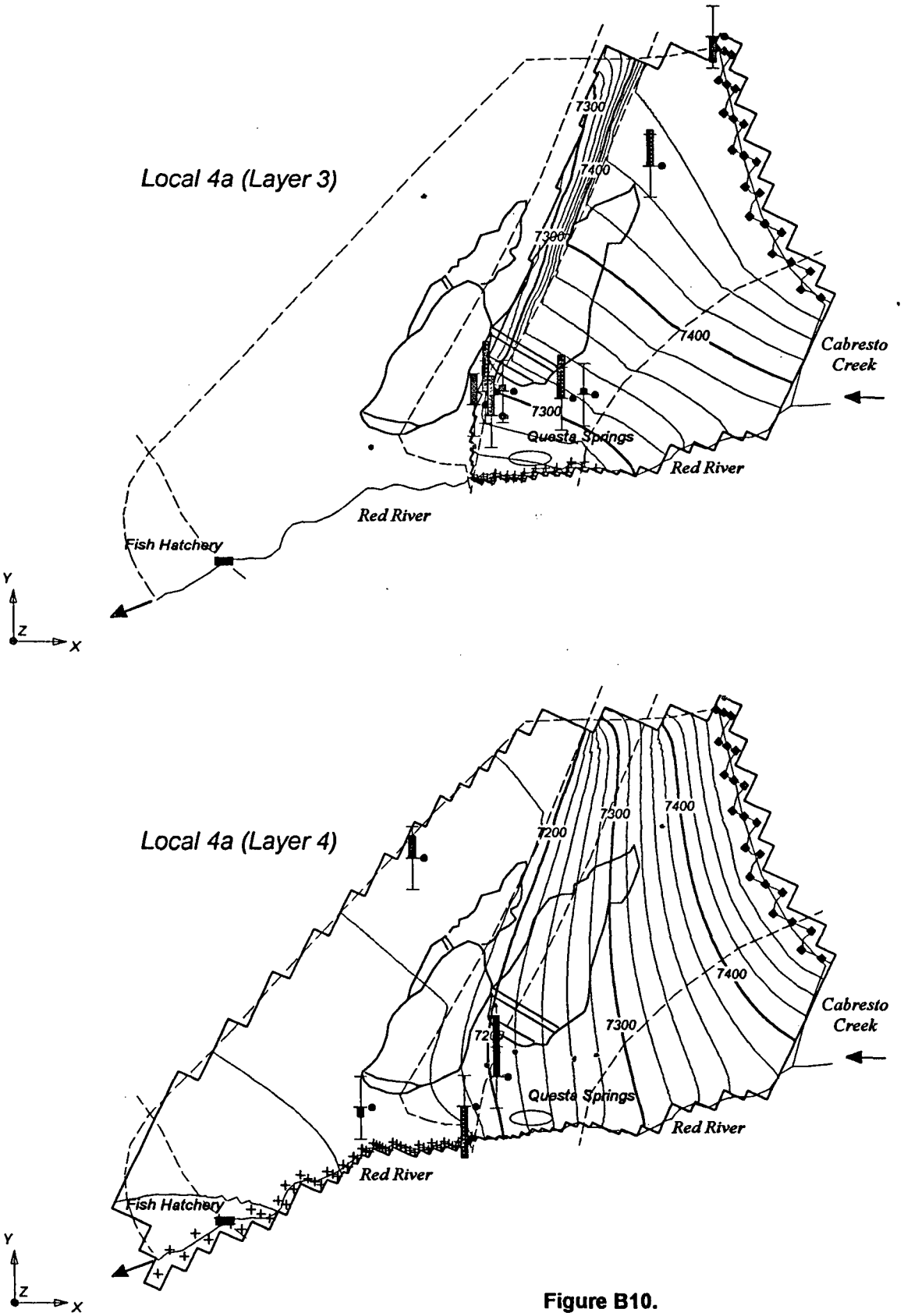
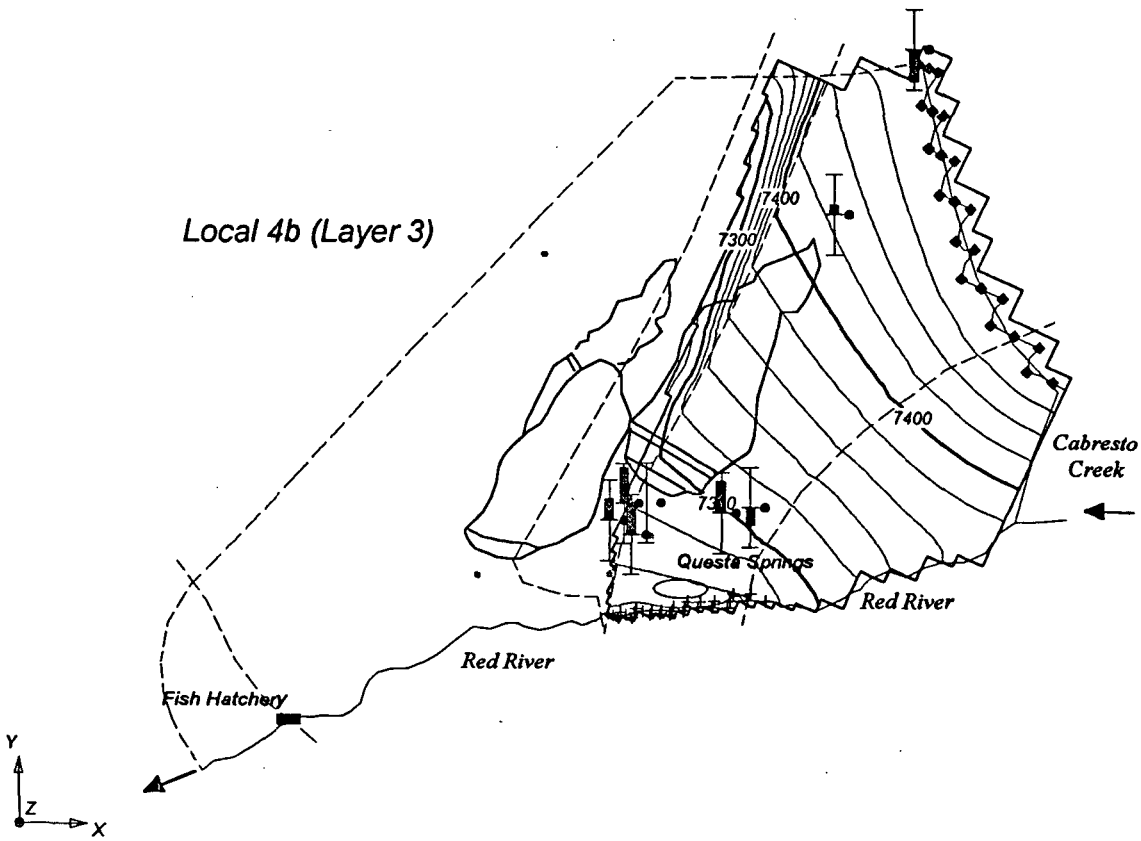


Figure B10.
Simulated heads for scenario "local 4a".



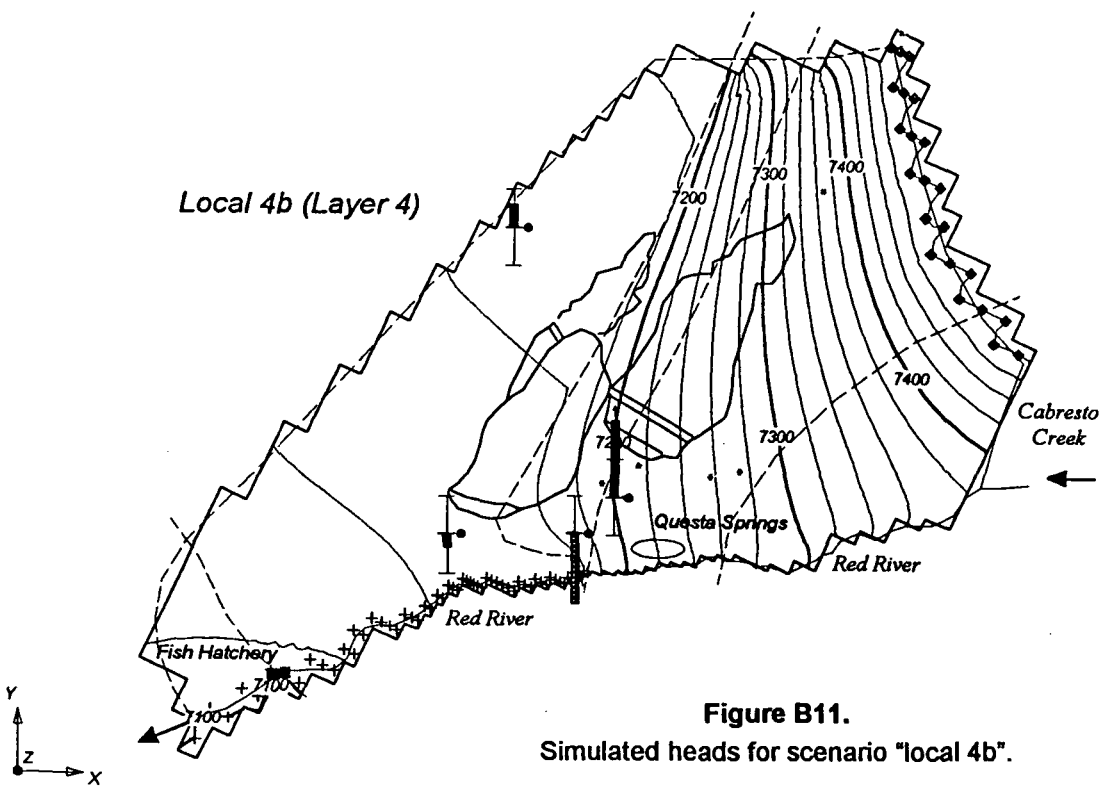
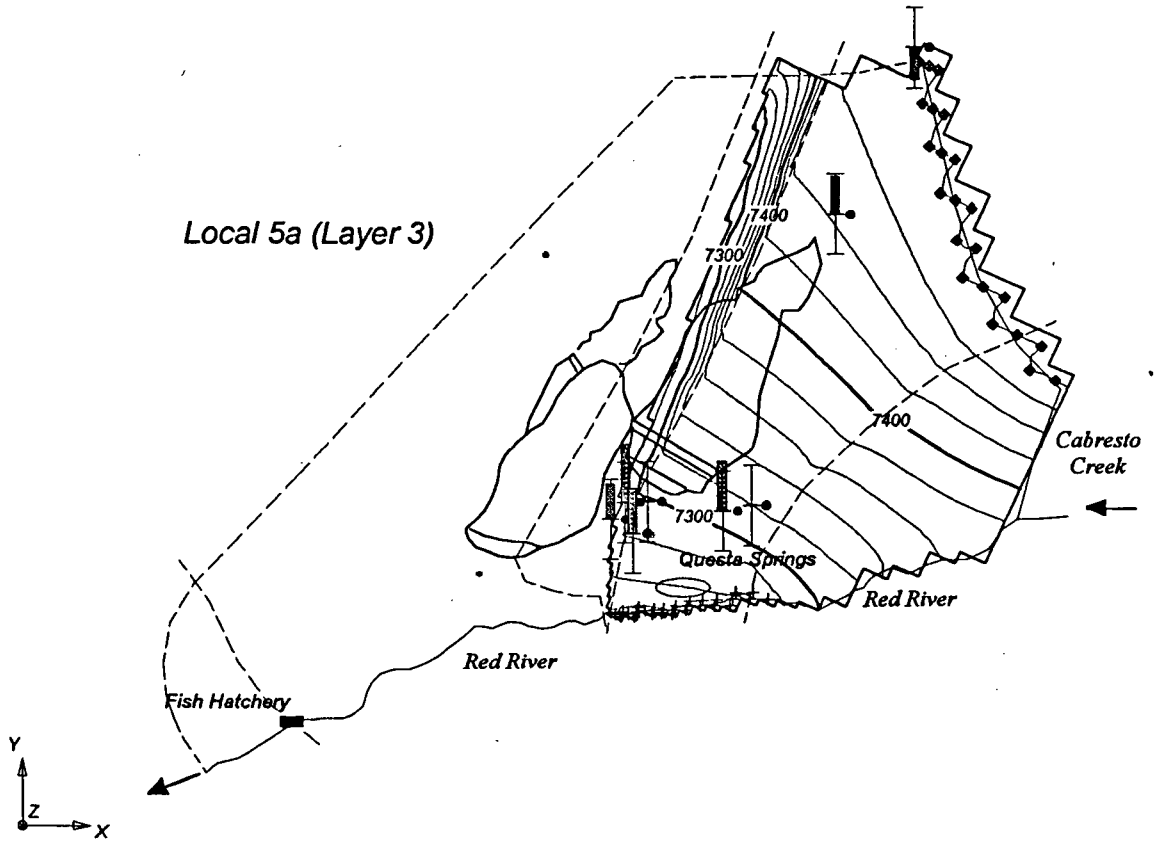


Figure B11.
Simulated heads for scenario "local 4b".



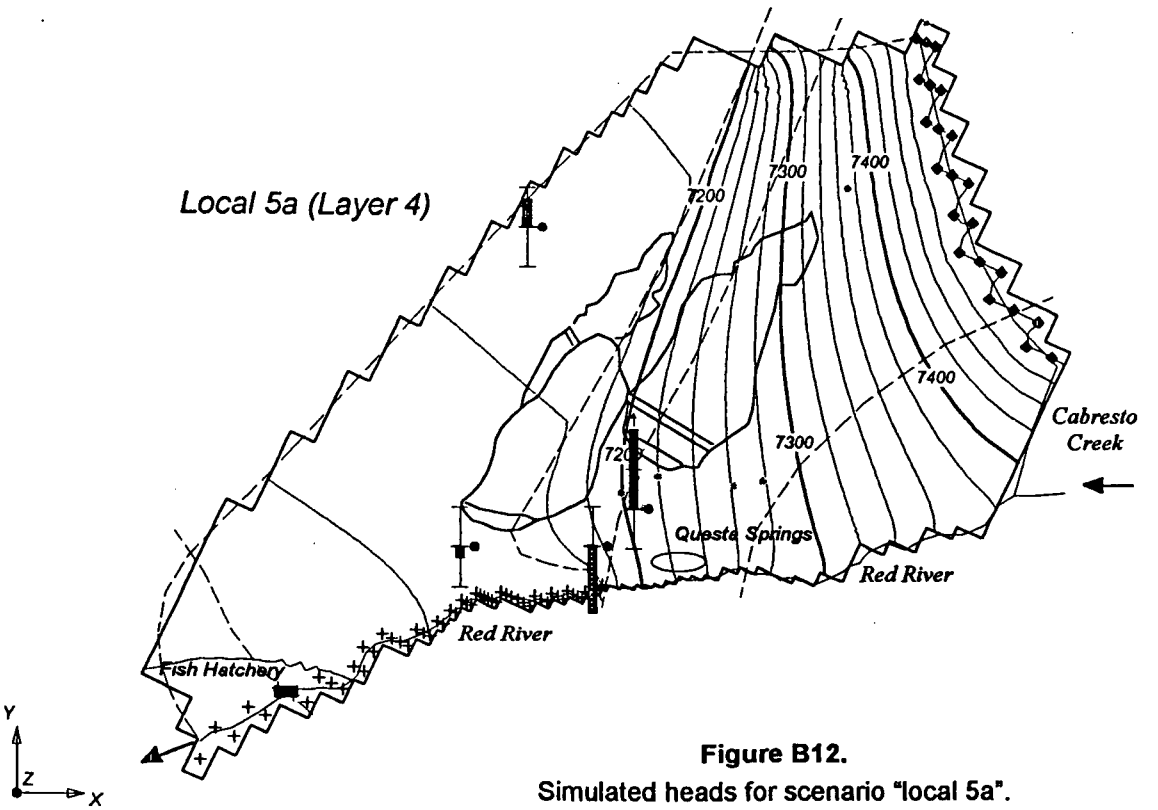
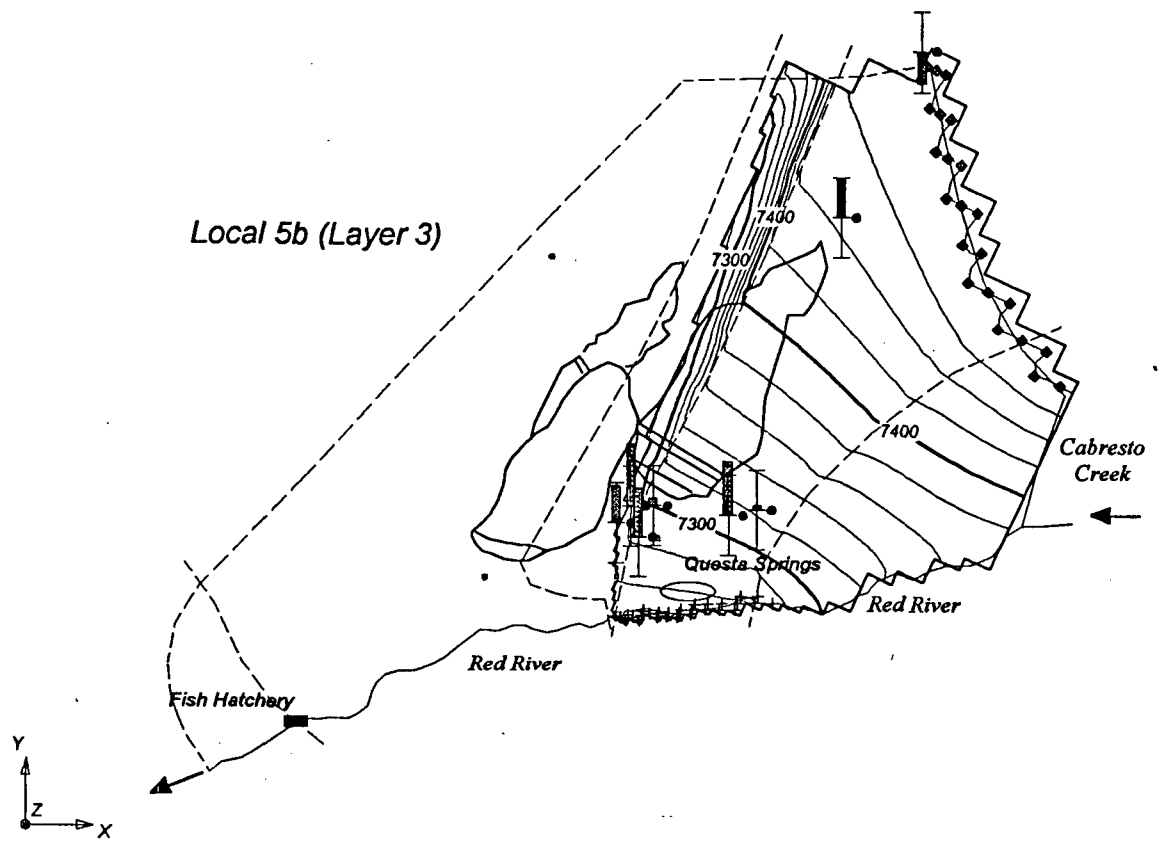


Figure B12.
Simulated heads for scenario "local 5a".



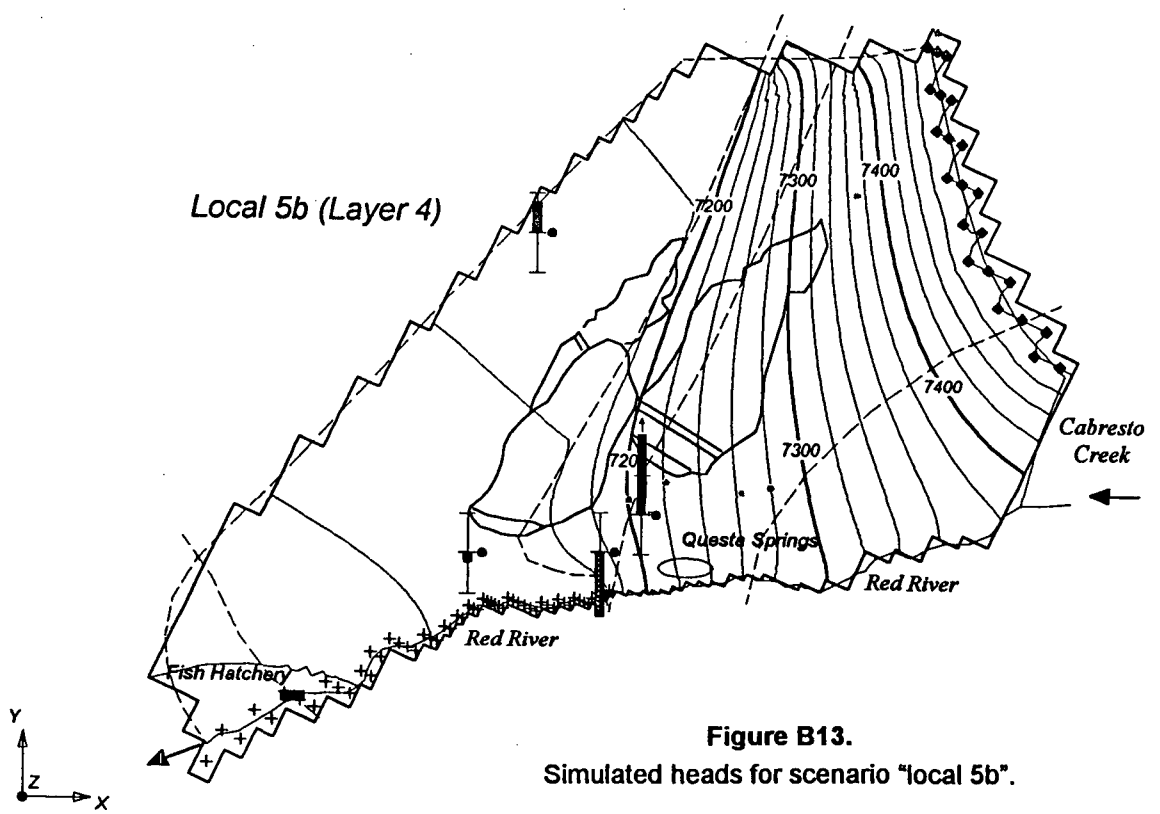
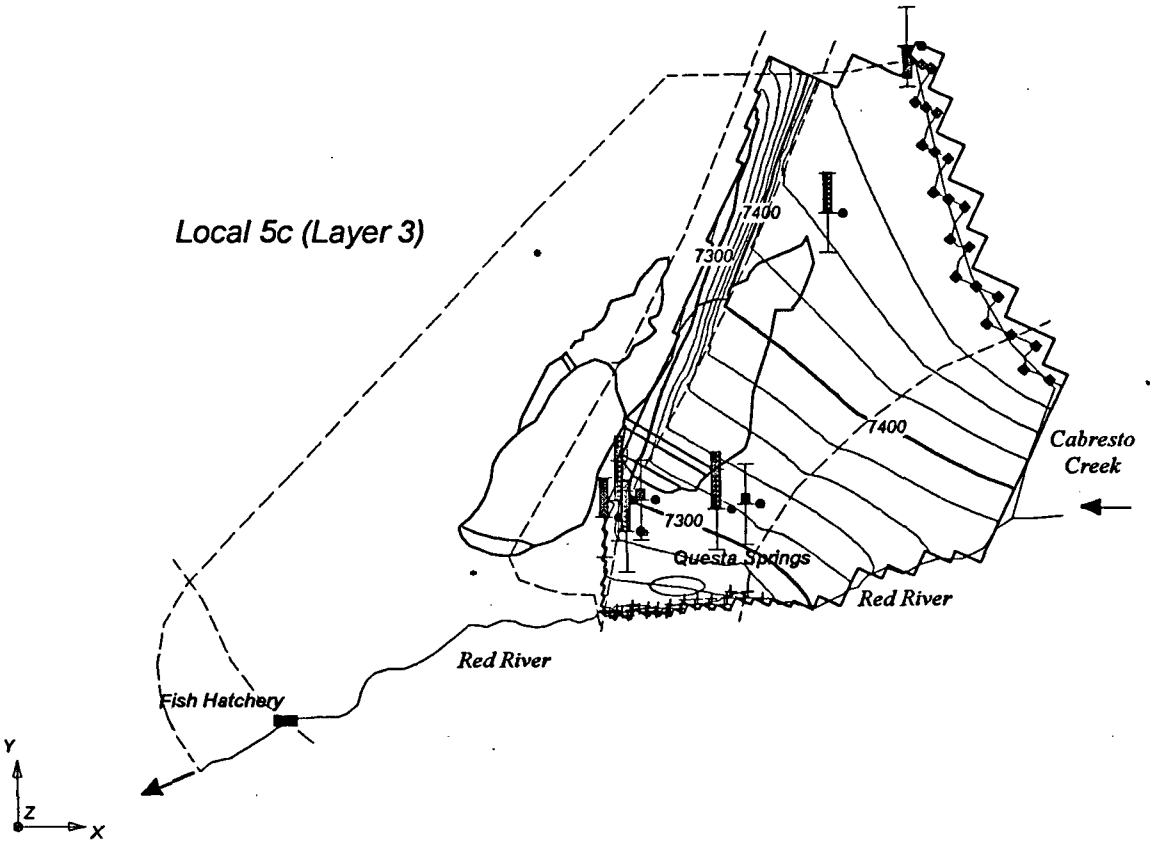


Figure B13.
Simulated heads for scenario "local 5b".



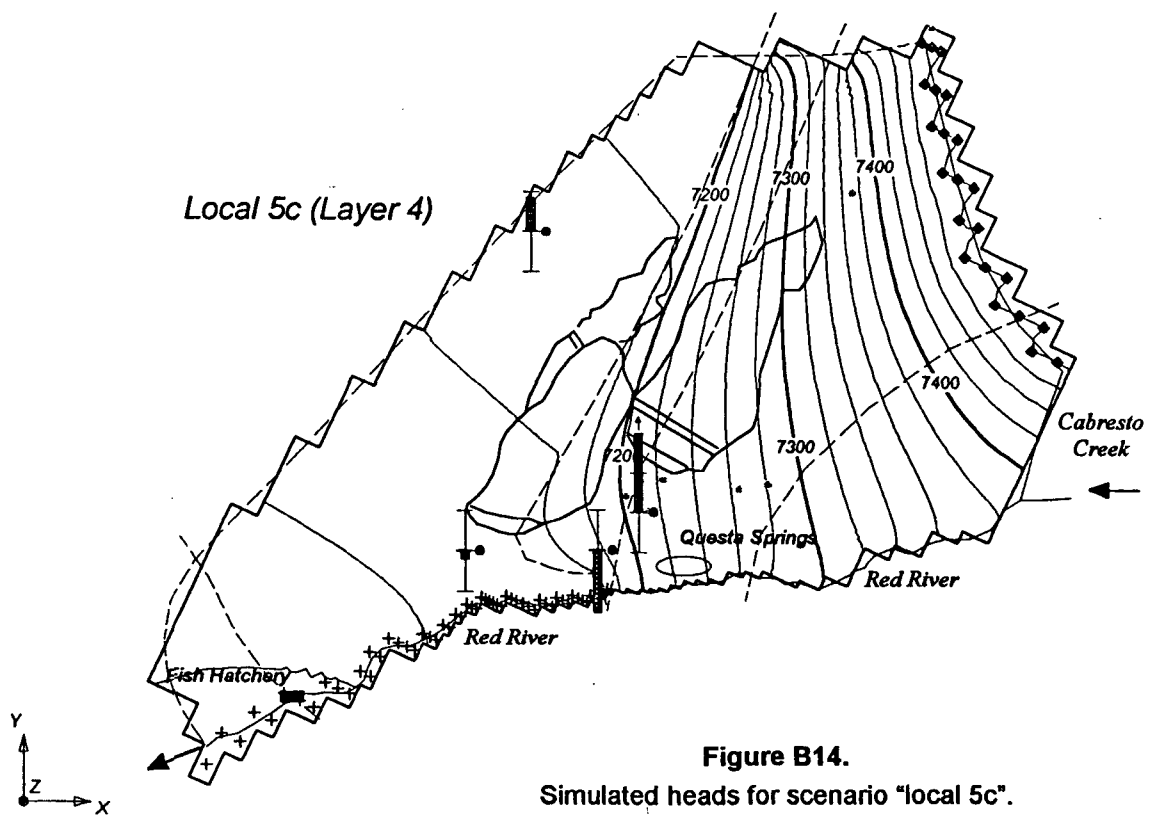


Figure B14.
Simulated heads for scenario "local 5c".

APPENDIX D

Results of Sensitivity Analysis for Tailings Seepage Model

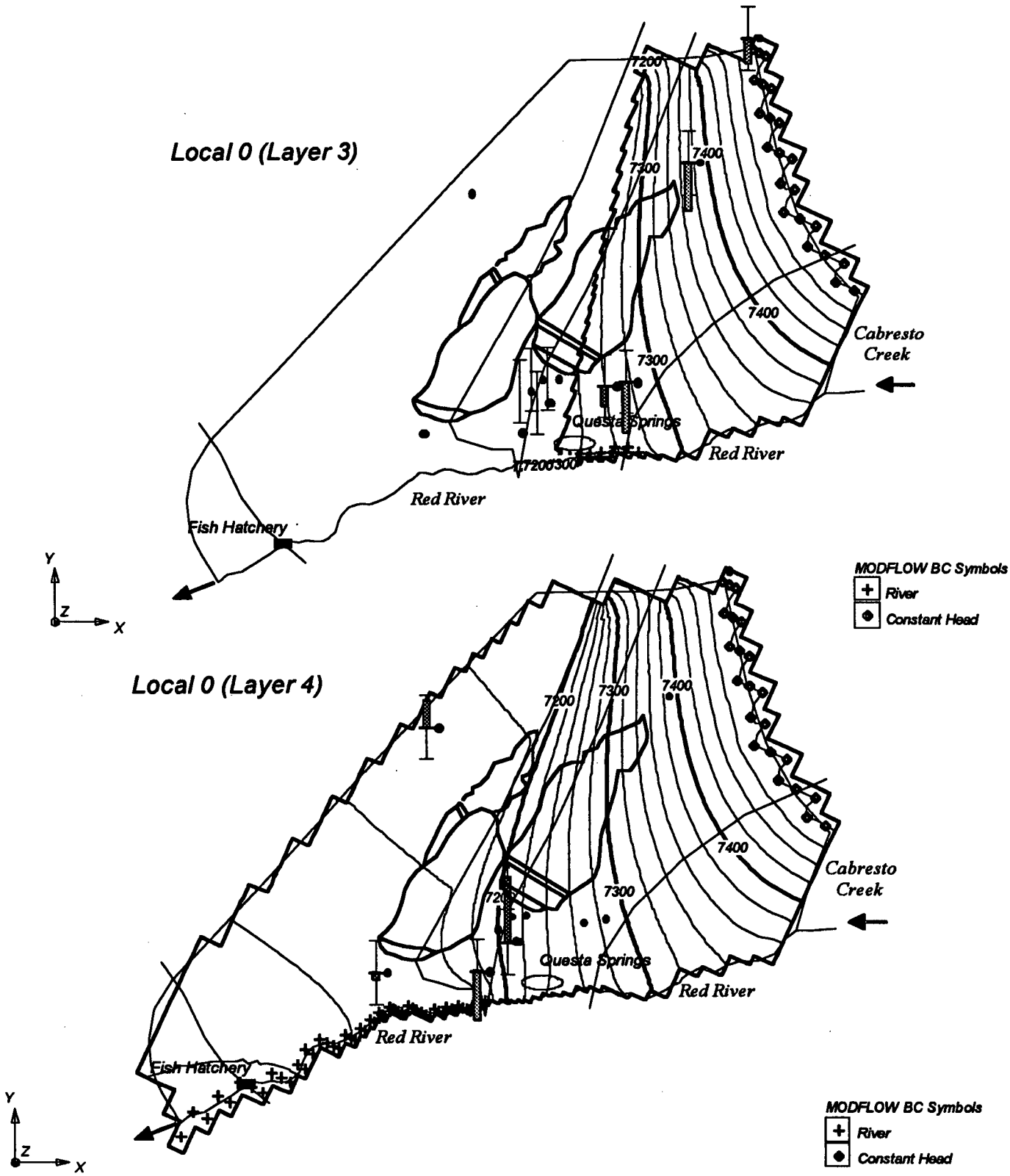


Figure B1.
Simulated heads for scenario "local 0".

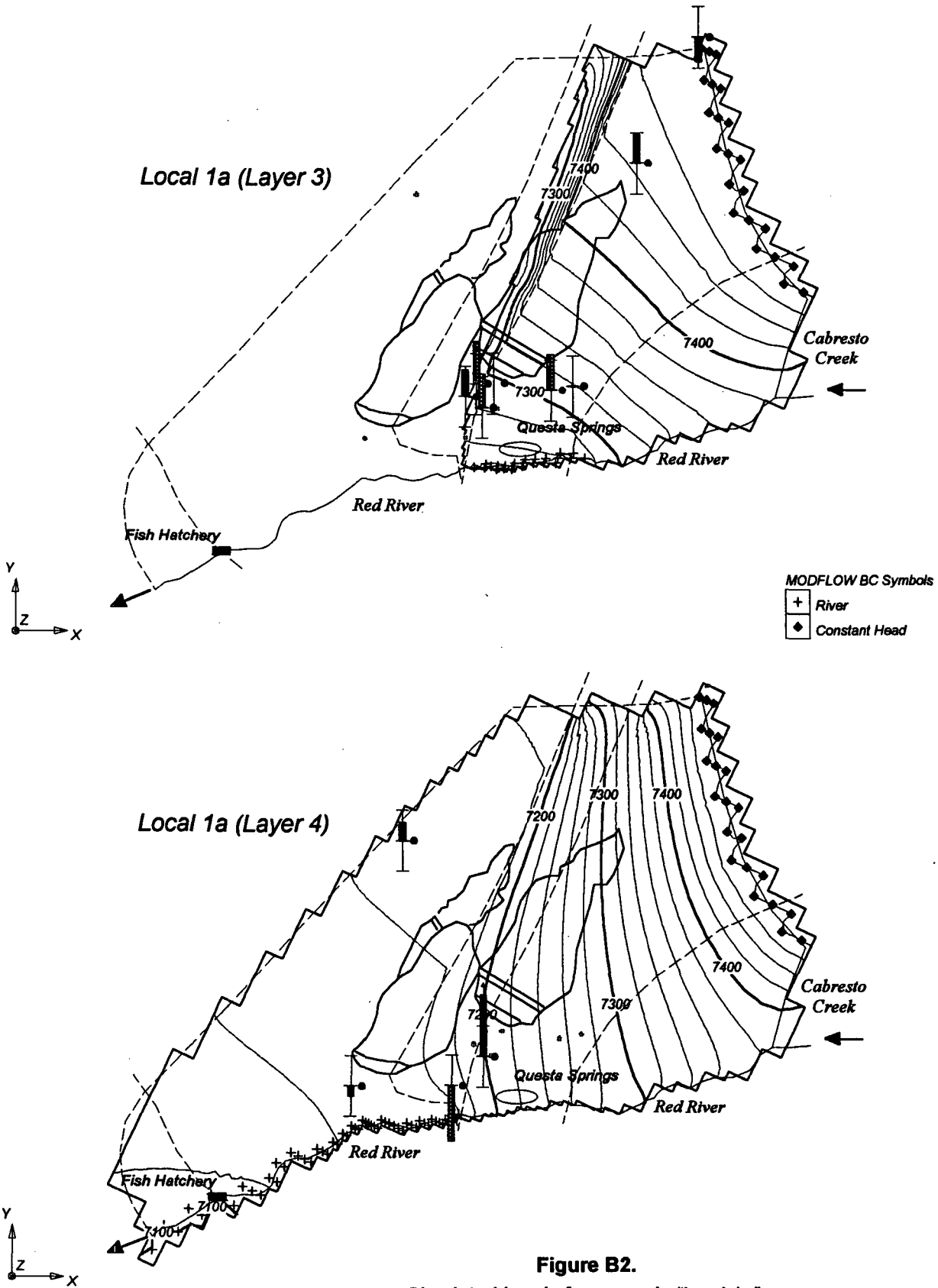
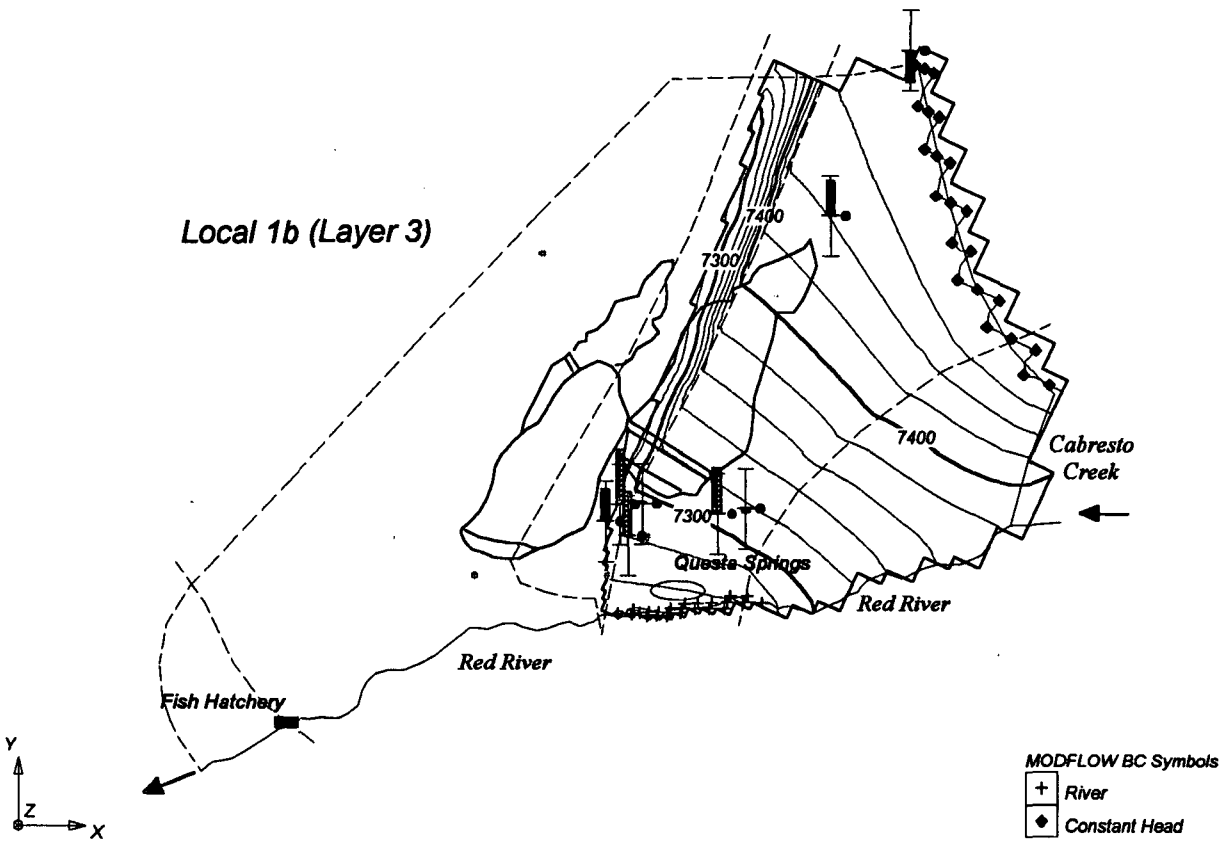


Figure B2.
Simulated heads for scenario "local 1a".



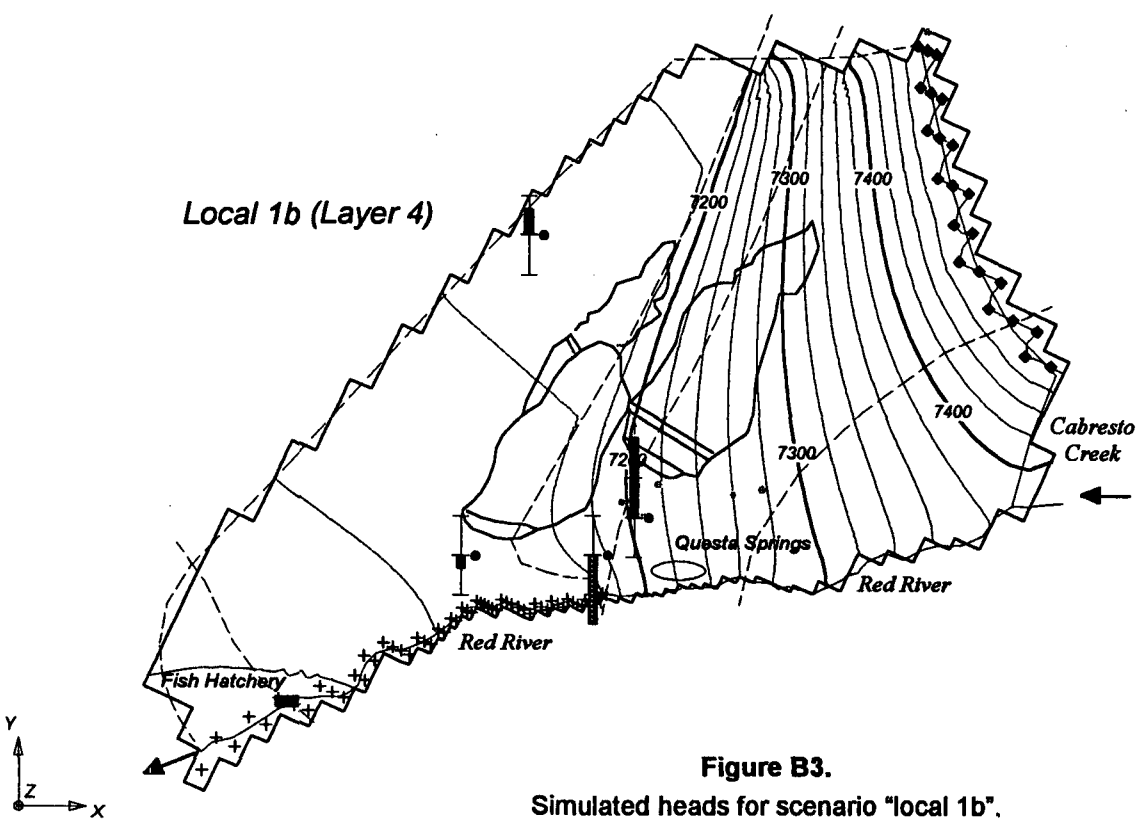
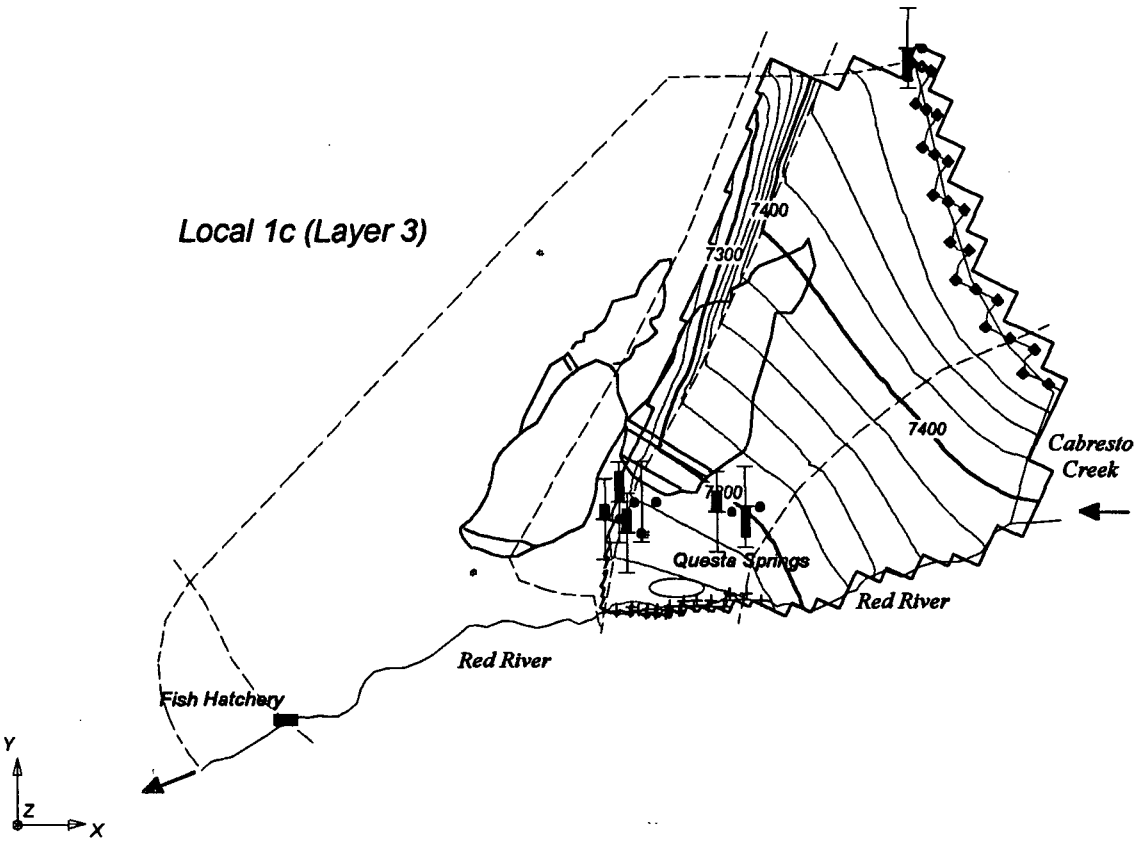


Figure B3.
Simulated heads for scenario "local 1b".



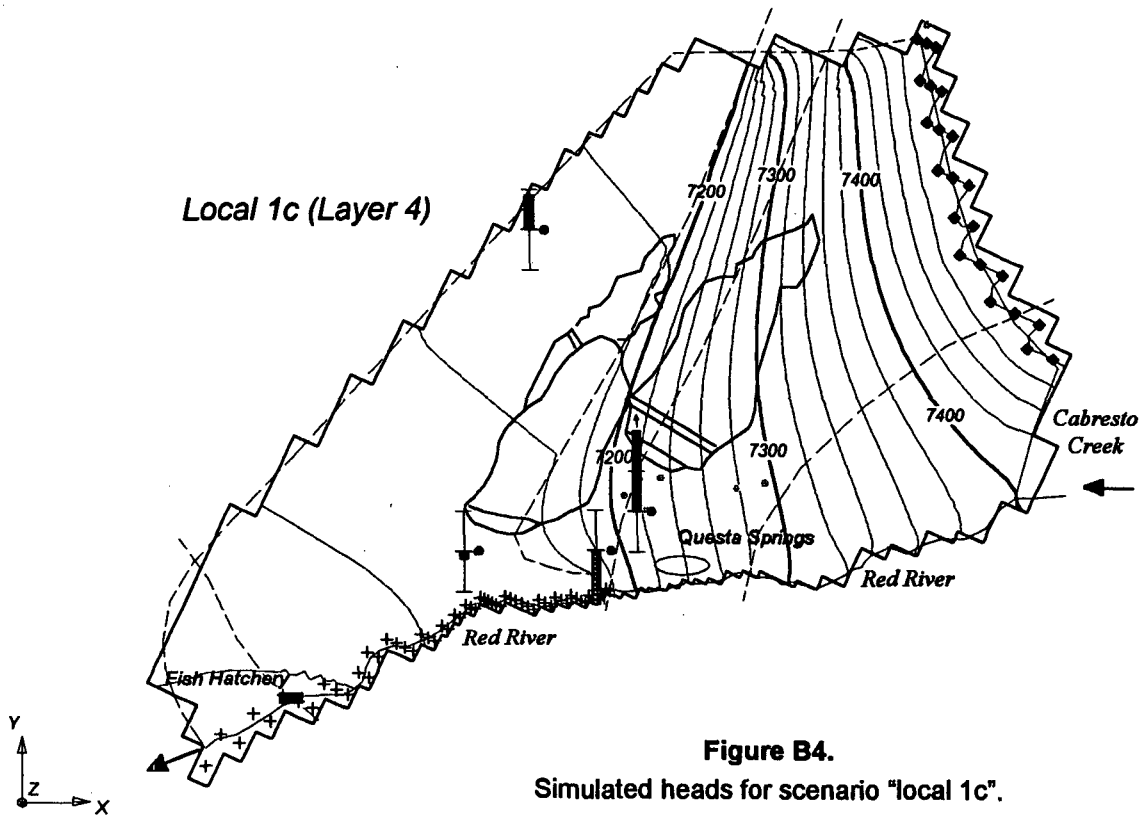
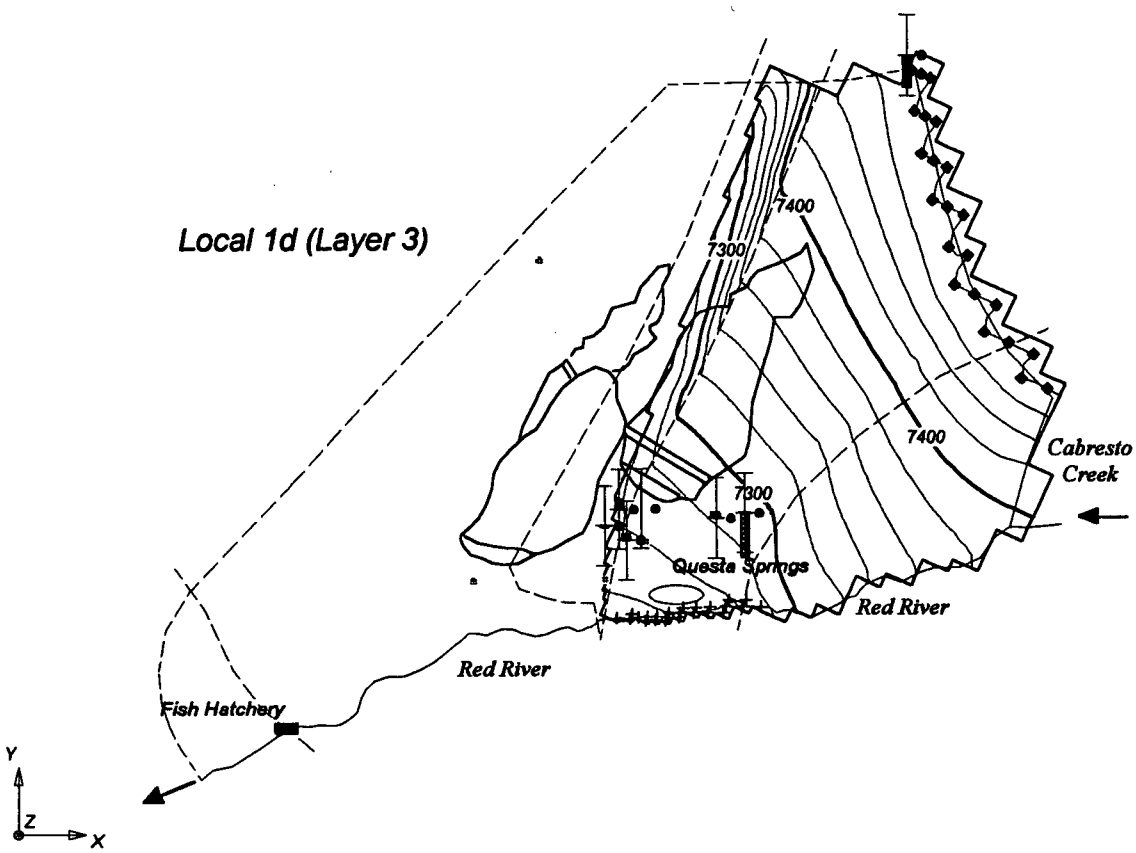


Figure B4.
Simulated heads for scenario "local 1c".



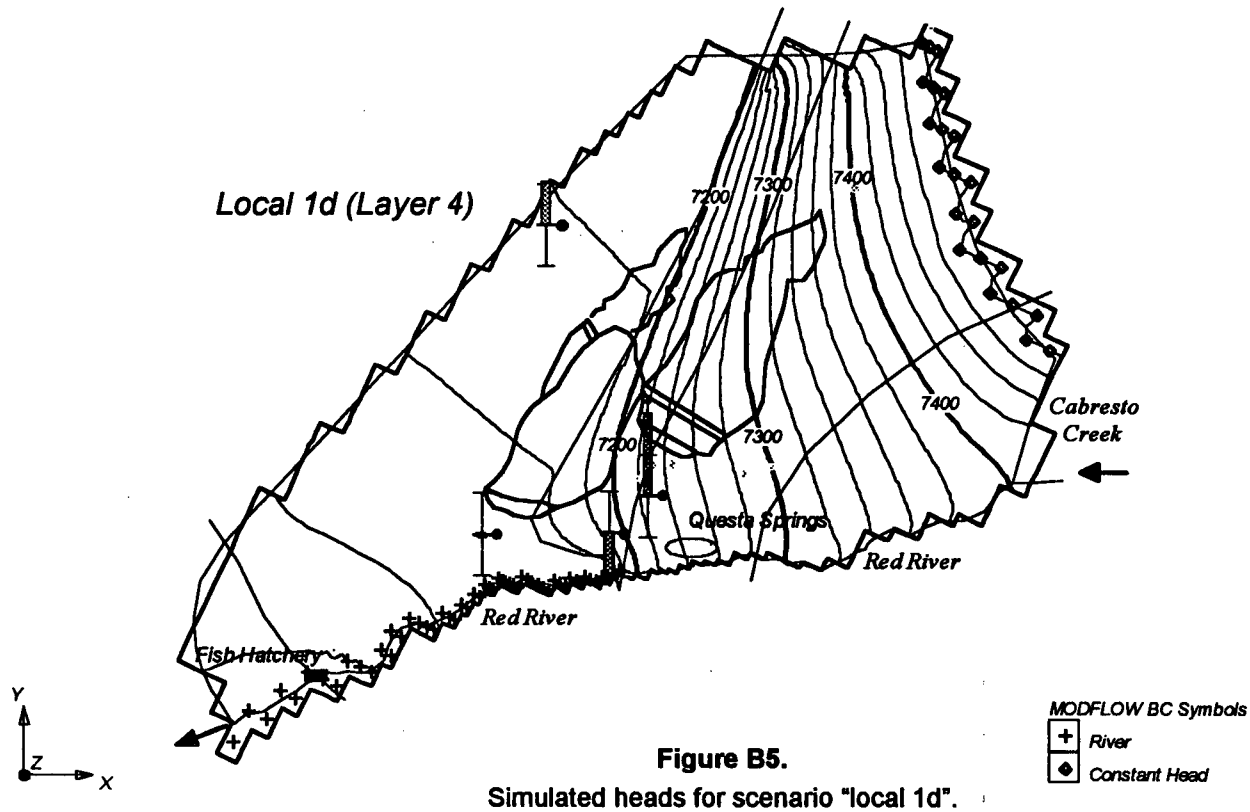
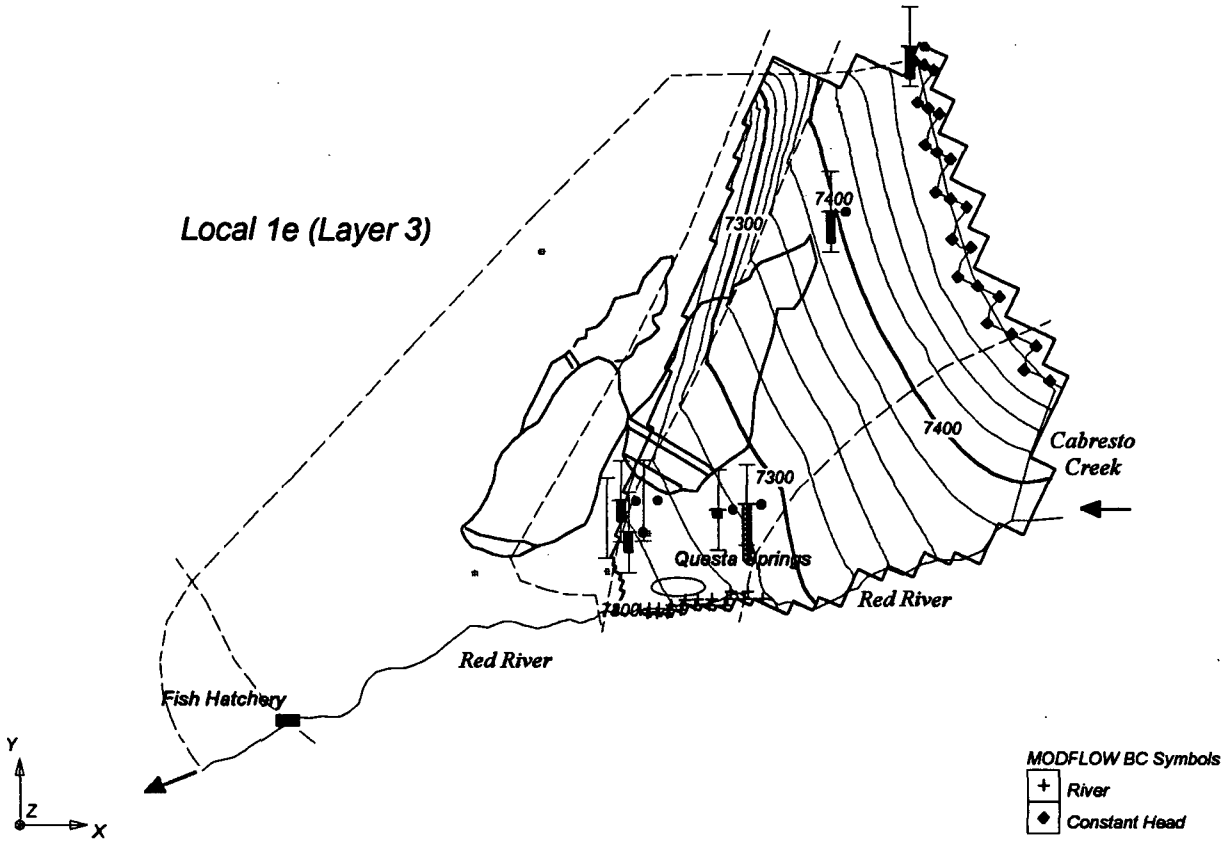


Figure B5.
Simulated heads for scenario "local 1d".



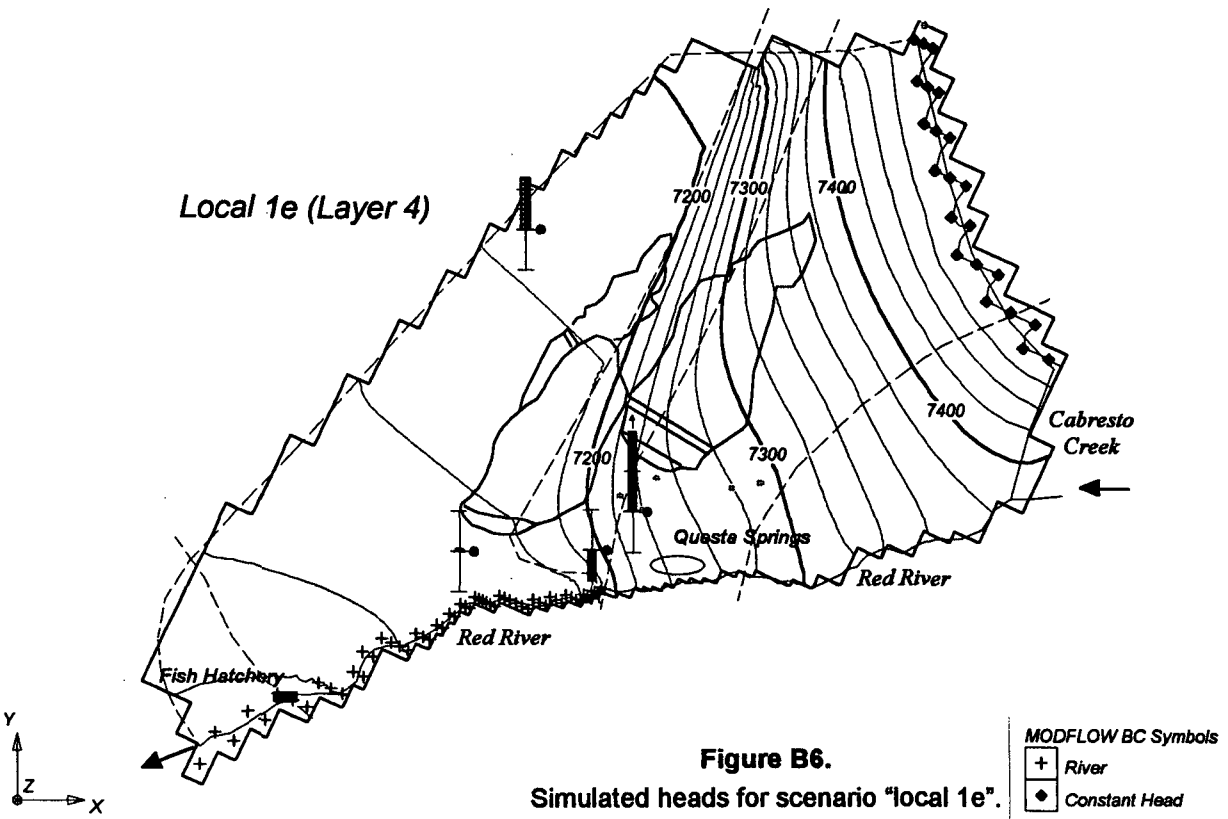
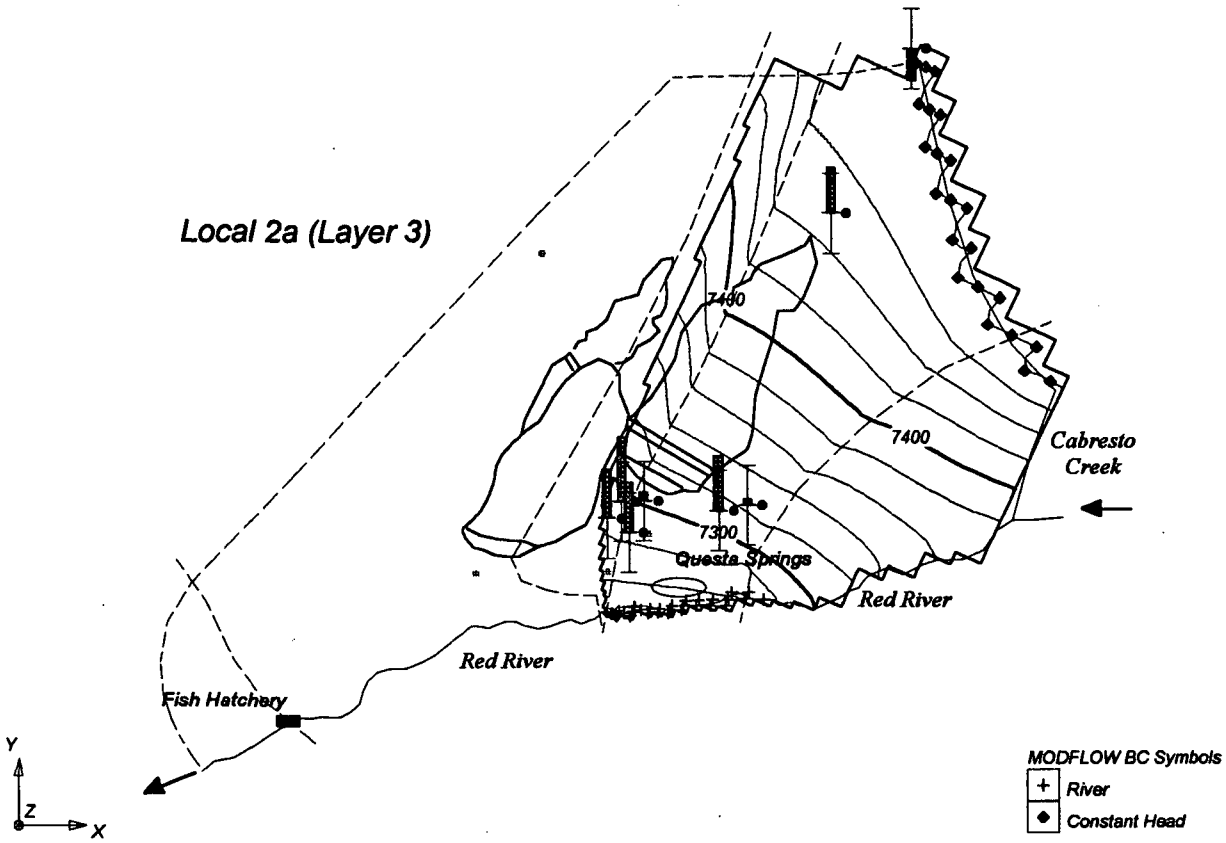


Figure B6.
Simulated heads for scenario "local 1e".



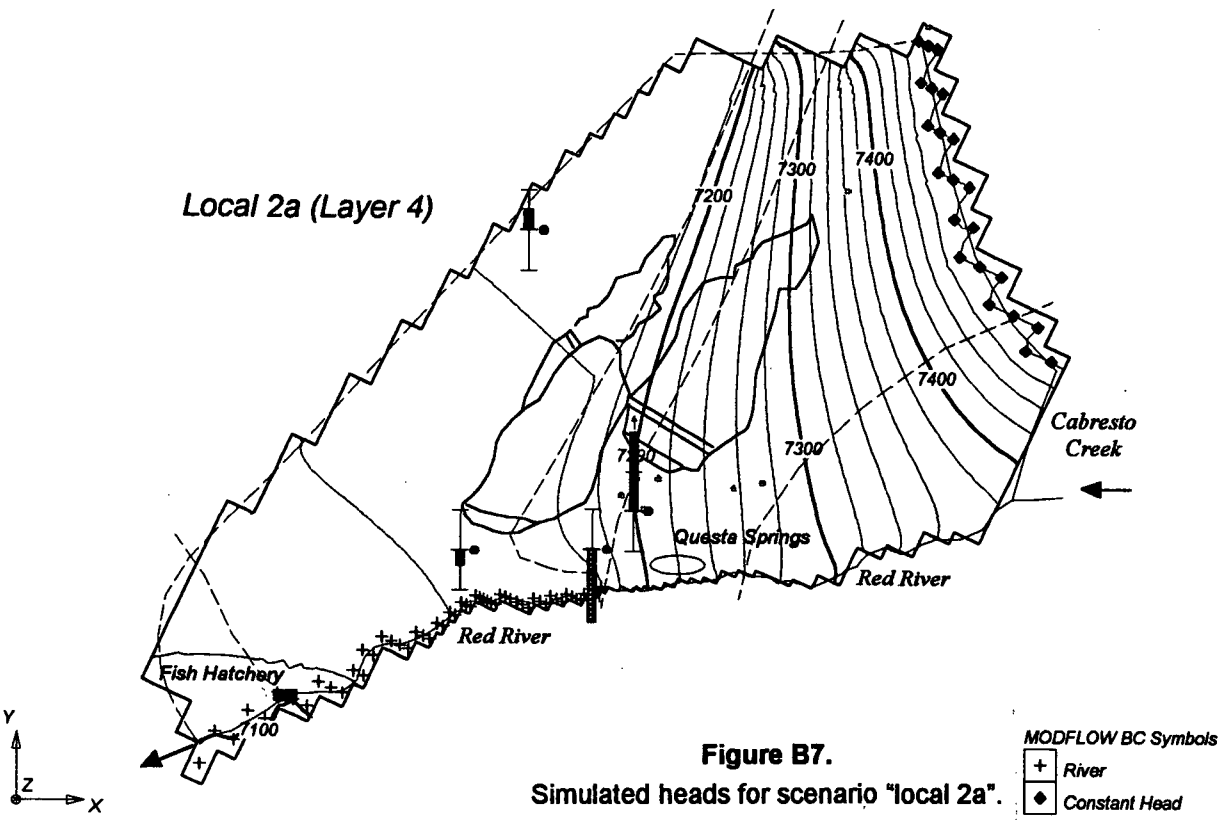
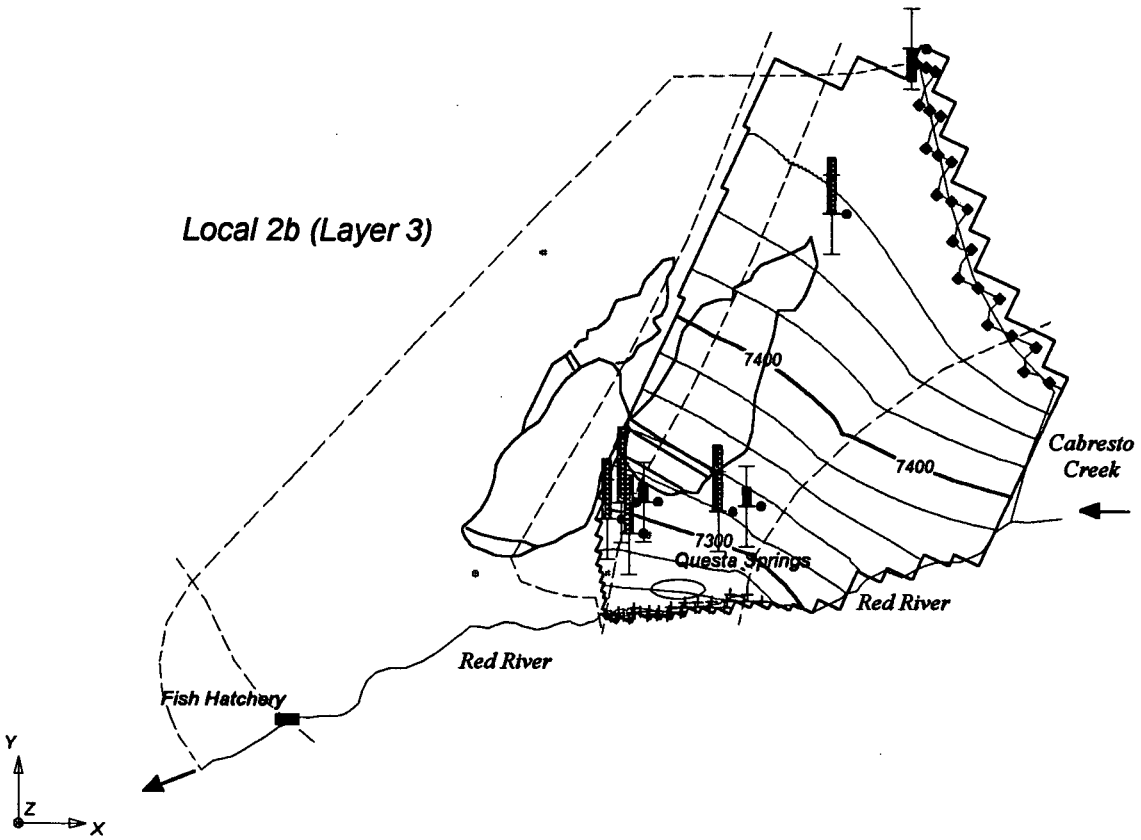


Figure B7.
Simulated heads for scenario "local 2a".



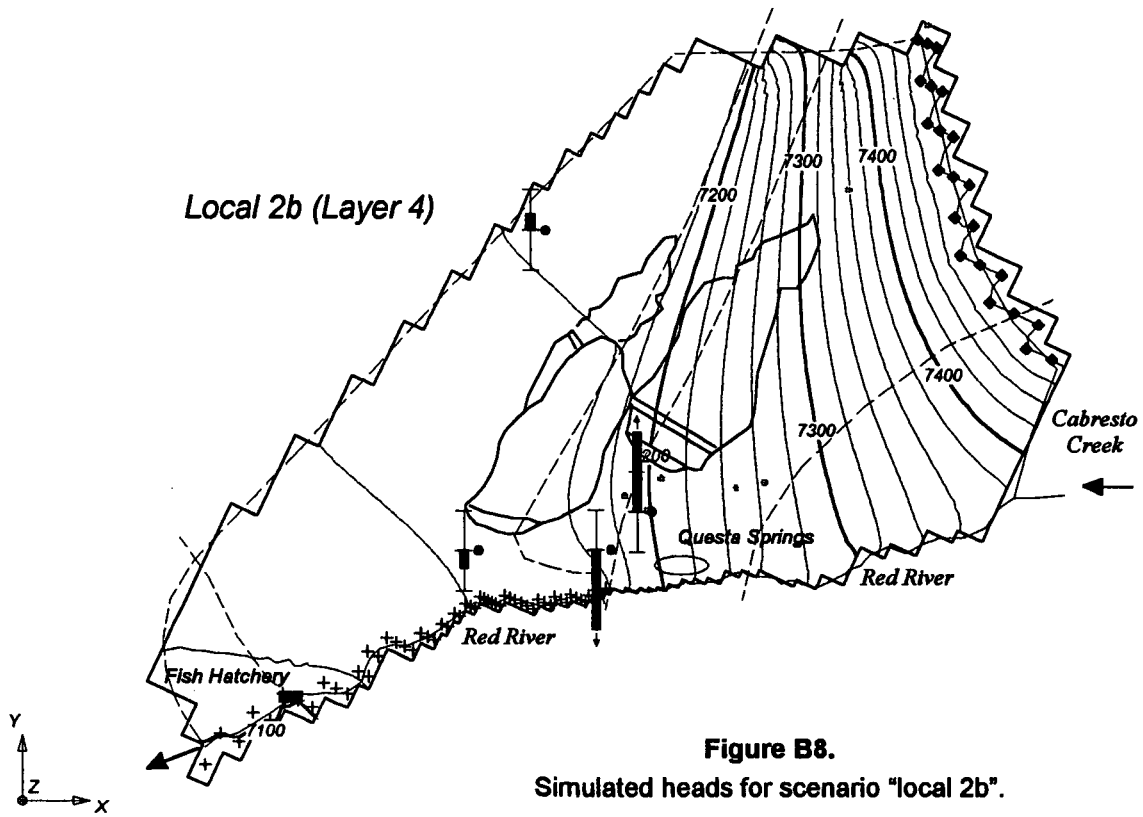


Figure B8.
Simulated heads for scenario "local 2b".

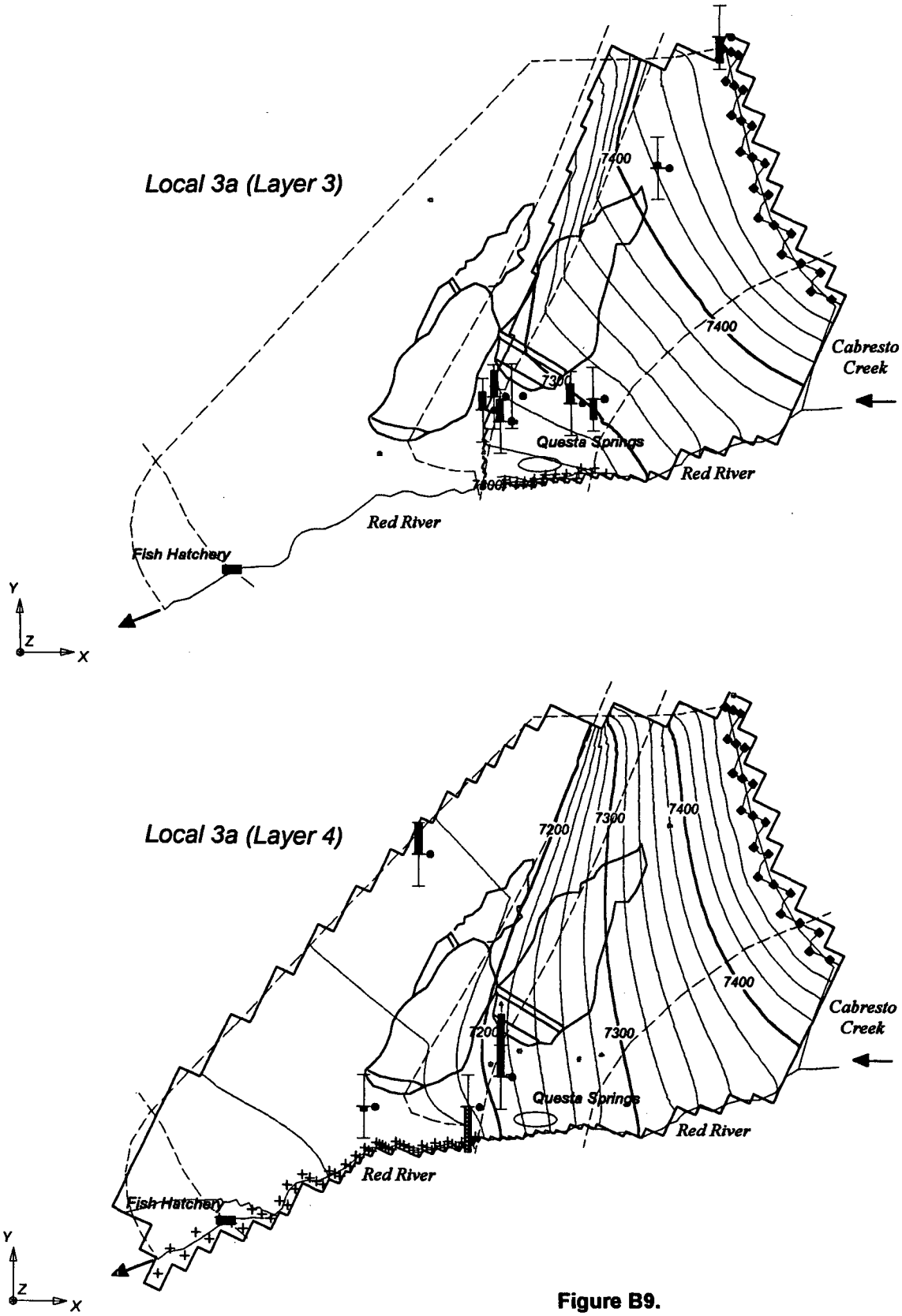
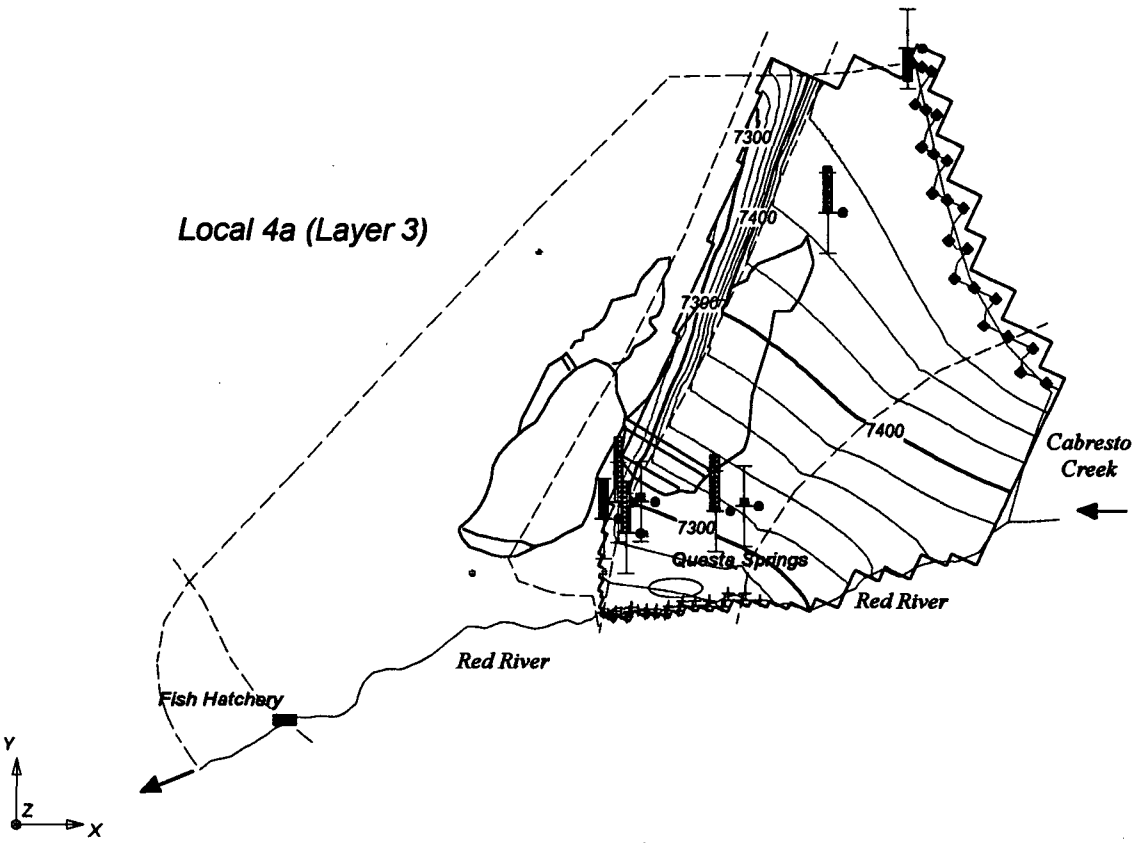


Figure B9.
Simulated heads for scenario "local 3a".



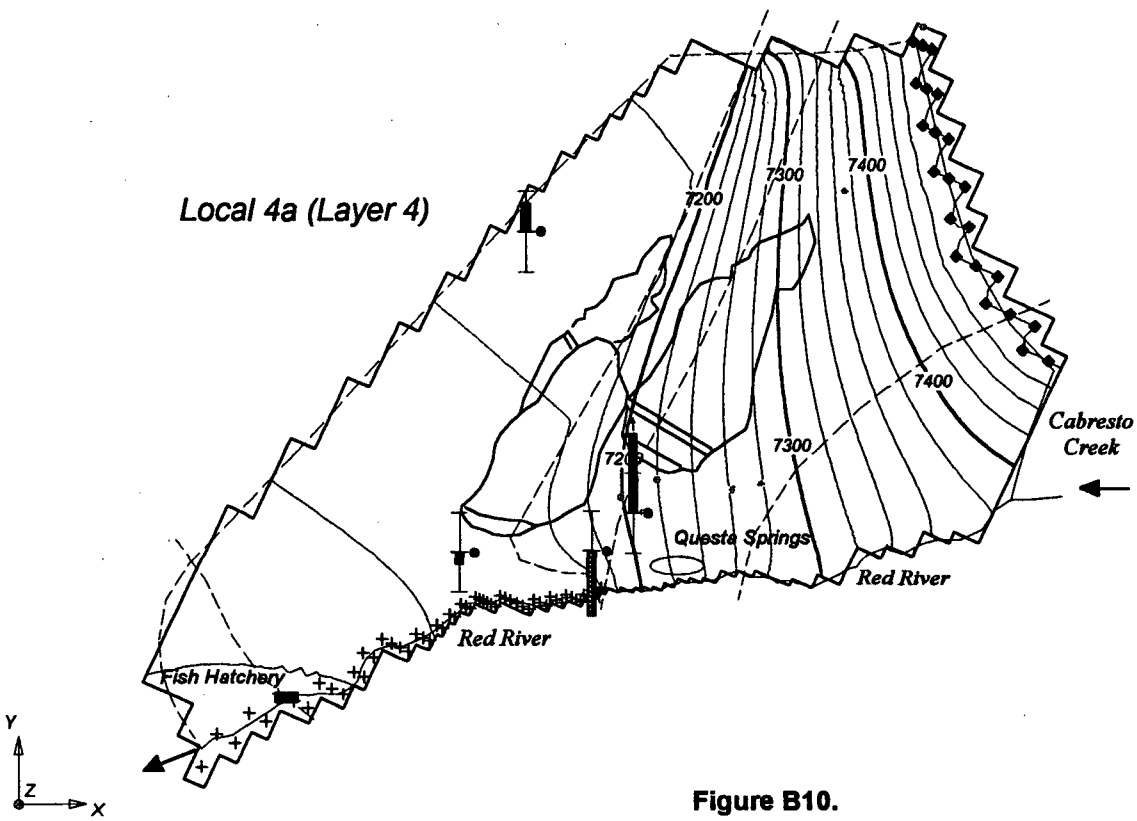
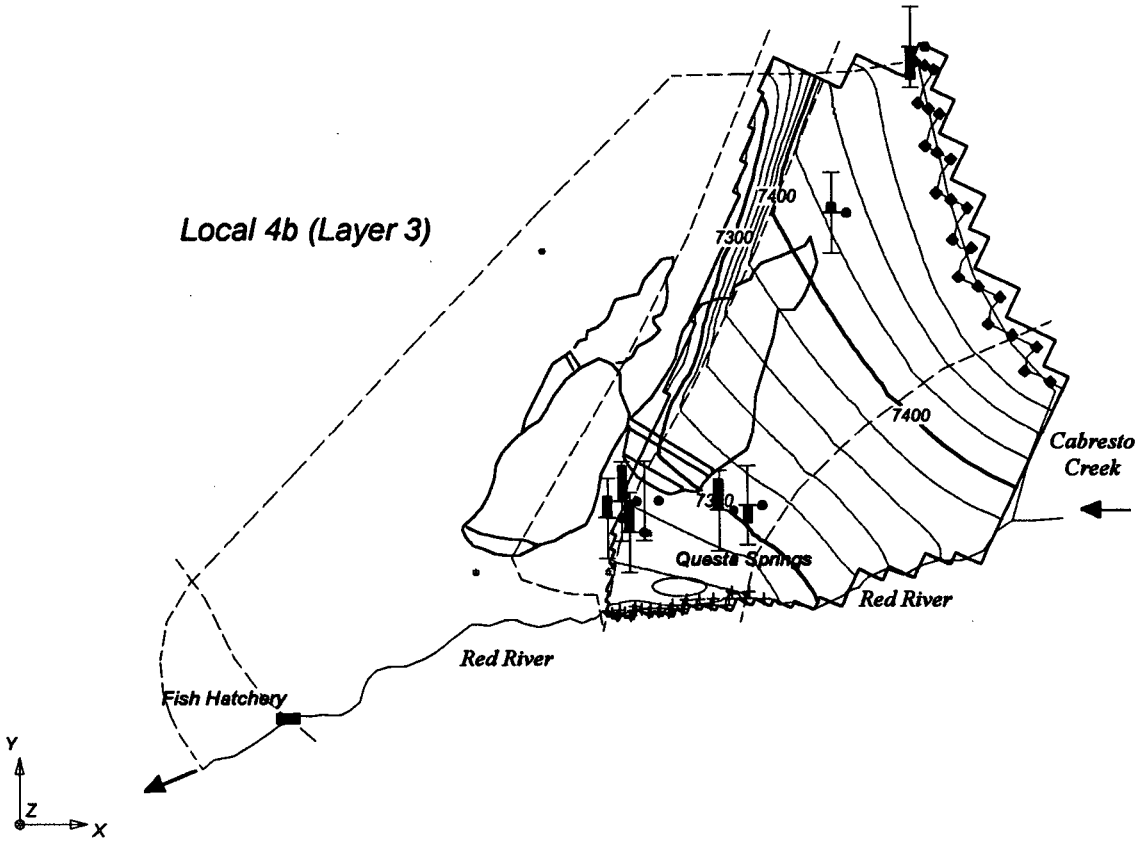


Figure B10.
Simulated heads for scenario "local 4a".



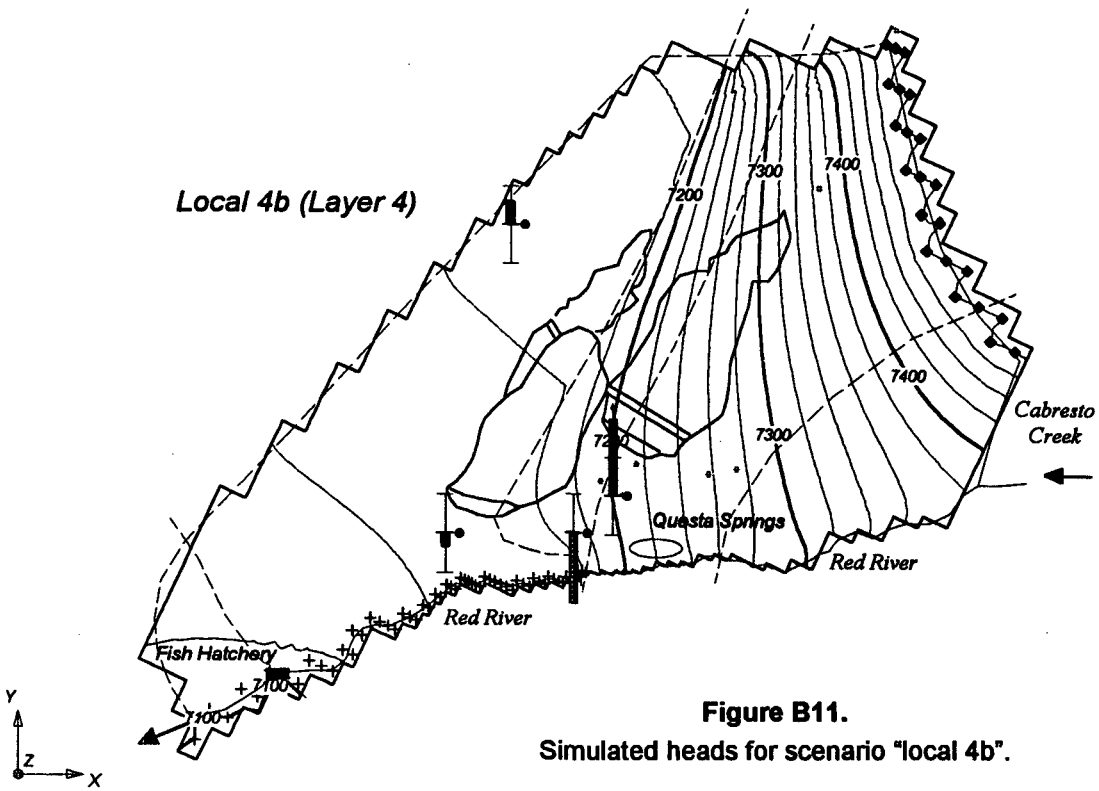
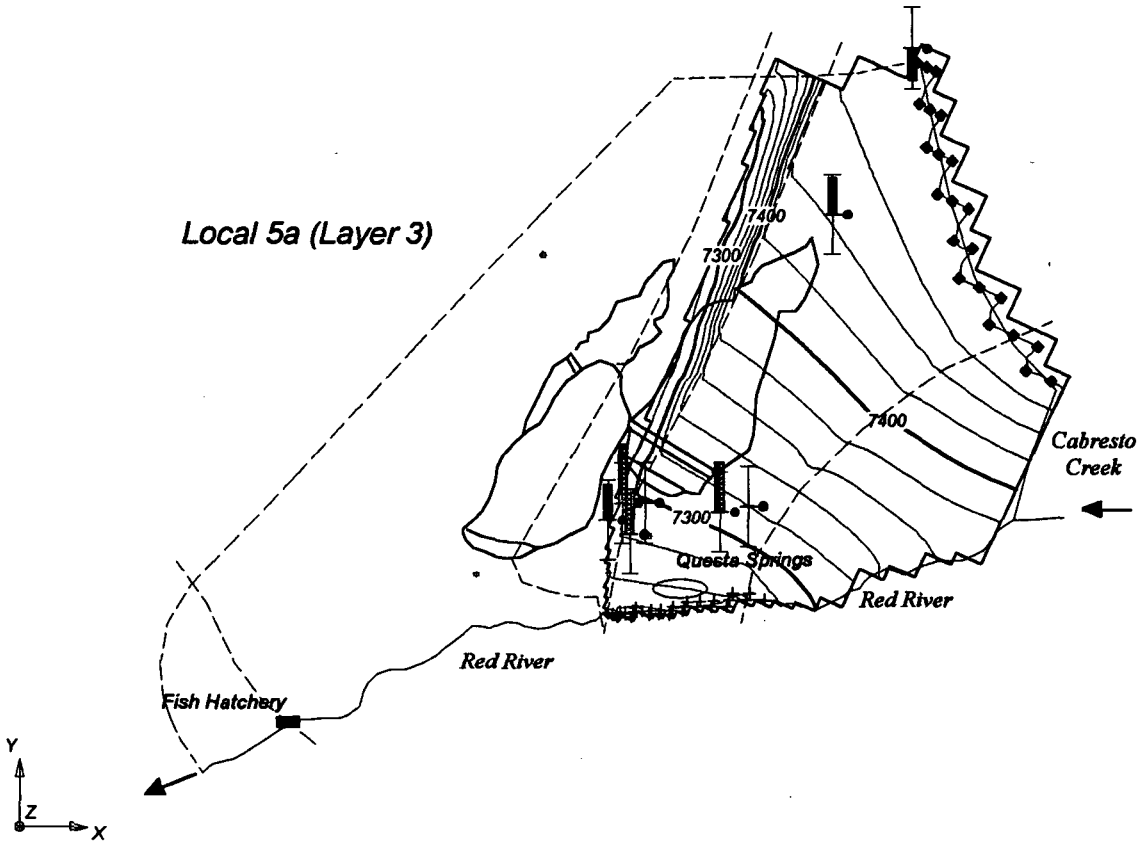


Figure B11.
Simulated heads for scenario "local 4b".



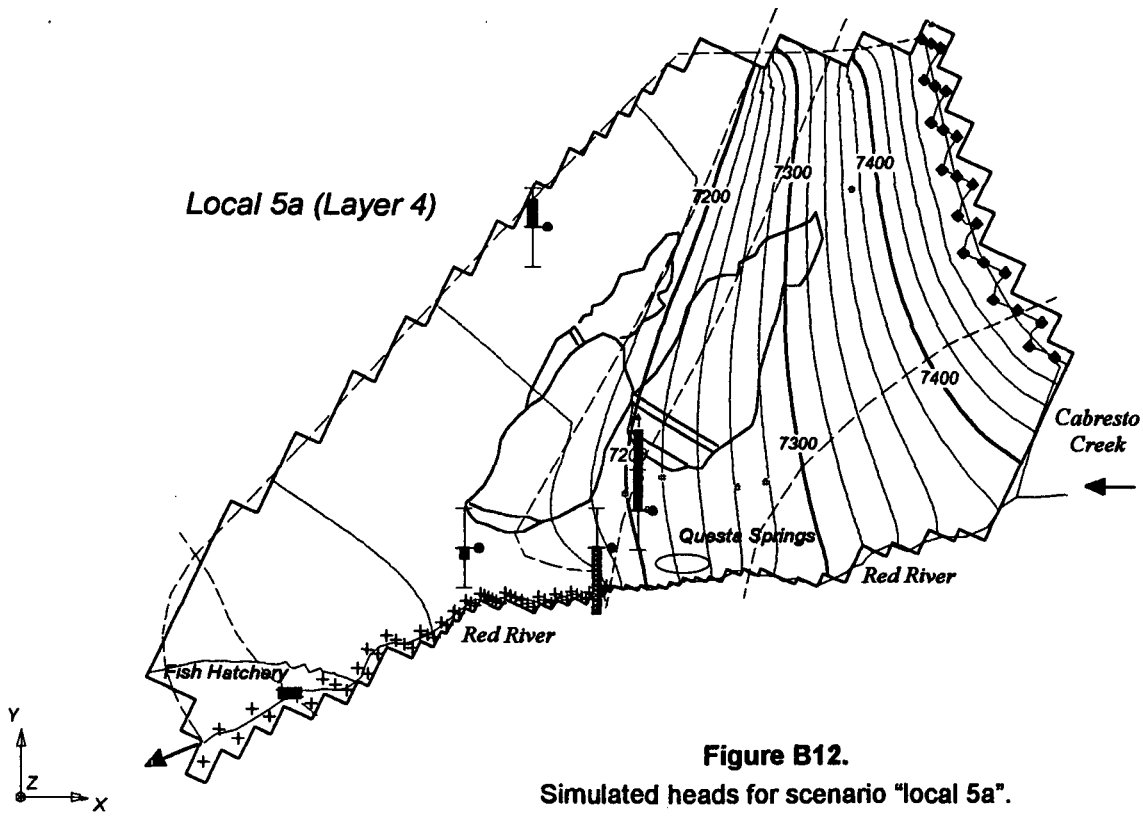
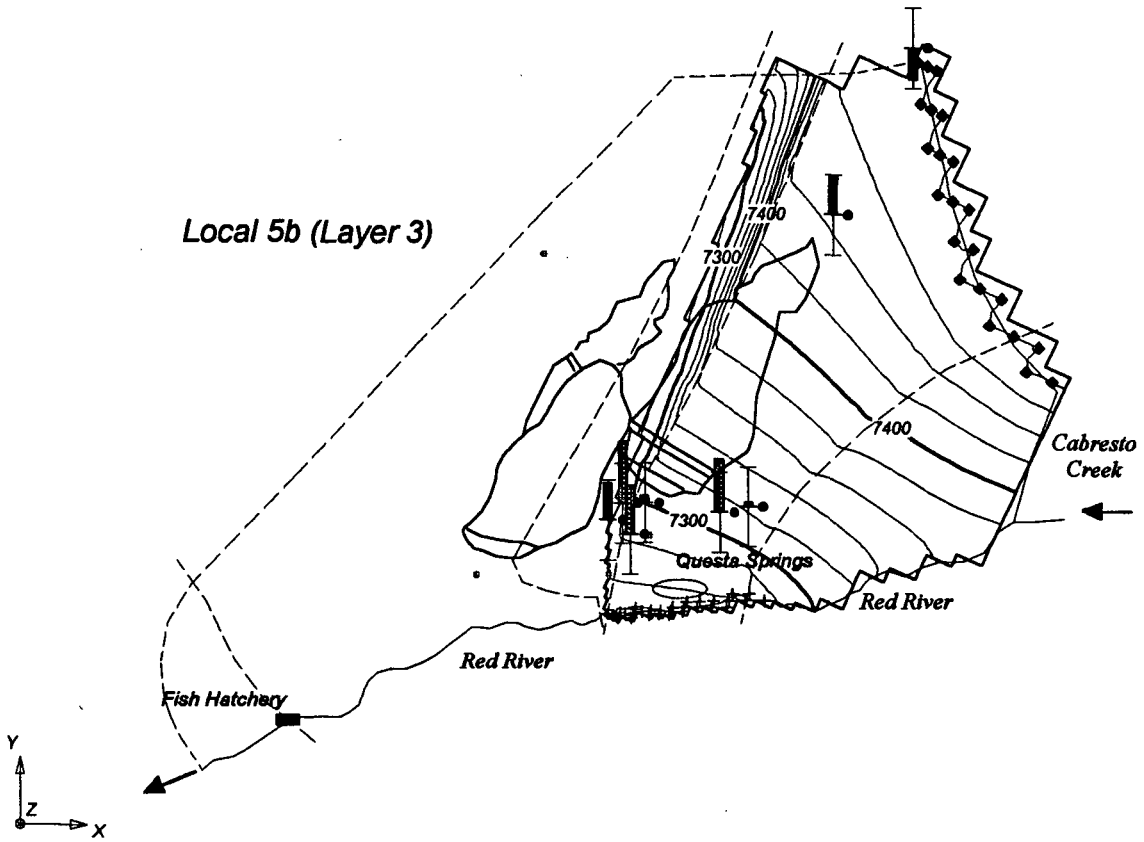


Figure B12.
Simulated heads for scenario "local 5a".



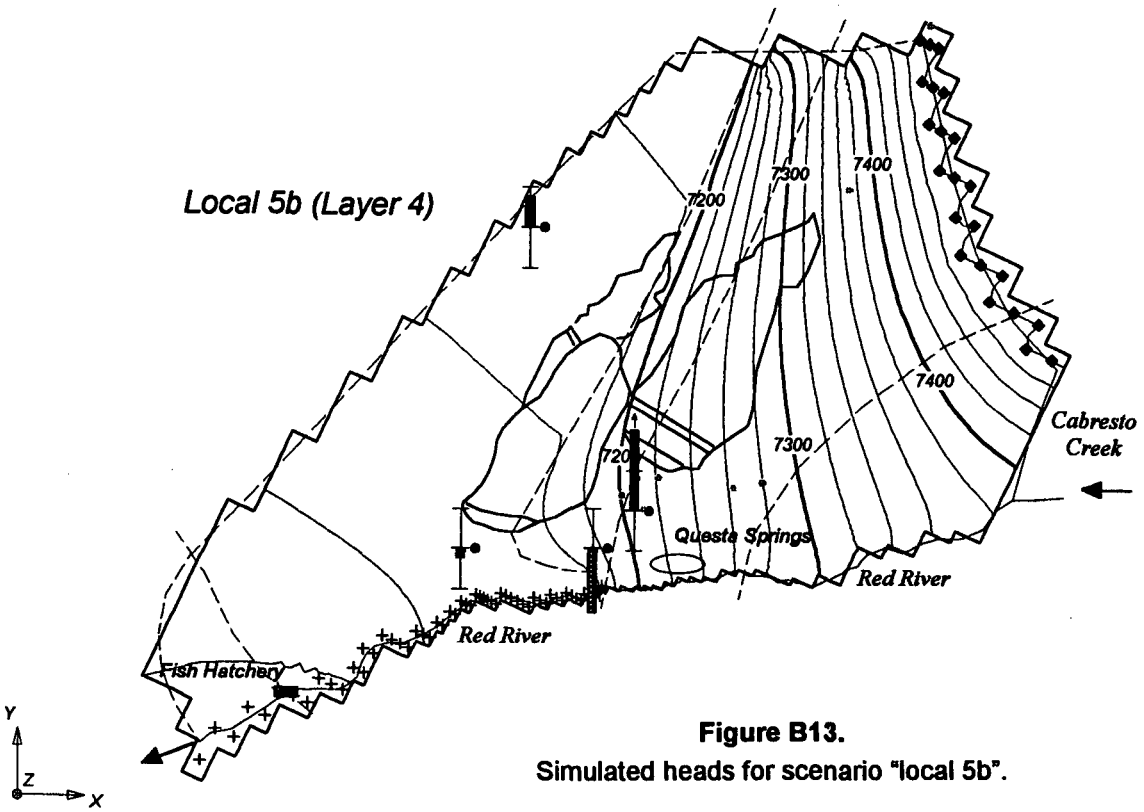
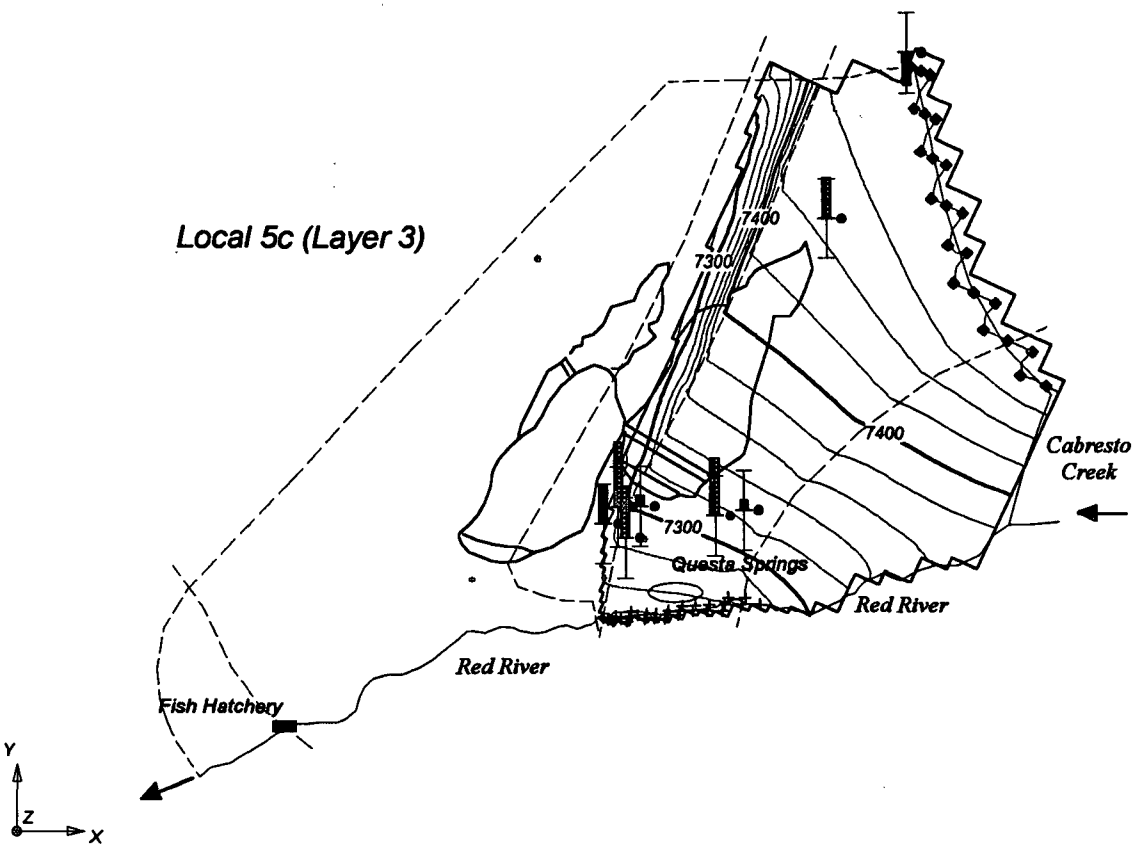


Figure B13.
Simulated heads for scenario "local 5b".



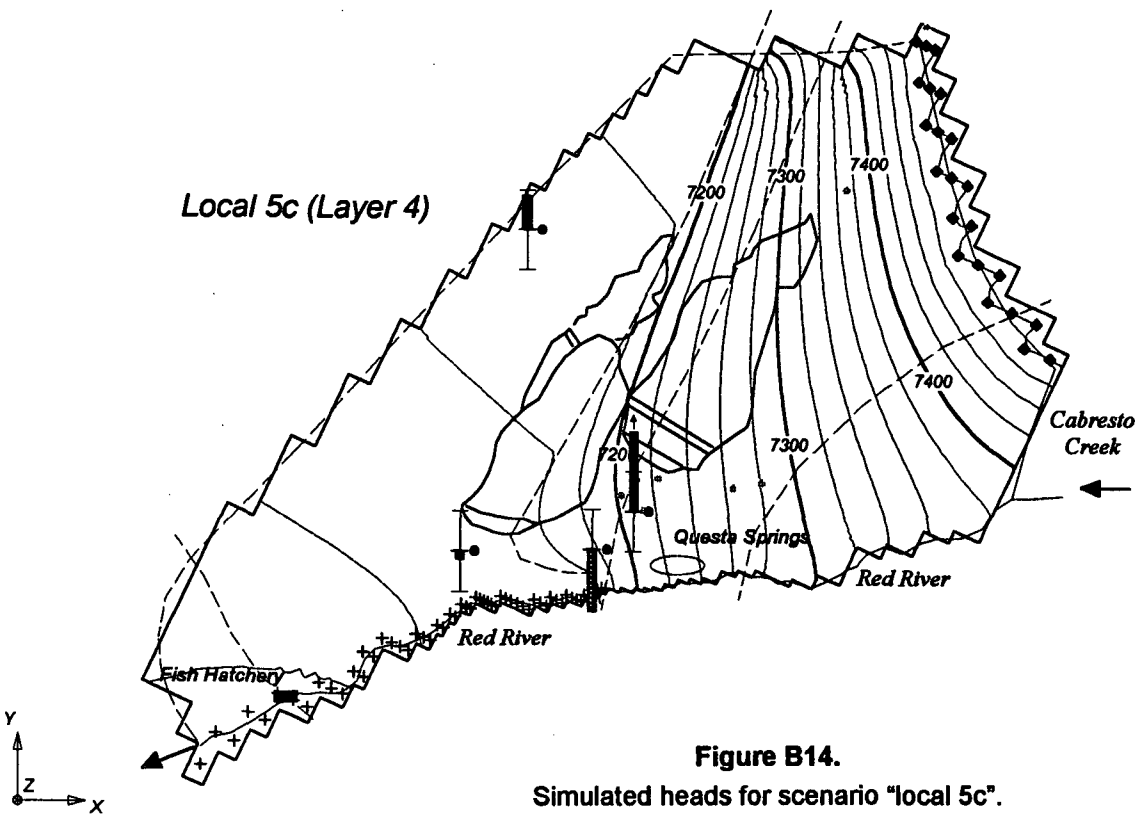


Figure B14.
Simulated heads for scenario "local 5c".

Appendix C

APPENDIX C

Results of Geotechnical Testing for Hydro(geo)logical Modeling

C Geotechnical Laboratory Test Results

C.1 Sampling and Laboratory Testing

Several soil samples including coarse and fine tailings, alluvial cover material and fine alluvial silt were taken in the fall of 1995 and in the spring of 1997 and analyzed in the SRK laboratories in Denver, Colorado for relevant physical and hydrological properties.

A first set of tests for those samples taken in the fall of 1995 was completed in the summer of 1996. A second set of tests for the samples taken in the spring of 1997 and two cover samples from the 1995 sampling campaign was completed in the summer of 1997. Table C1 lists the samples and specific tests, which were performed during the 1996 and 1997 testing programs, respectively.

C.2 Test Results

The raw data of the various laboratory tests are listed at the end of this Appendix. Table C1 summarizes the test results for those samples considered for modeling purposes. Note that the initial volumetric water contents for the coarse cover samples were significantly higher than the measured (or back-calculated) field porosity for a given sample. The procedure for measuring the soil moisture characteristic curve (or capillary moisture relationship; ASTM D2325) requires that all sample material greater than 2 mm (No. 10 sieve) be screened out. This screening, however, introduces a bias towards greater volumetric water contents, which needs to be corrected for (most particles greater than 2 mm take up pore space but provide little void space for soil moisture). Hence, the volumetric moisture contents of all samples were corrected to the measured (saturated) porosity of the respective unscreened sample for field compaction ("field porosity") using the formula:

$$Ø_{corrected} = Ø_{measured} * (Ø_s / Ø_{initial})$$

where

$Ø_s$ = volumetric water content at field compaction ("field porosity")

$Ø_{initial}$ = volumetric water content of screened sample at saturation

$Ø_{measured}$, $Ø_{scorrected}$ = the measured and corrected volumetric water contents for a gicven suction.

The soil water characteristic curves (using the corrected data) for the cover material samples and tailings samples are shown in Figures C1 and C2, respectively.

Table C1.
Summary of Geotechnical Laboratory Test

Sample	Description	Grain Size Distribution	Hydraulic Conductivity Tri-axial Flex Wall ASTM D5084 - 90	Hydraulic Conductivity Rigid Wall ASTM D2434	Capillary Moisture Relationship ASTM D2325	Standard Proctor	Specific Gravity
1996 Testing Program					ASTM D2325 - 68		
T-21 (Bulk)	fresh cover material (behind Dam No. 5A)	x		x	x		x
T-3 (Bulk)	old cover material (behind Dam No. 1C)	x		x	x		x
T-24	coarse tailings	x		x	x		x
T-2	fine tailings	x	x		x		x
1997 Testing Program					ASTM D2325 - 94		
T-21 (Bulk)	fresh cover material (behind Dam No. 5A)		x		x		
T-3 (Bulk)	old cover material (behind Dam No. 1C)		x		x		
97-Al-1	cover material in center of section 36	x	x		x	x	x
97-Al-2	alluvial silt exposed in diversion channel east of section 35	x	x		x	x	x
97-T-3	fine tailings near surface in section 36	x	x				
97-T-7	coarse tailings near surface in section 35	x	x		x		x

Table C2.

Geotechnical Testing of Cover Material and Tailings - Summary of Results

Soil Parameter	Alluvial Cover Material				Tailings Samples			
	fresh cover "T-21"	compacted (old) cover "T-3"	uncompacted cover "97-Al-1"	alluvial silt "97-Al-2"	fine tailings "T-2"	fine tailings "97-T-3"	sandy tailings "T-24"	sandy tailings "97-T-7"
USCS Soil Classification	clayey gravel w/ sand (GC)	clayey gravel w/ sand (GC)	clayey sand w/ gravel (SM or SL)	silty clay w/ sand (CL or ML)	silt (ML)	silt (ML)	silty sand (SM)	silty sand (SM)
% gravel	46.4	43.5	24.6	0.8	0.0	0.0	0.0	0.8
% sand	40.5	40.4	32.3	23.5	1.5	5.8	57.8	23.5
% fines	13.1	16.1	43.1	75.7	98.6	94.2	42.2	75.7
<2 mm (in %)	42.0	49.0	68.0	99.0	0.0	0.0	0.0	99.0
Permeability, K (in cm/s)	2.9E-04	1.7E-05	8.8E-06	1.3E-07	4.7E-07	3.3E-07	1.2E-03	1.5E-03
Field Porosity, Øs (in cm^3/cm^3)	0.29	0.24	0.39	0.35	0.41	0.40	0.45	0.45
Density (in pcf)	115	126	98.3	104	97	98	90	104
Specific Gravity (unitless)	2.69	2.67	2.68	2.63	2.69	n/a	n/a	2.71
Initial Water Content (in cm^3/cm^3) (1)	0.36 (0.22)	0.43 (0.27)	0.47 (0.38)	0.43 (0.41)	0.46	n/a	0.40	0.44
Residual Water Content (in cm^3/cm^3) (1)	0.22 (0.14)	0.27 (0.17)	0.32 (0.26)	0.32 (0.31)	0.36	n/a	0.10	0.06
Air Entry Value (in cm suction)	< 20	~ 20	< 20	~ 20	< 200	n/a	< 20	~ 20

Notes:

(1) values in brackets show water content corrected for screened out gravel

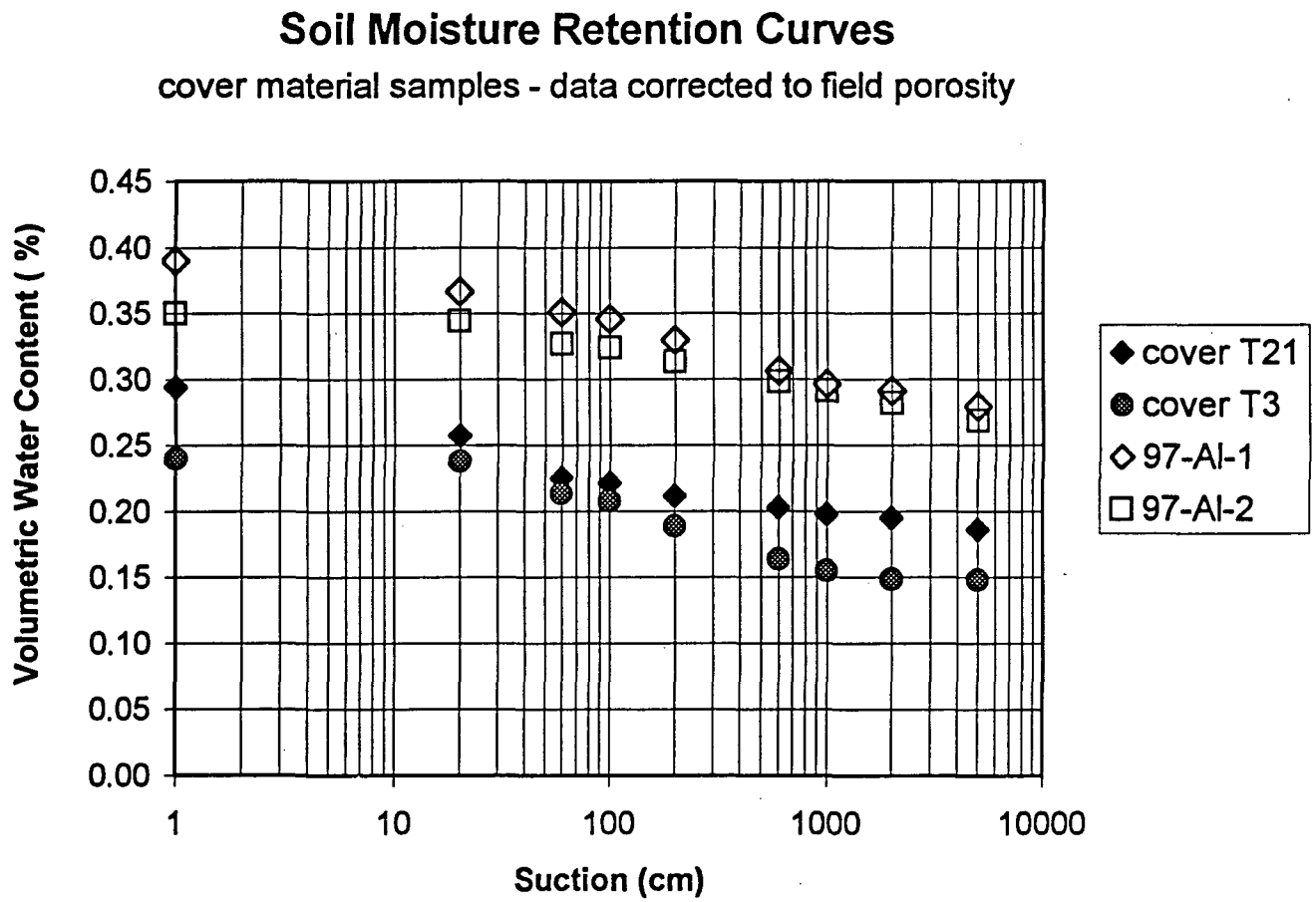


Figure C1.
Soil Water Characteristic Curves for Alluvial Cover Samples

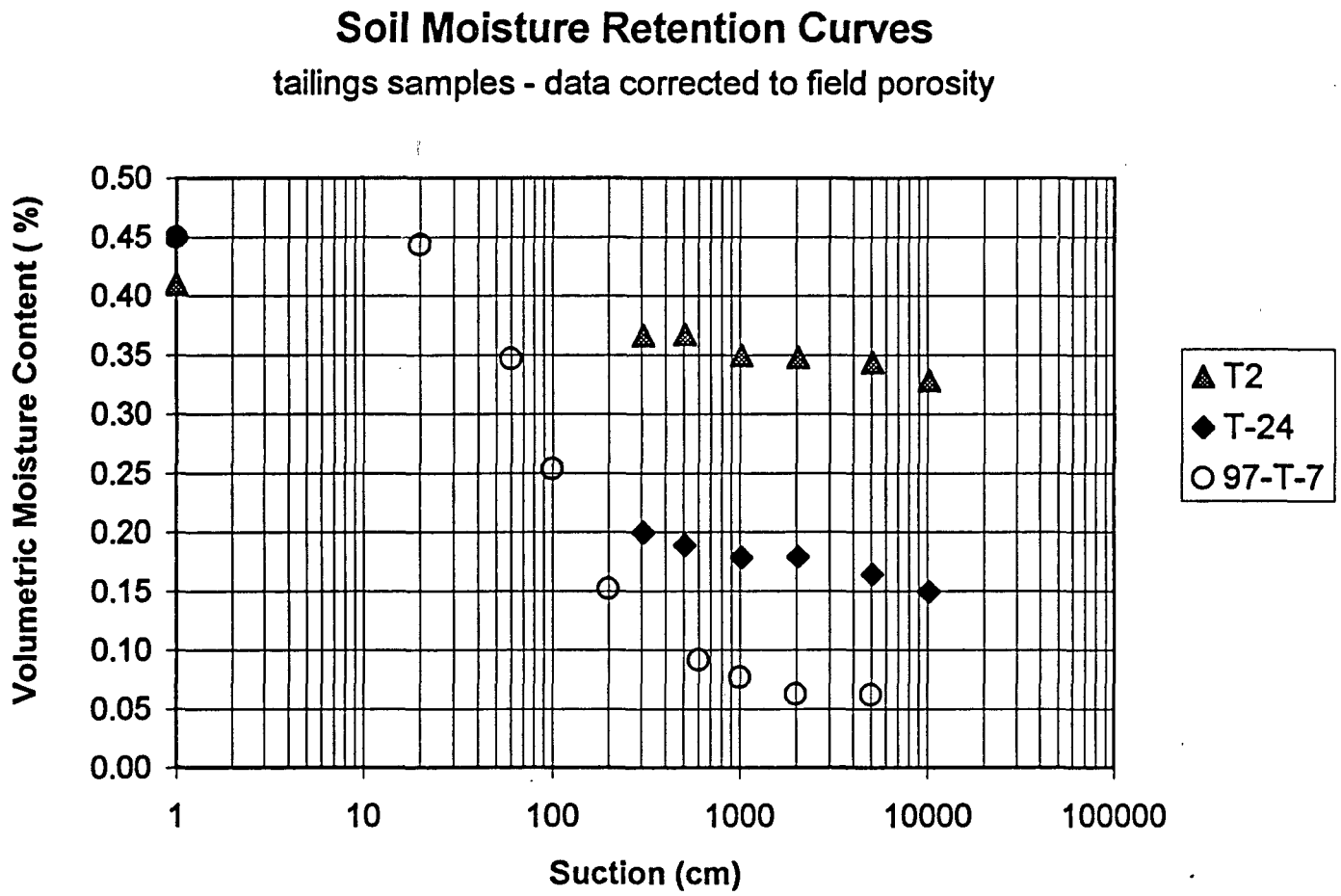


Figure C2.
Soil Water Characteristic Curves for Tailings Samples.

QUESTA
PROJECT NO. 036008
SUMMARY OF LABORATORY TEST RESULTS

Sample No.	Natural Moisture (%)	Gradation				Atterberg Limits		Standard Proctor		Permeability		Specific Gravity	Description (USCS)
		Gravel (%)	Sand (%)	Fines (%)		Liquid Limit (%)	Plasticity Index (%)	Max. Dry Density (pcf)	Optimum Moisture (%)	Triaxial Flex Wall (cm/sec)	Rigid Wall (cm/sec)		
				Silt (%)	Clay (%)								
97-AL-1	17.7	24.6	32.3	43.1				105.9	18.2	8.8E-06	9.0E-06	2.68	silty or clayey SAND w/gravel (SM or SC)
97-AL-2	19.3	0.8	23.5	75.7				104.0	18.4	1.3E-07		2.63	silty CLAY w/sand (ML or CL)
97-T-3	23.8	0.0	5.8	94.2						3.3E-07			SILT or CLAY (CL or ML)
97-T-7	8.7	0.0	70.6	29.4						1.5E-03		2.71	silty SAND (SM)
T-3 (Bulk)	8.9	43.5	40.4	6.7	9.4	29	15			1.7E-05	1.7E-05	2.67	clayey GRAVEL w/sand (GC)
T-21 (Bulk)	8.2	46.4	40.5	5.1	8.0	33	19			2.9E-04	2.0E-03	2.69	clayey GRAVEL w/sand (GC)

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

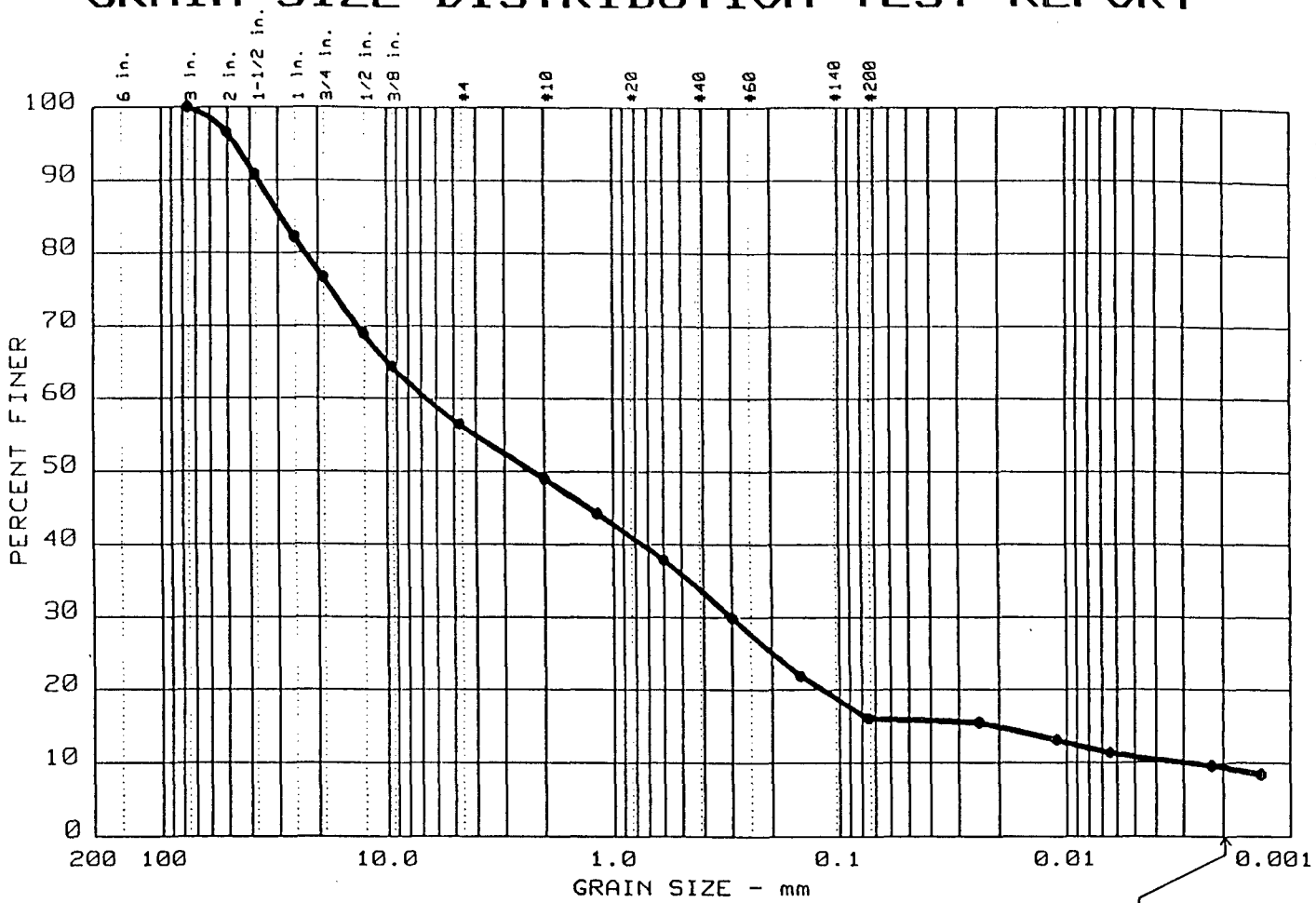
Project	Questa	Project No.	036008
Sample No.	T-3 Bulk	Tested By	SDD
Description	clayey GRAVEL w/sand	Checked By	CW
Sample Type	Remold	Date	06/19/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	7.29	Specific Gravity	2.67
Init. Ht. (cm)	14.49	Assumed?	No
Init. Vol (cm^3)	604.16	Init. Void Ratio	0.351
Init. Sample Wet Wt. (g)	1272.29	Initial Porosity	0.260
Init. Moisture Content	6.6%	Init. Dry Density (pcf)	123.3
		Initial Calculated Saturation	50.0%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm^2)	40.75
Confining Pressure (psi)	4.0	Height Change (cm)	0.01
Volume Change (cc)	14.01	Final Ht. (cm)	14.48
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	1534.03	Final Void Ratio	0.319
Final Dry Wt. + Pan (g)	1388.39	Final Volume (cm^3)	590.15
Pan Wt. Only (g)	194.58	Final Dry Density (pcf)	126.3
Final Moisture Content	12.2%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	1.00	Final Porsity	0.242

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	7.6	40.3				
5	9.2	38.7	1.5	101.40	1.44	1.7E-05
5	10.7	37.2	1.4	98.30	1.40	1.6E-05
5	12.2	35.7	1.4	95.30	1.36	1.7E-05
5	13.6	34.3	1.3	92.40	1.31	1.6E-05
					Average =	1.7E-05

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	43.5	40.4	6.7	9.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	29	15	29.1	6.59	2.26	0.301	0.0195	0.0026	5.37	2570.4

MATERIAL DESCRIPTION	USCS	AASHTO
● clayey GRAVEL w/sand, brown	GC	

Project No.: 09208.04
Project: Questa
● Location: T-3 Bulk, Cover Material

Date: 4/1/96

Remarks:

Specific gravity = 2.67

GRAIN SIZE DISTRIBUTION TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: _____

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

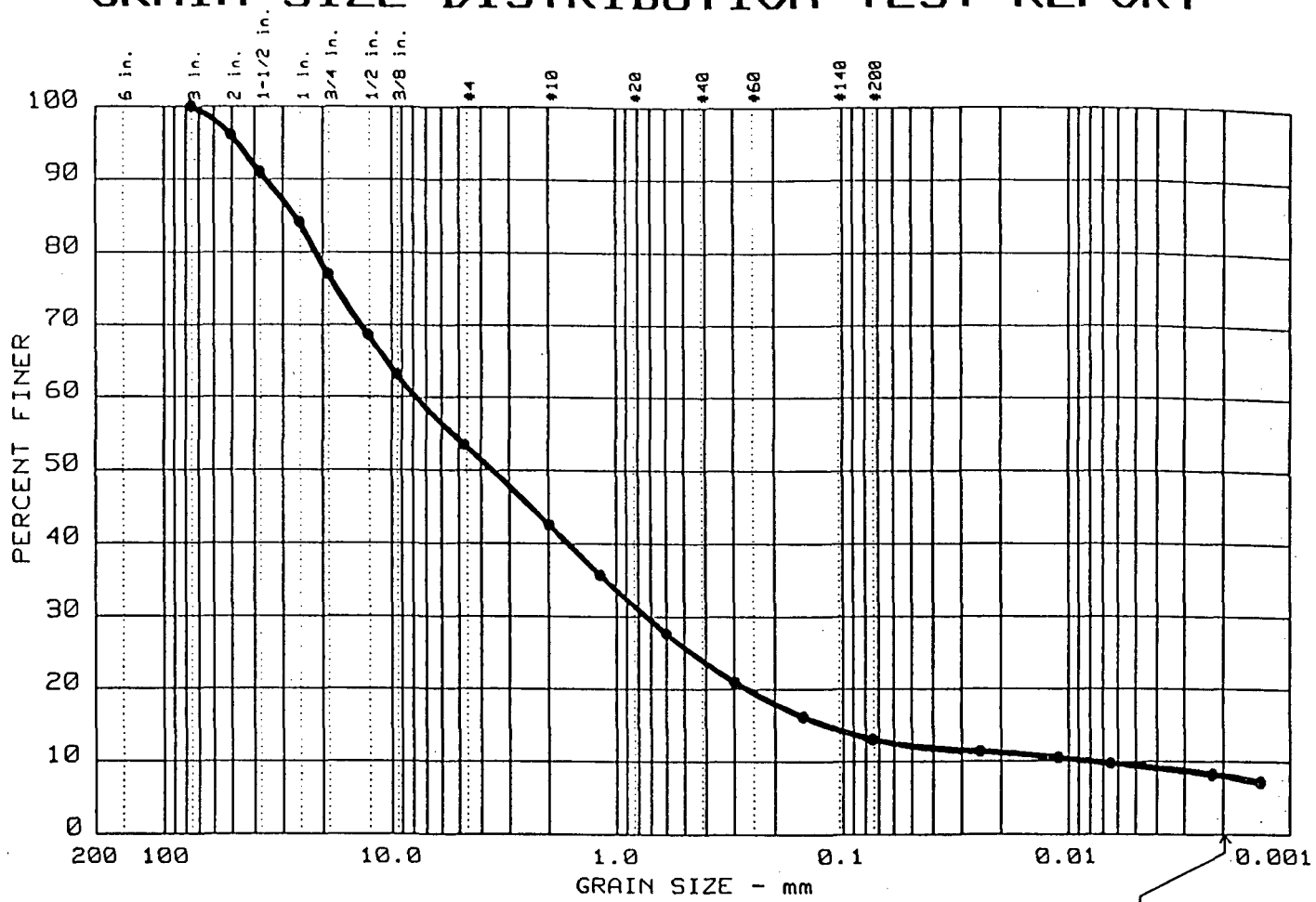
Project	Questa	Project No.	036008
Sample No.	T-21 Bulk	Tested By	SDD
Description	clayey GRAVEL w/sand	Checked By	CW
Sample Type	Remold	Date	06/18/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	7.26	Specific Gravity	2.69
Init. Ht. (cm)	14.40	Assumed?	No
Init. Vol (cm^3)	595.86	Init. Void Ratio	0.481
Init. Sample Wet Wt. (g)	1182.62	Initial Porosity	0.325
Init. Moisture Content	9.3%	Init. Dry Density (pcf)	113.3
		Initial Calculated Saturation	52.1%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm^2)	39.93
Confining Pressure (psi)	4.0	Height Change (cm)	0.12
Volume Change (cc)	25.66	Final Ht. (cm)	14.28
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	1481.72	Final Void Ratio	0.417
Final Dry Wt. + Pan (g)	1309.56	Final Volume (cm^3)	570.20
Pan Wt. Only (g)	227.77	Final Dry Density (pcf)	118.4
Final Moisture Content	15.9%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	0.40	Final Porsity	0.294

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	5.1	43.6				
2	11.7	37.0	6.0	60.02	0.85	3.0E-04
2	16.9	31.8	4.7	48.22	0.69	2.9E-04
2	20.9	27.8	3.6	39.02	0.56	2.8E-04
2	24.1	24.6	2.9	31.82	0.45	2.7E-04
					Average =	2.9E-04

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	46.4	40.5	5.1	8.0

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	33	19	26.3	7.76	3.55	0.733	0.117	0.0070	9.89	1109.2

MATERIAL DESCRIPTION	USCS	AASHTO
● clayey GRAVEL w/sand, brown	GC	

Project No.: 09208.04
Project: Questa
● Location: T-21 Bulk, cover material

Date: 3/26/96

Remarks:

Specific gravity = 2.69

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: _____

CONSTANT HEAD PERMEABILITY
RIGID WALL

Project	Questa	Project No.	036008
Sample No.	97-AL-1, Cover Material	Tested By	SDD
Depth	N/A	Checked By	CW
Sample Type	Remolded (6" mold)	Date	06/30/97

INITIAL SAMPLE DATA

Sample Dia (cm)	15.24	Specific Gravity	2.68
Init. Ht. (cm)	7.062	Assumed?	No
Init. Vol (cm^3)	1288.18	Init. Void Ratio	0.687
Init. Sample Wet Wt. (g)	2419.22	Init. Dry Density (pcf)	99.2
Init. Moisture Content	18.2%	Initial Calculated Saturation	71.0%

CONSOLIDATION DATA

Area (cm^2)	182.415
Final Ht. (cm)	6.888

FINAL SAMPLE DATA

Final Wet Wt. + Pan (g)	2774.0	Final Void Ratio	0.644
Final Dry Wt. + Pan (g)	2285.5	Final Volume (cm^3)	1256.56
Pan Wt. Only (g)	238.5	Final Dry Density (pcf)	101.7
Final Moisture Content	23.9%	Final Calculated Saturation	99.3%

TEST DATA

Date	Elapsed Time (min)	Elapsed Time (sec)	Total Head (cm)	Flow Q (cc)	Permeability k (cm/sec)
06/27/97	60	3600	39.50	33.8	9.0E-06
06/27/97	90	5400	39.50	51.0	9.0E-06
06/28/97	1535	92100	39.50	880.3	9.1E-06
06/29/97	1420	85200	39.50	807.5	9.1E-06
				Average =	9.0E-06

NOTE: Seating load of 4 psi applied to sample.

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

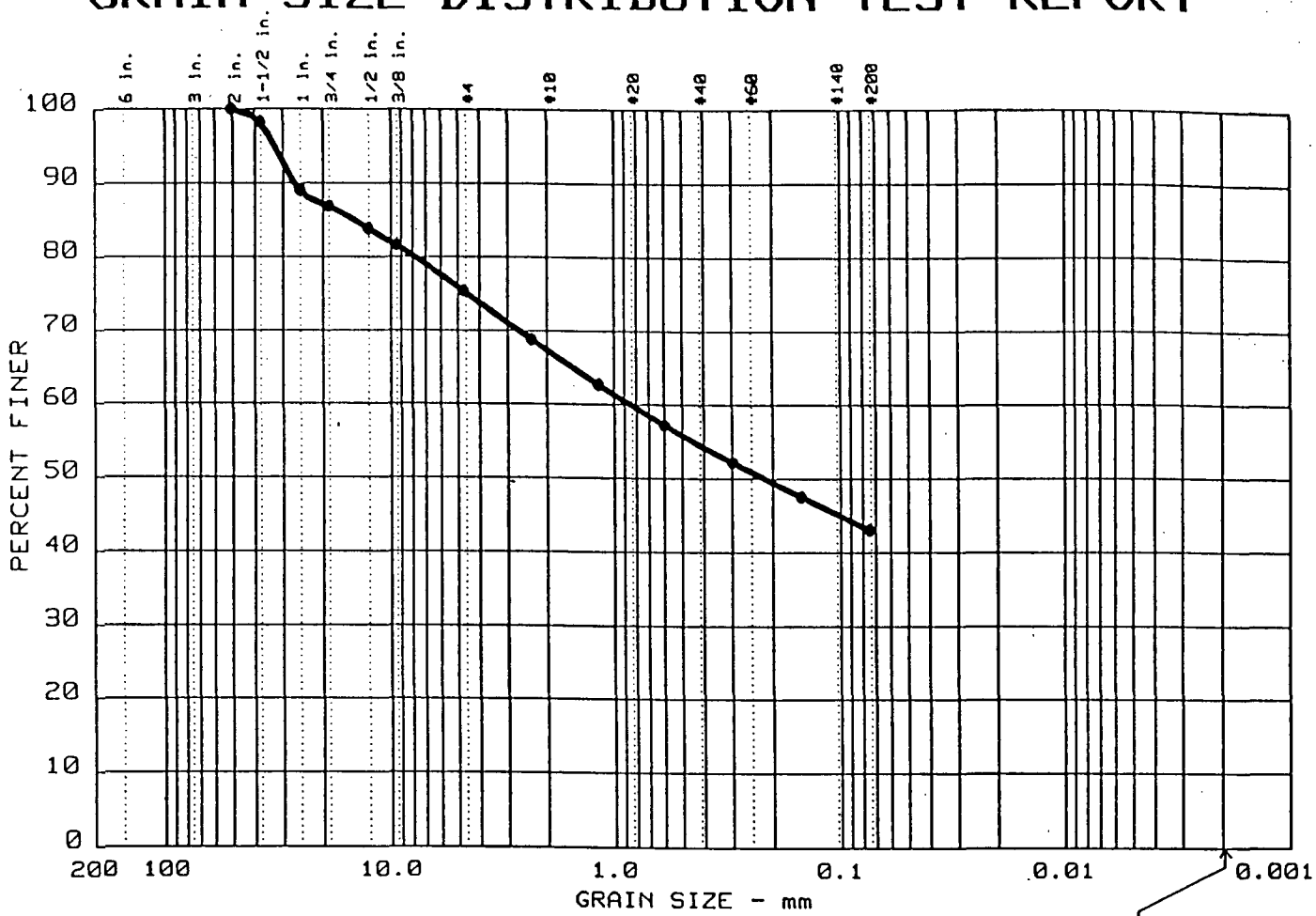
Project	Questa	Project No.	036008
Sample No.	97-AL-1 (Cover Material)	Tested By	SDD
Description	clayey SAND w/gravel, brown	Checked By	CW
Sample Type	Remold	Date	06/20/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	7.24	Specific Gravity	2.68
Init. Ht. (cm)	14.36	Assumed?	NO
Init. Vol (cm^3)	591.88	Init. Void Ratio	0.701
Init. Sample Wet Wt. (g)	1108.13	Initial Porosity	0.412
Init. Moisture Content	18.9%	Init. Dry Density (pcf)	98.3
		Initial Calculated Saturation	72.2%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm^2)	39.78
Confining Pressure (psi)	4.0	Height Change (cm)	0.03
Volume Change (cc)	22.02	Final Ht. (cm)	14.32
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	1383.44	Final Void Ratio	0.638
Final Dry Wt. + Pan (g)	1124.75	Final Volume (cm^3)	569.86
Pan Wt. Only (g)	192.75	Final Dry Density (pcf)	102.1
Final Moisture Content	27.8%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	2.00	Final Porsity	0.390

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	10.5	37.7				
5	11.9	36.4	1.2	166.45	2.37	8.9E-06
5	13.2	35.1	1.2	163.80	2.33	8.7E-06
5	14.5	33.8	1.2	161.20	2.29	8.8E-06
5	15.8	32.5	1.2	158.60	2.26	9.0E-06
					Average =	8.8E-06

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	24.6	32.3	43.1	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			14.6	0.832	0.211					

MATERIAL DESCRIPTION	USCS	AASHTO
● silty or clayey SAND w/gravel, brown	SM or SC	

Project No.: 036008
Project: Questa
● Location: 97-AL-1, Cover material

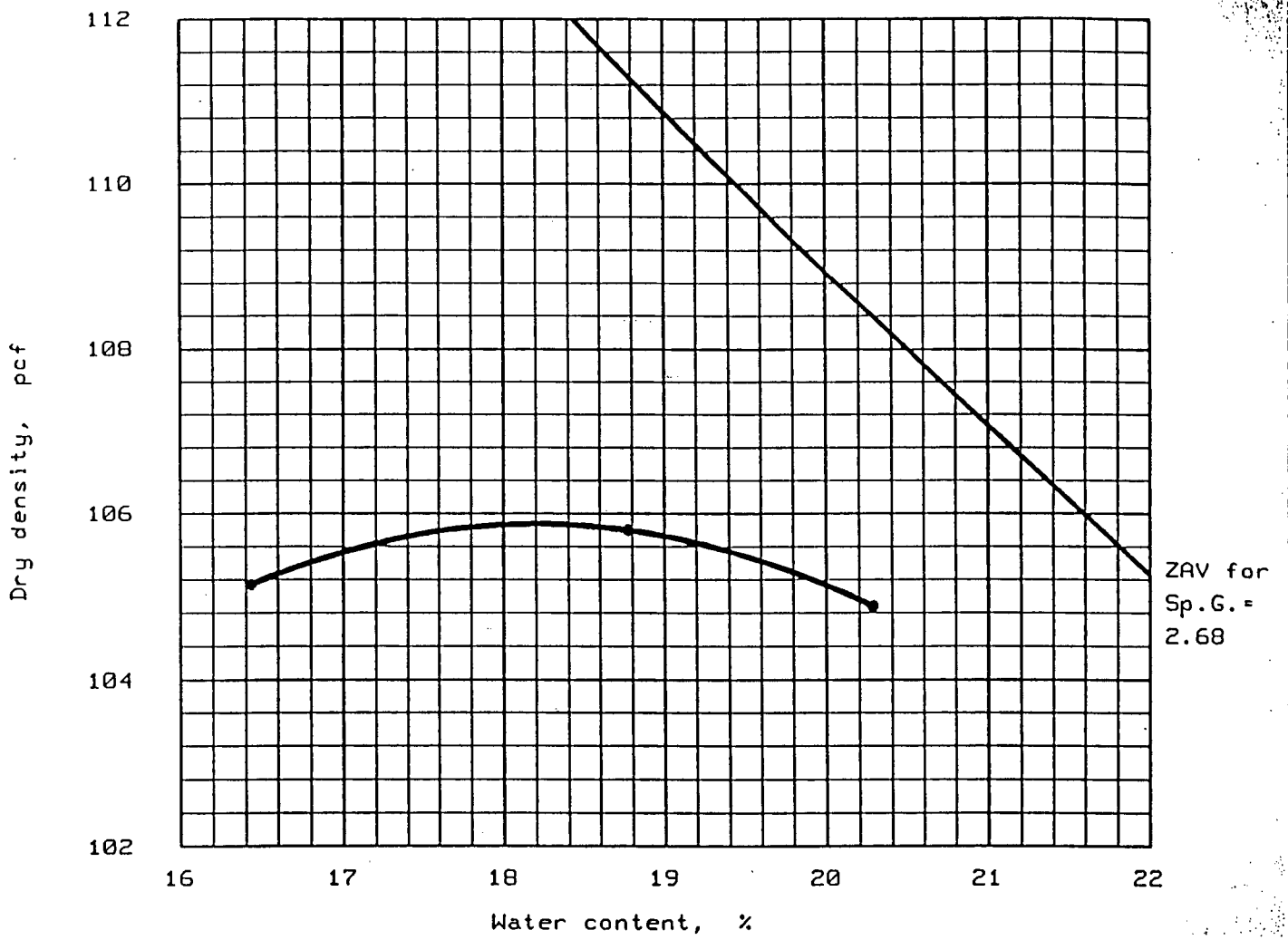
Date: 06/10/97

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Remarks:
Natural Moisture - 17.7%
Plasticity Index was not requested
Specific Gravity - 2.68

Fig. No.: _____

PROCTOR TEST REPORT



"Standard" Proctor, ASTM D 698, Method B

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/8 in	% < No.200
	USCS	AASHTO						
	SC		17.7 %	2.68			19.4 %	43.1 %

TEST RESULTS	MATERIAL DESCRIPTION
Optimum moisture = 18.2 % Maximum dry density = 105.9 pcf	clayey SAND w/gravel Brown

Project No.: 036008

Project: Questa

Location: Cover Material

Sample 97-AL-1

Date: 6/12/97

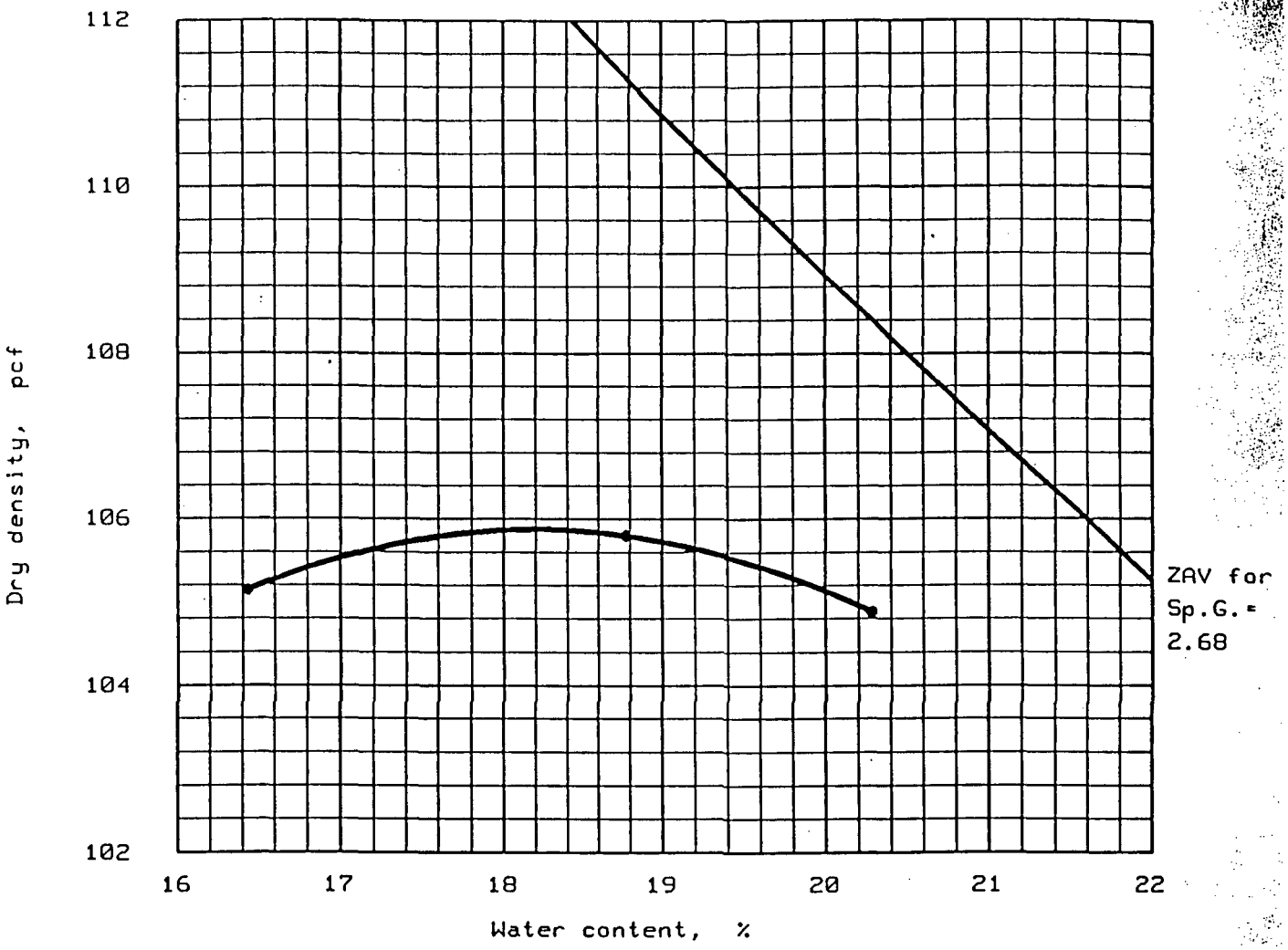
Remarks:

PROCTOR TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Figure No. _____

PROCTOR TEST REPORT



"Standard" Proctor, ASTM D 698, Method B, ASTM D 4718 correction applied

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/8 in	% < No.200
	USCS	AASHTO						
	SC		17.7 %	2.68			19.4 %	43.1 %

TEST RESULTS	MATERIAL DESCRIPTION
Optimum moisture = 14.7 % Maximum dry density = 113.7 pcf	clayey SAND w/gravel Brown

Project No.: 036008

Project: Questa

Location: Cover Material

Sample 97-AL-1

Date: 6/12/97

Remarks:

PROCTOR TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.

Consulting Engineers and Scientists

Figure No. _____

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

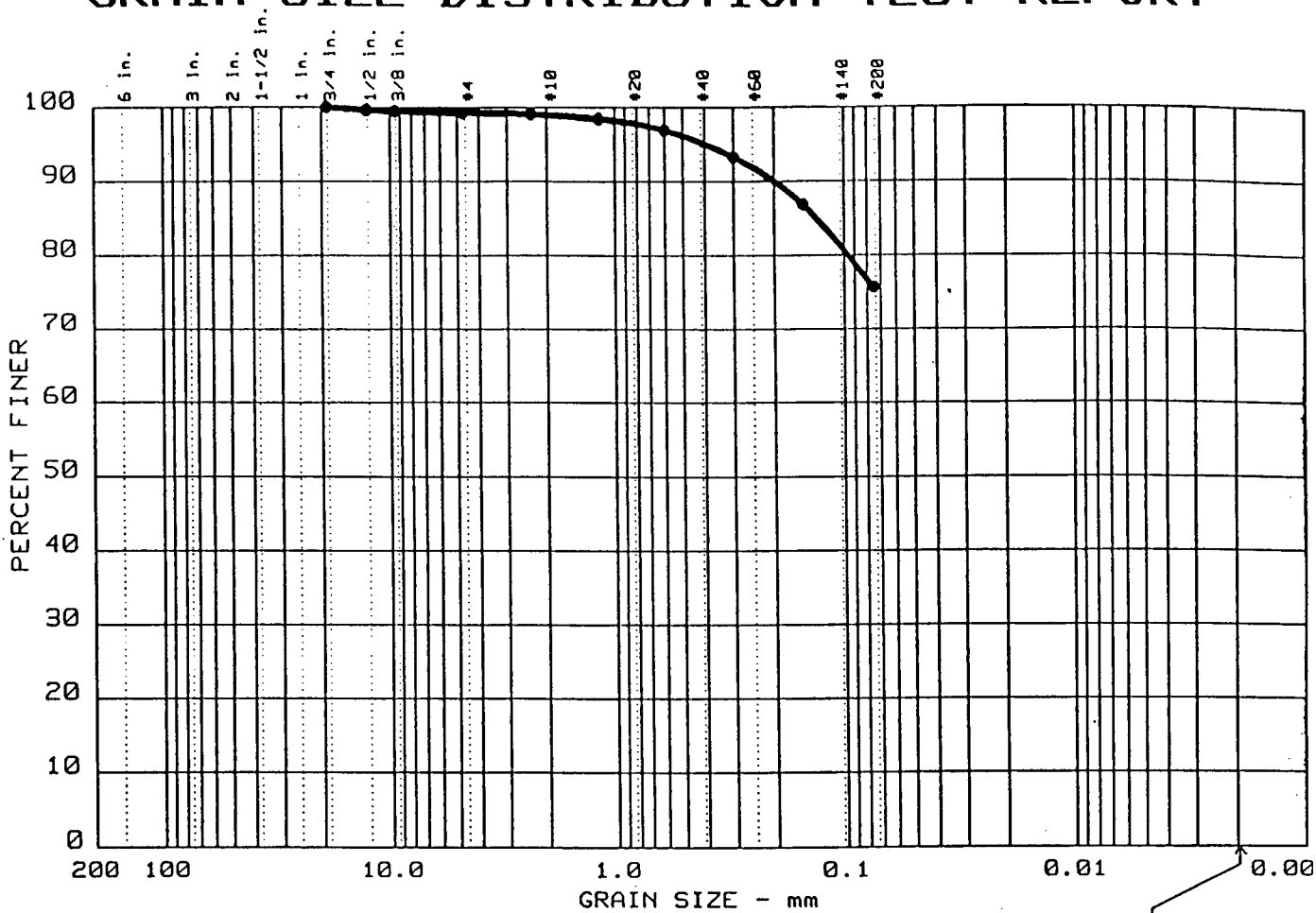
Project	Questa	Project No.	036008
Sample No.	97-AL-2 (Cover Material)	Tested By	SDD
Description	CLAY w/sand, brown	Checked By	CW
Sample Type	Remold	Date	06/25/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	7.24	Specific Gravity	2.63
Init. Ht. (cm)	14.35	Assumed?	NO
Init. Vol (cm^3)	589.92	Init. Void Ratio	0.573
Init. Sample Wet Wt. (g)	1166.93	Initial Porosity	0.364
Init. Moisture Content	18.3%	Init. Dry Density (pcf)	104.3
		Initial Calculated Saturation	84.2%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm^2)	40.62
Confining Pressure (psi)	4.0	Height Change (cm)	0.08
Volume Change (cc)	10.28	Final Ht. (cm)	14.27
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	1336.40	Final Void Ratio	0.545
Final Dry Wt. + Pan (g)	1111.18	Final Volume (cm^3)	579.64
Pan Wt. Only (g)	125.02	Final Dry Density (pcf)	106.2
Final Moisture Content	22.8%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	6.00	Final Porsity	0.353

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	4.6	41.8				
900	14.8	31.1	9.5	448.55	6.38	1.4E-07
120	16.0	29.7	1.2	436.80	6.21	1.3E-07
120	17.2	28.3	1.2	434.20	6.18	1.3E-07
120	18.4	27.1	1.1	431.70	6.14	1.2E-07
					Average =	1.3E-07

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
◐	0.0	0.8	23.5	75.7	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
◐			0.130							

MATERIAL DESCRIPTION	USCS	AASHTO
◐ silty CLAY w/sand, brown	CL or ML	

Project No.: 036008
Project: Questa
◐ Location: 97-AL-2, Cover material

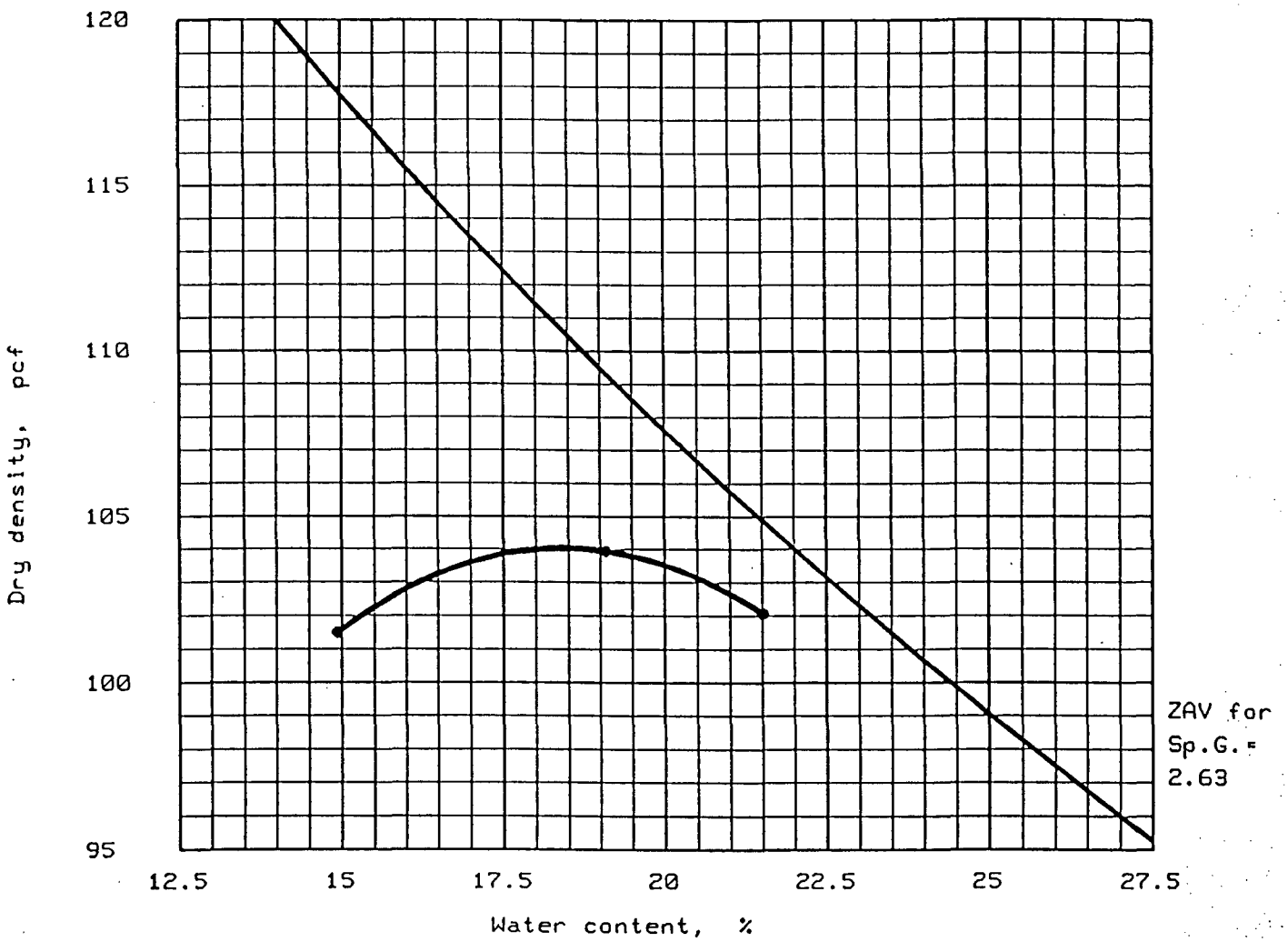
Date: 06/10/97

Remarks:
Natural Moisture - 19.3%
Plasticity Index was not requested
Specific Gravity - 2.63

Fig. No.: _____

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

PROCTOR TEST REPORT



"Standard" Proctor, ASTM D 698, Method A

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
	CL or ML		19.3 %	2.63			0.8 %	75.7 %

TEST RESULTS	MATERIAL DESCRIPTION
Optimum moisture = 18.4 % Maximum dry density = 104.0 pcf	silty CLAY w/sand Brown

Project No.: 036008

Project: Questa

Location: Cover Material

Sample 97-AL-2

Date: 6/12/97

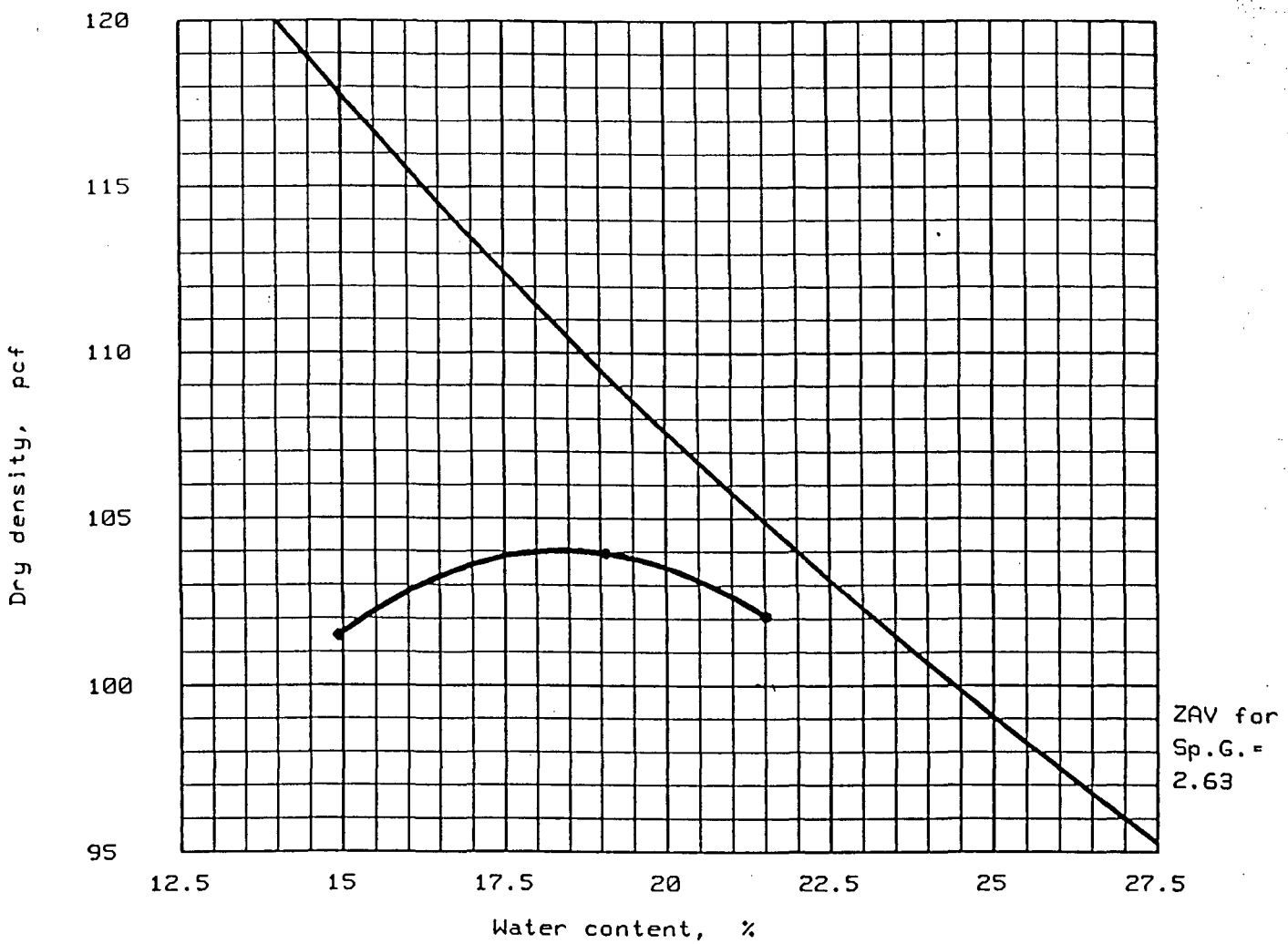
Remarks:

PROCTOR TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Figure No. _____

PROCTOR TEST REPORT



"Standard" Proctor, ASTM D 698, Method A, ASTM D 4718 correction applied

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
	CL or ML		19.3 %	2.63			0.8 %	75.7 %

TEST RESULTS	MATERIAL DESCRIPTION
Optimum moisture = 18.3 % Maximum dry density = 104.3 pcf	silty CLAY w/sand Brown

Project No.: 036008

Project: Questa

Location: Cover Material

Sample 97-AL-2

Date: 6/12/97

Remarks:

PROCTOR TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Figure No. _____

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

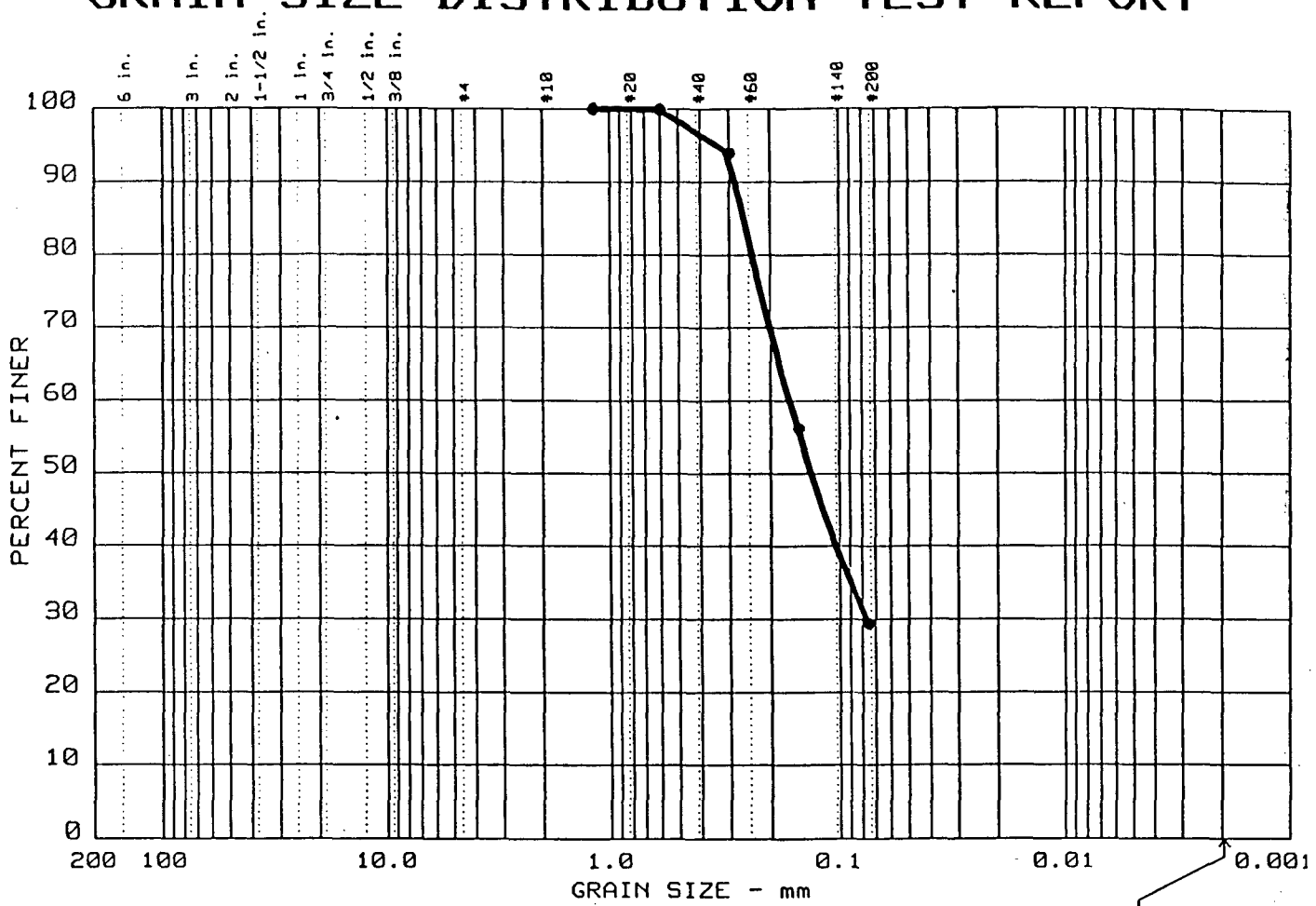
Project	Questa	Project No.	036008
Sample No.	97-T-7 (Sandy Tailing)	Tested By	SDD
Description	silty SAND, gray	Checked By	CW
Sample Type	Remold	Date	06/18/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	6.10	Specific Gravity	2.71
Init. Ht. (cm)	12.80	Assumed?	NO
Init. Vol (cm^3)	374.13	Init. Void Ratio	0.843
Init. Sample Wet Wt. (g)	622.22	Initial Porosity	0.457
Init. Moisture Content	13.1%	Init. Dry Density (pcf)	91.8
		Initial Calculated Saturation	42.2%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm^2)	29.10
Confining Pressure (psi)	4.0	Height Change (cm)	0.07
Volume Change (cc)	3.46	Final Ht. (cm)	12.74
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	902.43	Final Void Ratio	0.826
Final Dry Wt. + Pan (g)	733.15	Final Volume (cm^3)	370.68
Pan Wt. Only (g)	183.08	Final Dry Density (pcf)	92.6
Final Moisture Content	30.8%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	0.20	Final Porsity	0.452

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	6.2	42.9				
1	14.9	34.3	7.9	42.11	0.60	1.4E-03
1	20.9	28.4	5.4	27.51	0.39	1.4E-03
1	25.0	24.5	3.6	17.56	0.25	1.5E-03
1	27.5	21.9	2.3	11.01	0.16	1.5E-03
					Average =	1.5E-03

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	70.6	29.4	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.259	0.163	0.132	0.0762				

MATERIAL DESCRIPTION	USCS	AASHTO
● silty SAND, gray	SM	

Project No.: 036008
Project: Questa
● Location: 97-T-7, sandy tailing

Date: 06/10/97

Remarks:
Natural Moisture - 8.7%
Plasticity Index was not requested
Specific Gravity - 2.71

Fig. No.: _____

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
FLEXIBLE WALL PERMEAMETER (ASTM D 5084 - 90)

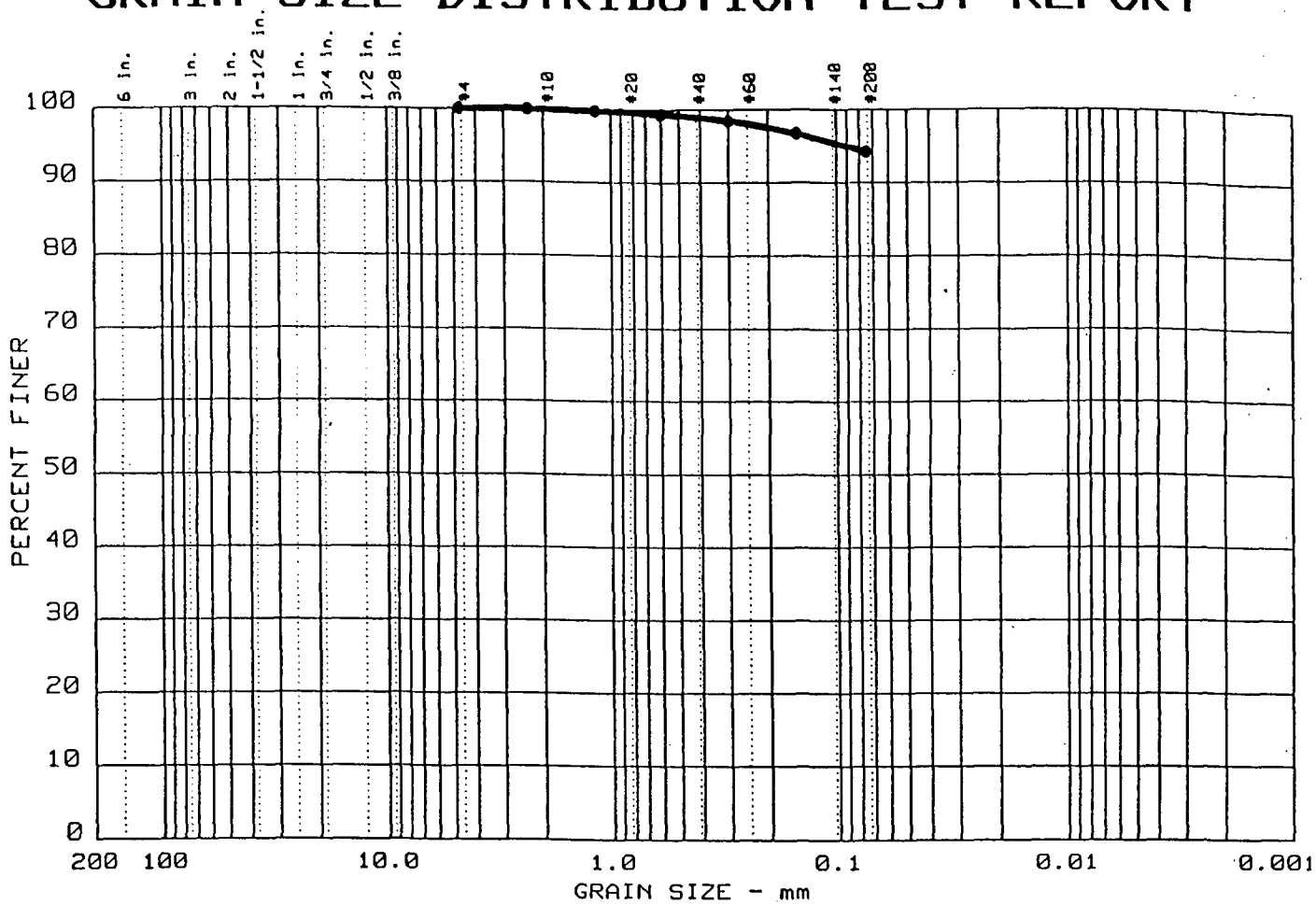
Project	Questa	Project No.	036008
Sample No.	97-T-3 (Fine Tailing)	Tested By	SDD
Description	CLAY, gray	Checked By	CW
Sample Type	Remold	Date	06/25/97

INITIAL SAMPLE DATA			
Sample Dia (cm)	6.11	Specific Gravity	2.70
Init. Ht. (cm)	12.83	Assumed?	Yes
Init. Vol (cm³)	376.49	Init. Void Ratio	0.715
Init. Sample Wet Wt. (g)	740.18	Initial Porosity	0.417
Init. Moisture Content	24.9%	Init. Dry Density (pcf)	98.3
		Initial Calculated Saturation	94.1%
CONSOLIDATION DATA			
Back Pressure (psi)	40.0	Final Area (cm²)	28.62
Confining Pressure (psi)	4.0	Height Change (cm)	0.08
Volume Change (cc)	11.47	Final Ht. (cm)	12.75
FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	876.40	Final Void Ratio	0.663
Final Dry Wt. + Pan (g)	717.37	Final Volume (cm³)	365.02
Pan Wt. Only (g)	124.75	Final Dry Density (pcf)	101.3
Final Moisture Content	26.8%	Final Calculated Saturation	100.0%
Burrette Calibration (cc/cm)	0.91		
Constant Pressure Head (psi)	6.00	Final Porsity	0.399

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	4.1	44.8				
120	6.8	42.1	2.5	459.80	6.54	3.3E-07
900	26.3	22.6	17.7	437.60	6.22	3.3E-07
120	28.7	20.1	2.2	415.65	5.91	3.3E-07
120	31.1	17.7	2.2	410.80	5.84	3.3E-07
					Average =	3.3E-07

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	5.8	94.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●										

MATERIAL DESCRIPTION	USCS	AASHTO
● SILT or CLAY, gray	ML or CL	

Project No.: 036008
Project: Questa
● Location: 97-T-3, fine tailing

Date: 06/10/97

Remarks:
Natural Moisture - 23.8%
Plasticity Index was not requested

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: _____

CAPILLARY MOISTURE RETENTION TEST - ASTM D2325 - 94

Project: Questa
Project No: 036008

Started: 06/16/97
Finished: 06/30/97

Tested By: SDD
Checked By: CW

Ring No.	14	18	20	11	9	16	17	5	21	8
Ring Vol: (cc)	18.41652	18.162149	18.334929	18.288625	18.596391	18.480985	18.465499	19.180821	18.267896	19.16204

Sample	Ring Mass g	Initial Mass g	Sat. Mass g	20 cm Mass g	60 cm Mass g	100 cm Mass g	200 cm Mass g	600 cm Mass g	1000 cm Mass g	2000 cm Mass g	5000 cm Mass g	Dry Mass Filter + Ring + Dish g	Dish Wt. g
Filter Only	--	0.388	1.429	1.191	1.051	0.918	0.716	0.567	0.540	0.492	0.487	32.319	31.983
T-21 Bulk	11.301	48.296	52.007	50.940	50.062	49.837	49.420	49.072	48.925	48.813	48.616	75.678	31.408
T-21 Bulk (R)	11.205	47.695	51.213	50.456	49.485	49.262	48.799	48.320	48.159	48.023	47.825	75.481	31.862
T-3 Bulk	11.342	51.055	57.709	57.406	56.417	56.076	55.223	54.217	53.886	53.615	53.591	59.370	10.991
T-3 Bulk (R)	11.268	50.881	56.916	56.582	56.284	56.069	55.039	54.074	53.815	53.589	53.187	59.412	11.246
97-AL-1	11.444	46.461	50.097	49.358	48.885	48.634	48.081	47.434	47.199	47.033	46.772	51.495	10.819
97-AL-1 (R)	11.428	46.223	50.656	49.420	48.815	48.512	47.942	47.312	47.067	46.867	46.597	51.347	10.767
97-AL-2	11.436	48.177	51.076	50.712	50.200	49.995	49.564	49.088	48.913	48.674	48.383	53.678	11.077
97-AL-2 (R)	10.568	48.740	52.124	51.721	51.247	51.017	50.544	50.003	49.838	49.637	49.481	49.429	6.234
97-T-7	11.258	41.271	47.064	46.708	44.851	43.065	41.061	39.842	39.549	39.247	39.233	44.333	6.296
97-T-7 (R)	10.572	42.037	48.429	48.025	46.086	45.148	42.833	41.450	41.195	40.893	40.879	45.065	6.108

Sample	Dry Mass g	Unit Wt. g/cc	Sat. Mass g	Total H20 g	Sat. MC % DM	Sat. MC % Vol.	20 cm Ret H20	20 cm % DM	20 cm % Vol.	60 cm Ret H20	60 cm % DM	60 cm % Vol.
T-21 Bulk	32.581	1.76911	39.277	6.696	20.55%	36.36%	5.867	18.01%	31.86%	5.129	15.74%	27.85%
T-21 Bulk (R)	32.026	1.76333	38.579	6.553	20.46%	36.08%	6.034	18.84%	33.22%	5.203	16.25%	28.65%
T-3 Bulk	36.649	1.99886	44.938	8.289	22.62%	45.21%	8.224	22.44%	44.85%	7.375	20.12%	40.22%
T-3 Bulk (R)	36.510	1.99632	44.219	7.709	21.12%	42.15%	7.613	20.85%	41.63%	7.455	20.42%	40.76%
97-AL-1	28.844	1.55105	37.224	8.380	29.05%	45.06%	7.879	27.32%	42.37%	7.546	26.16%	40.58%
97-AL-1 (R)	28.774	1.55695	37.799	9.025	31.37%	48.83%	8.027	27.90%	43.43%	7.562	26.28%	40.92%
97-AL-2	30.677	1.66221	38.211	7.534	24.56%	40.82%	7.408	24.15%	40.14%	7.036	22.94%	38.12%
97-AL-2 (R)	32.239	1.68079	40.127	7.888	24.47%	41.12%	7.723	23.96%	40.26%	7.389	22.92%	38.52%
97-T-7	26.391	1.44466	34.377	7.986	30.26%	43.72%	7.868	29.81%	43.07%	6.151	23.31%	33.67%
97-T-7 (R)	27.997	1.46106	36.428	8.431	30.11%	44.00%	8.265	29.52%	43.13%	6.466	23.10%	33.74%

Sample	100 cm Ret H20	100 cm % DM	100 cm % Vol.	200 cm Ret H20	200 cm % DM	200 cm % Vol.	600 cm Ret H20	600 cm % DM	600 cm % Vol.	1000 cm Ret H20	1000 cm % DM	1000 cm % Vol.
T-21 Bulk	5.037	15.46%	27.35%	4.823	14.80%	26.19%	4.623	14.19%	25.10%	4.503	13.82%	24.45%
T-21 Bulk (R)	5.113	15.97%	28.15%	4.853	15.15%	26.72%	4.522	14.12%	24.90%	4.388	13.70%	24.16%
T-3 Bulk	7.167	19.56%	39.09%	6.517	17.78%	35.54%	5.659	15.44%	30.87%	5.355	14.61%	29.21%
T-3 Bulk (R)	7.373	20.19%	40.32%	6.546	17.93%	35.79%	5.729	15.69%	31.33%	5.497	15.06%	30.06%
97-AL-1	7.428	25.75%	39.94%	7.078	24.54%	38.06%	6.579	22.81%	35.38%	6.371	22.09%	34.26%
97-AL-1 (R)	7.392	25.69%	40.00%	7.025	24.41%	38.01%	6.543	22.74%	35.40%	6.325	21.98%	34.22%
97-AL-2	6.964	22.70%	37.73%	6.736	21.96%	36.50%	6.408	20.89%	34.72%	6.260	20.41%	33.92%
97-AL-2 (R)	7.292	22.62%	38.02%	7.022	21.78%	36.61%	6.629	20.56%	34.56%	6.491	20.13%	33.84%
97-T-7	4.498	17.04%	24.62%	2.697	10.22%	14.76%	1.626	6.16%	8.90%	1.360	5.15%	7.45%
97-T-7 (R)	4.743	16.94%	24.75%	2.834	10.12%	14.79%	1.747	6.24%	9.12%	1.546	5.52%	8.07%

Sample	2000 cm Ret H20	2000 cm % DM	2000 cm % Vol.	5000 cm Ret H20	5000 cm % DM	5000 cm % Vol.
T-21 Bulk	4.439	86.13%	24.10%	4.247	84.32%	23.06%
T-21 Bulk (R)	4.300	84.10%	23.68%	4.107	80.32%	22.61%
T-3 Bulk	5.132	71.61%	27.99%	5.113	71.34%	27.89%
T-3 Bulk (R)	5.319	72.14%	29.08%	4.922	66.76%	26.91%
97-AL-1	6.253	84.18%	33.63%	5.997	80.74%	32.25%
97-AL-1 (R)	6.173	83.51%	33.40%	5.908	79.92%	31.97%
97-AL-2	6.069	87.16%	32.86%	5.783	83.04%	31.34%
97-AL-2 (R)	6.338	86.92%	33.04%	6.187	84.86%	32.26%
97-T-7	1.106	24.59%	6.05%	1.097	24.39%	6.01%
97-T-7 (R)	1.340	28.26%	6.99%	1.336	28.17%	6.97%

CAPILLARY MOISTURE RETENTION TEST - ASTM D2325 - 94

Project: Questa
Project No: 036008

Started: 06/16/97
Finished: 06/30/97

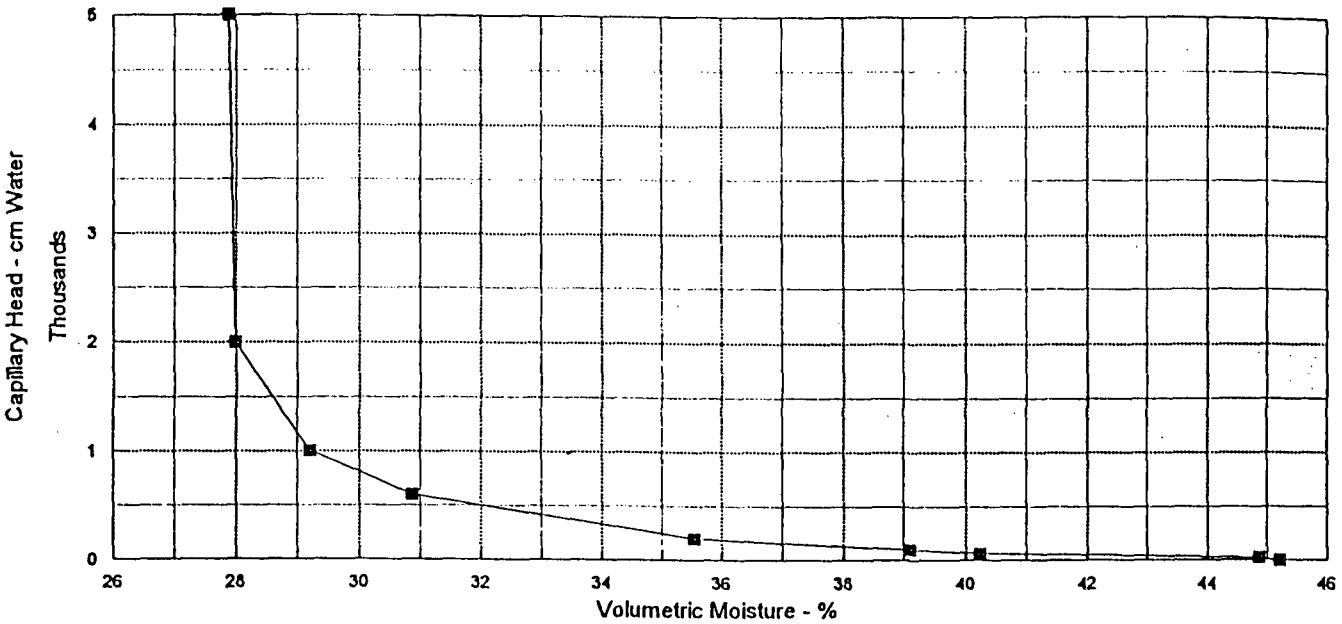
Tested By: SDD
Checked By: CW

Sample	Vol. MC (%) Sat.	Vol. MC (%) 20 cm	Vol. MC (%) 60 cm	Vol. MC (%) 100 cm	Vol. MC (%) 200 cm	Vol. MC (%) 600 cm	Vol. MC (%) 1000 cm	Vol. MC (%) 2000 cm	Vol. MC (%) 6000 cm
T-21 Bulk	36.36	31.86	27.85	27.35	26.19	25.10	24.45	24.10	23.06
T-21 Bulk (R)	36.08	33.22	28.65	28.15	26.72	24.90	24.16	23.68	22.61
T-3 Bulk	45.21	44.85	40.22	39.09	35.54	30.87	29.21	27.99	27.89
T-3 Bulk (R)	42.16	41.63	40.76	40.32	35.79	31.33	30.06	29.08	26.91
97-AL-1	45.06	42.37	40.58	39.94	38.06	35.38	34.26	33.63	32.25
97-AL-1 (R)	48.83	43.43	40.92	40.00	38.01	35.40	34.22	33.40	31.97
97-AL-2	40.82	40.14	38.12	37.73	36.50	34.72	33.92	32.88	31.34
97-AL-2 (R)	41.12	40.26	38.52	38.02	36.61	34.56	33.84	33.04	32.26
97-T-7	43.72	43.07	33.67	24.62	14.76	8.90	7.45	6.05	6.01
97-T-7 (R)	44.00	43.13	33.74	24.75	14.79	9.12	8.07	6.99	6.97

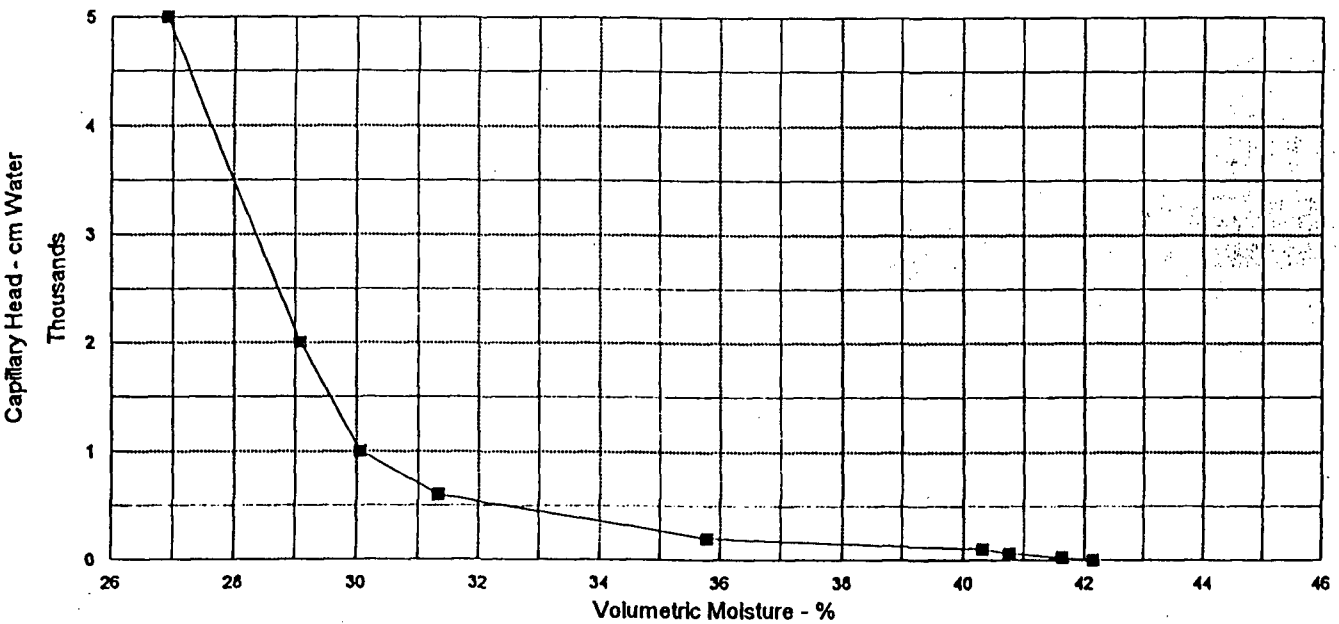
Heads Used									
psi	0.00	0.28	0.85	1.42	2.84	8.53	14.22	28.45	71.11
cm H20	0	20	60	100	200	600	1000	2000	6000

%DM = Moisture Content By Dry Mass
%Vol. = Volumectric Moisture Content

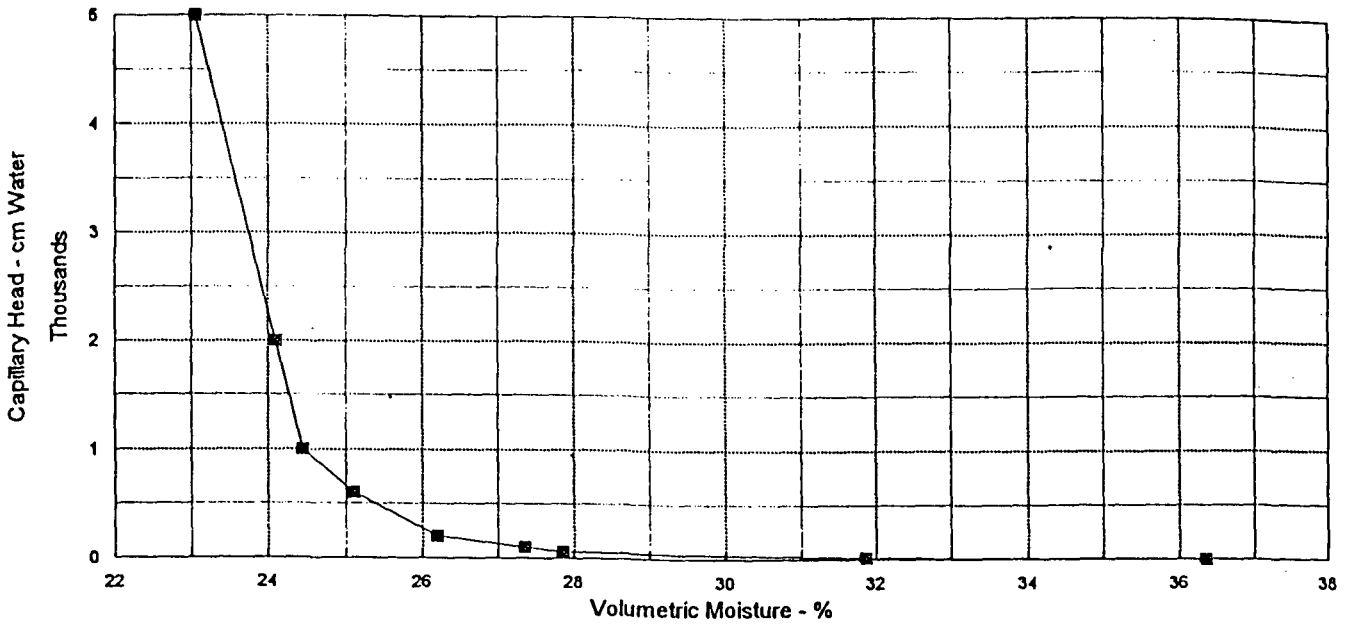
CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk



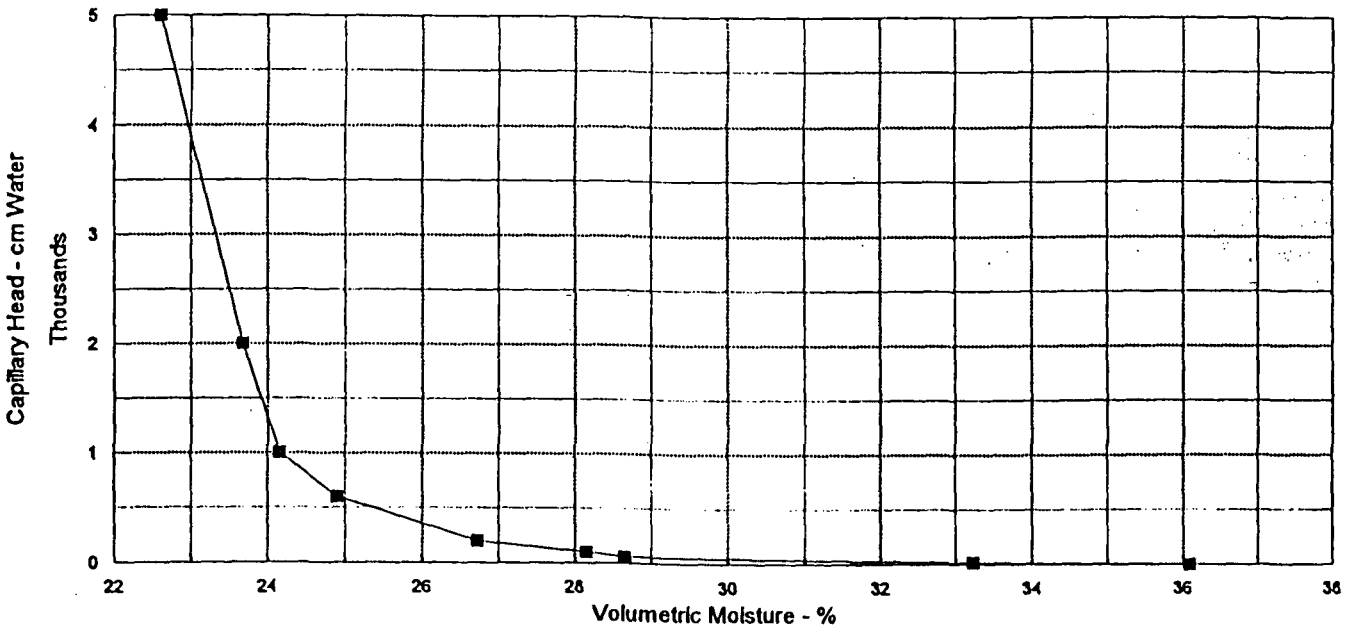
CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk (R)



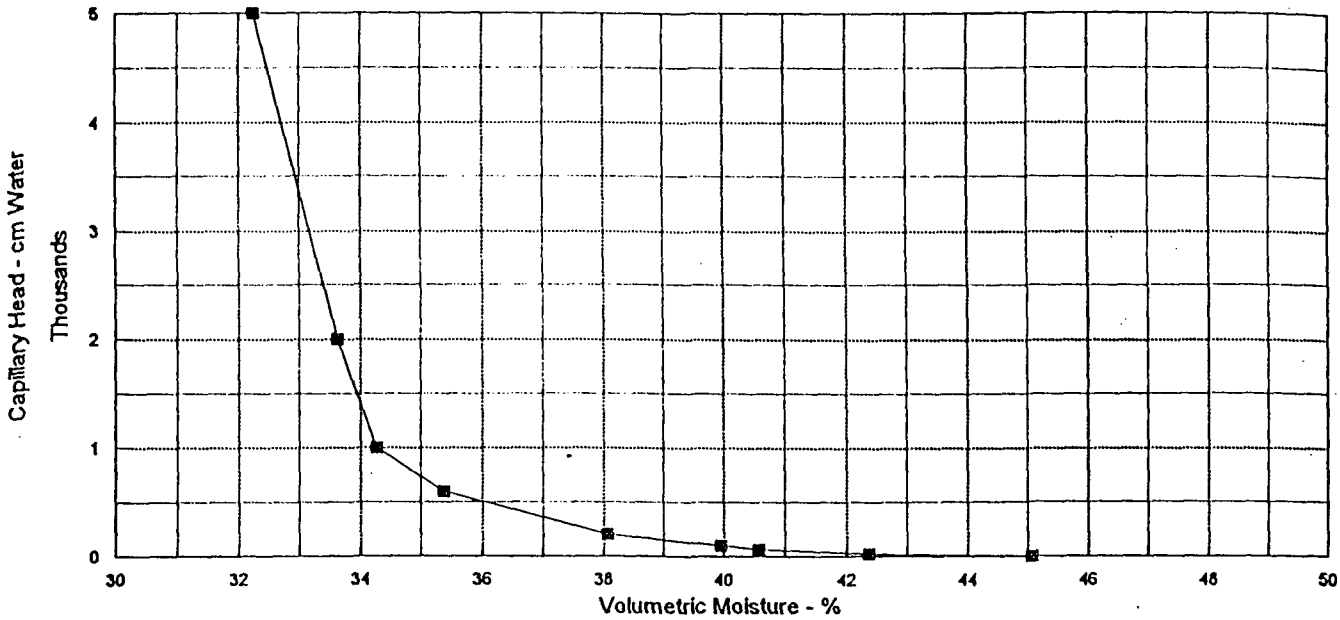
CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk



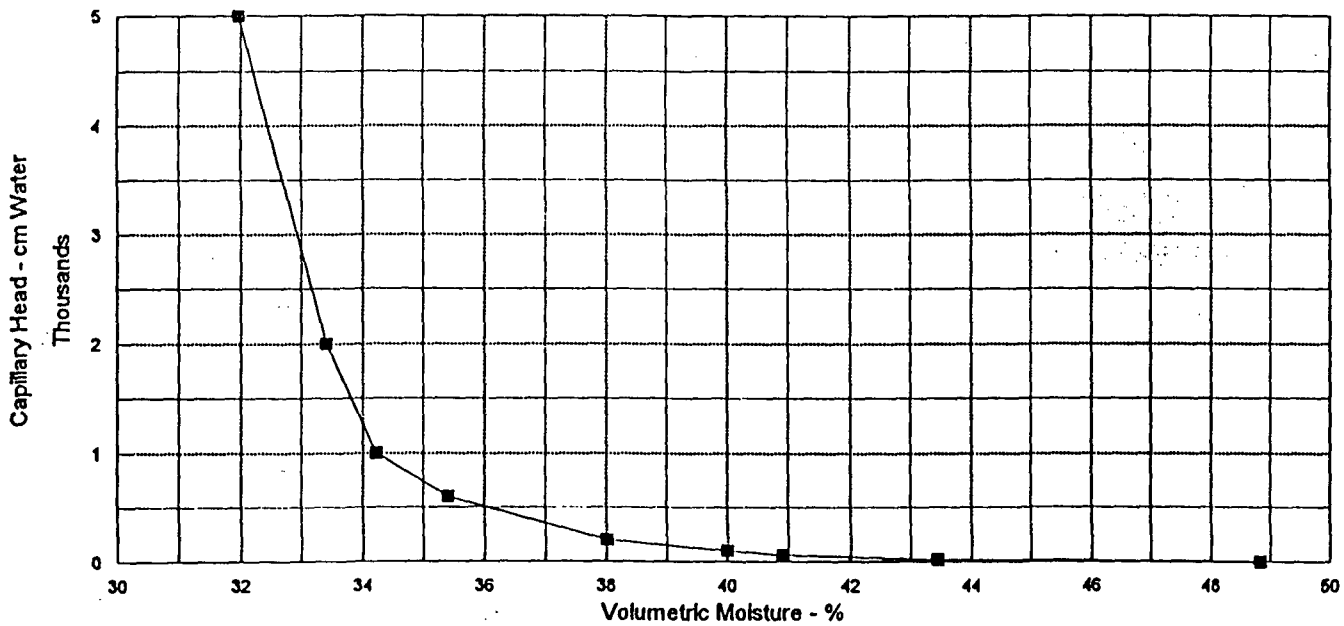
CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk (R)



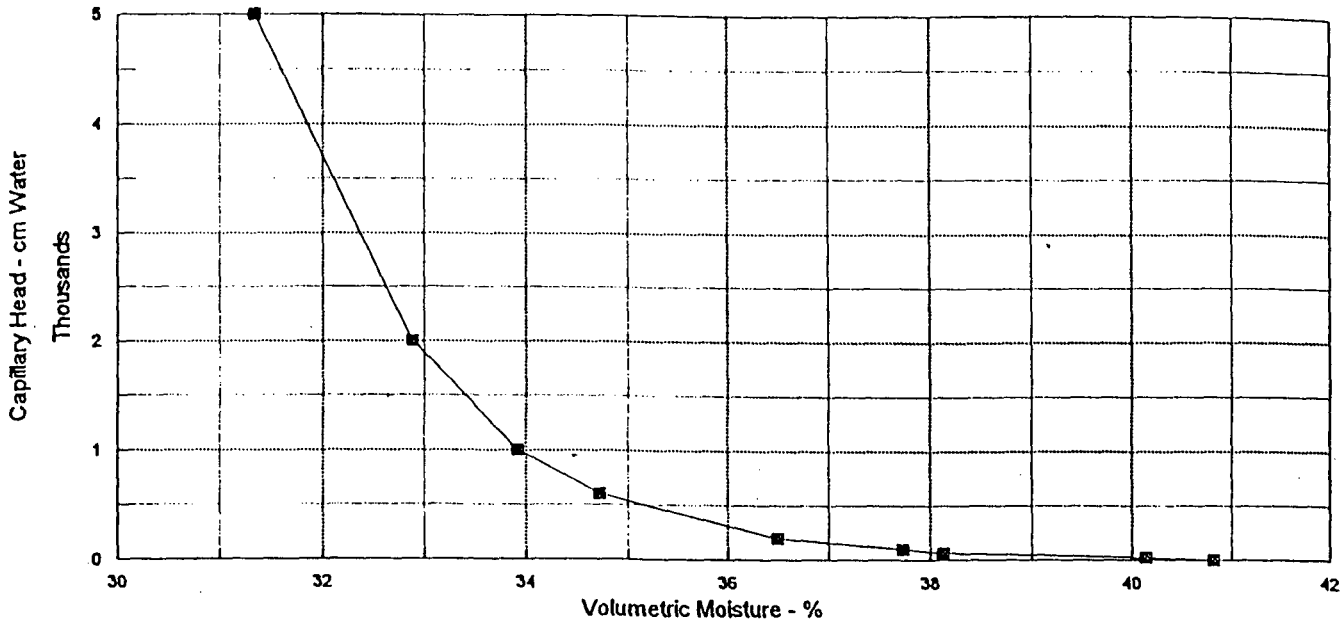
CAPILLARY MOISTURE RETENTION CURVE
97-AL-1



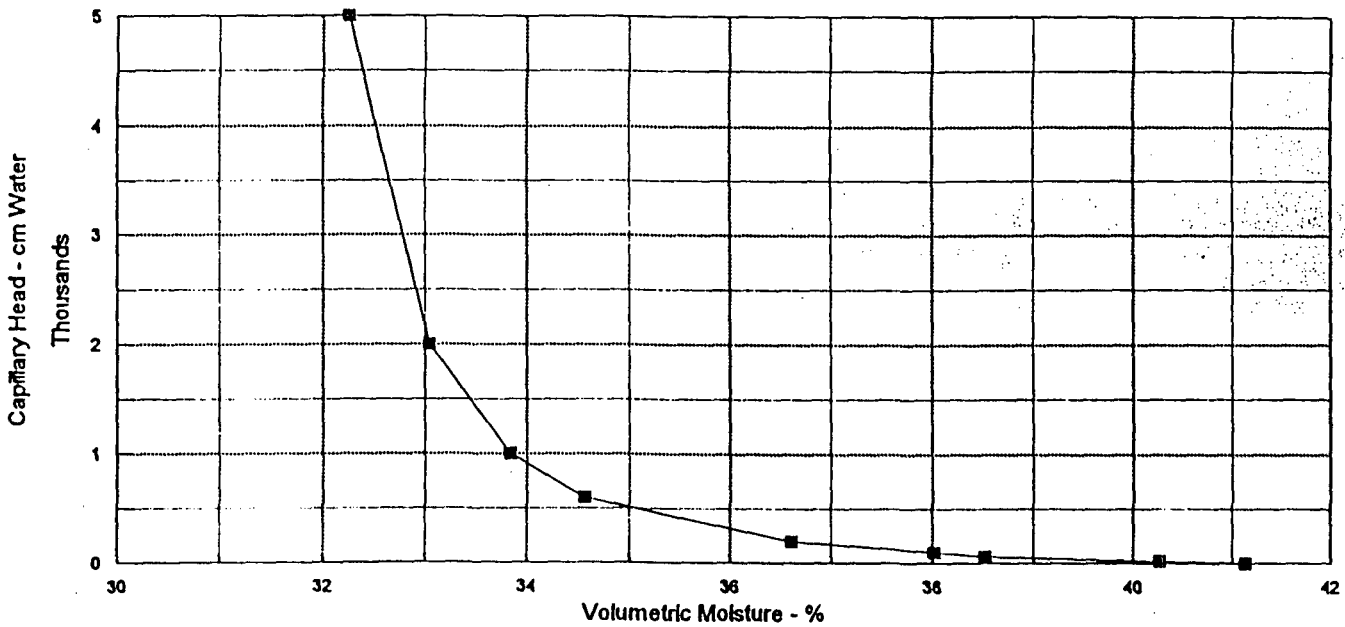
CAPILLARY MOISTURE RETENTION CURVE
97-AL-1 (R)



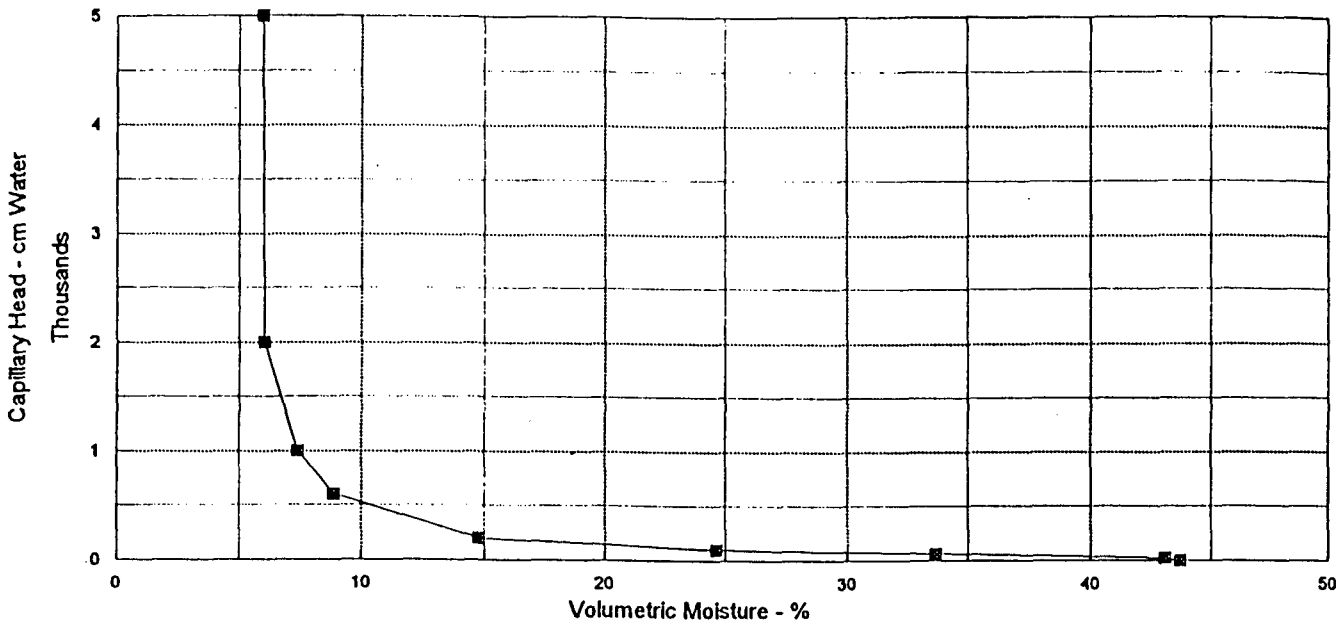
CAPILLARY MOISTURE RETENTION CURVE
97-AL-2



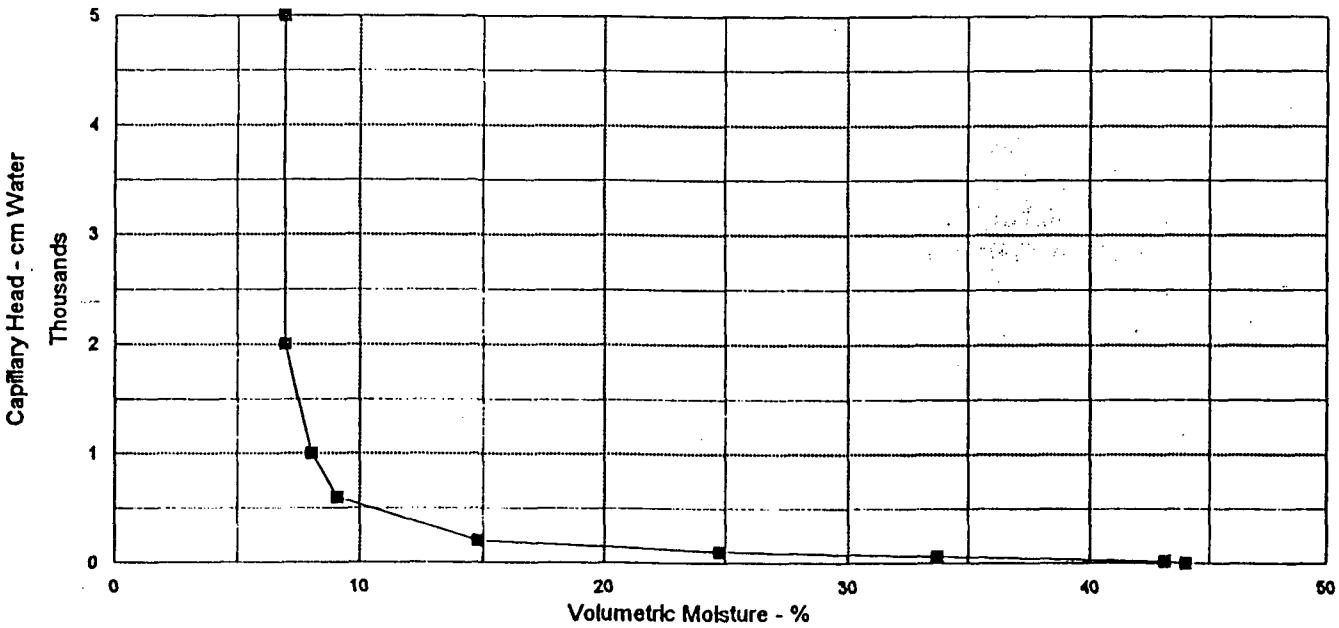
CAPILLARY MOISTURE RETENTION CURVE
97-AL-2 (R)



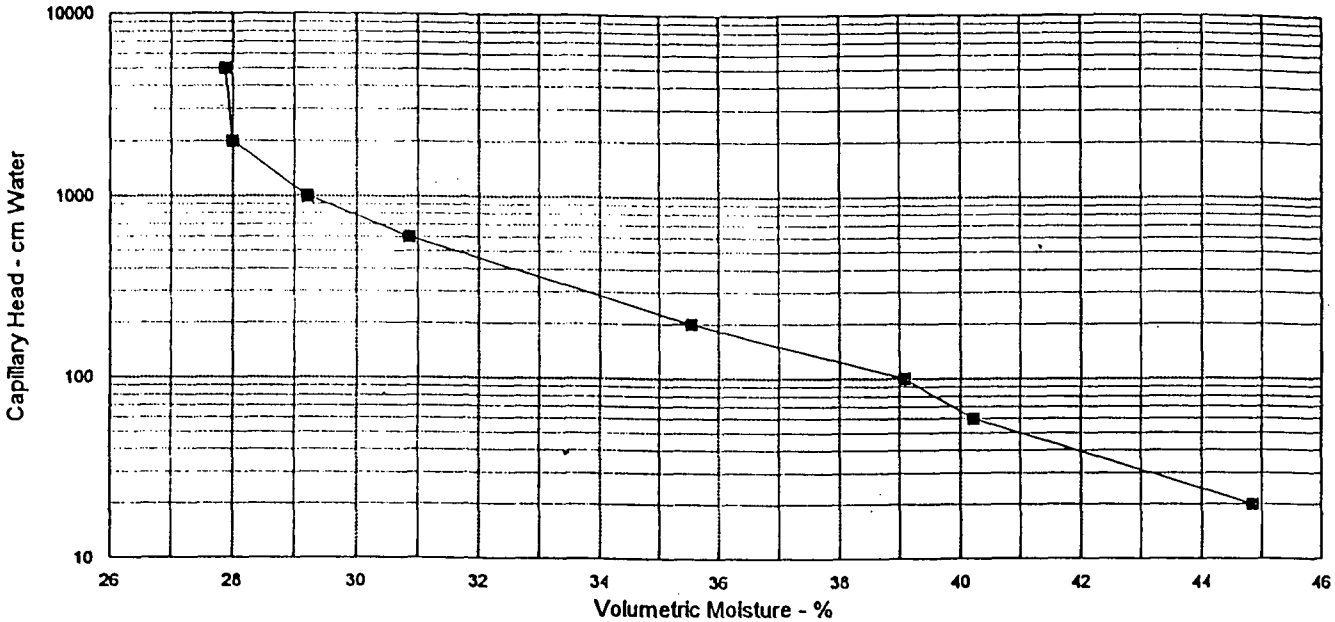
CAPILLARY MOISTURE RETENTION CURVE
97-T-7



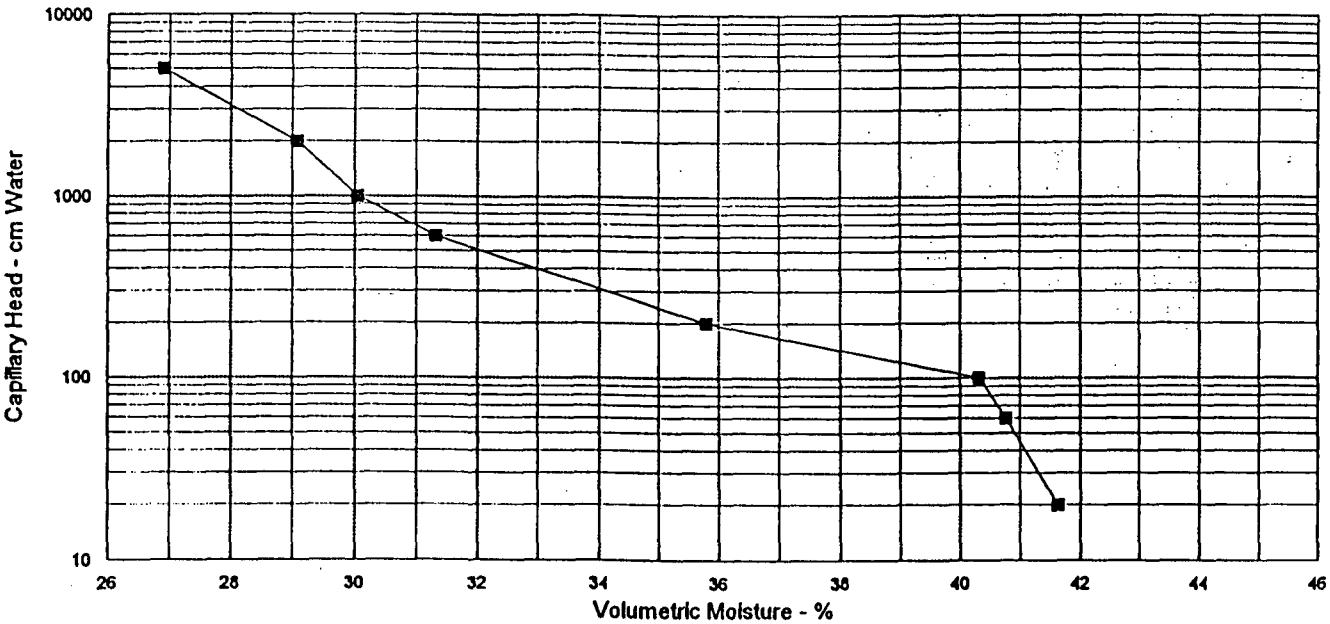
CAPILLARY MOISTURE RETENTION CURVE
97-T-7 (R)



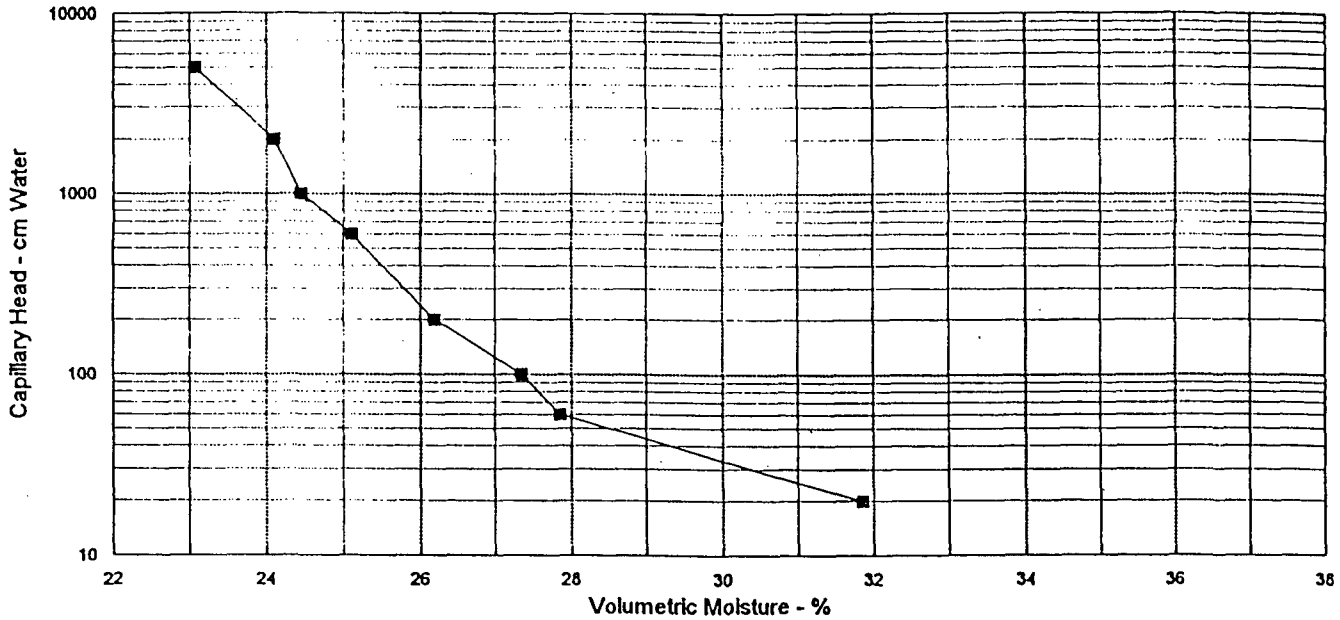
CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk



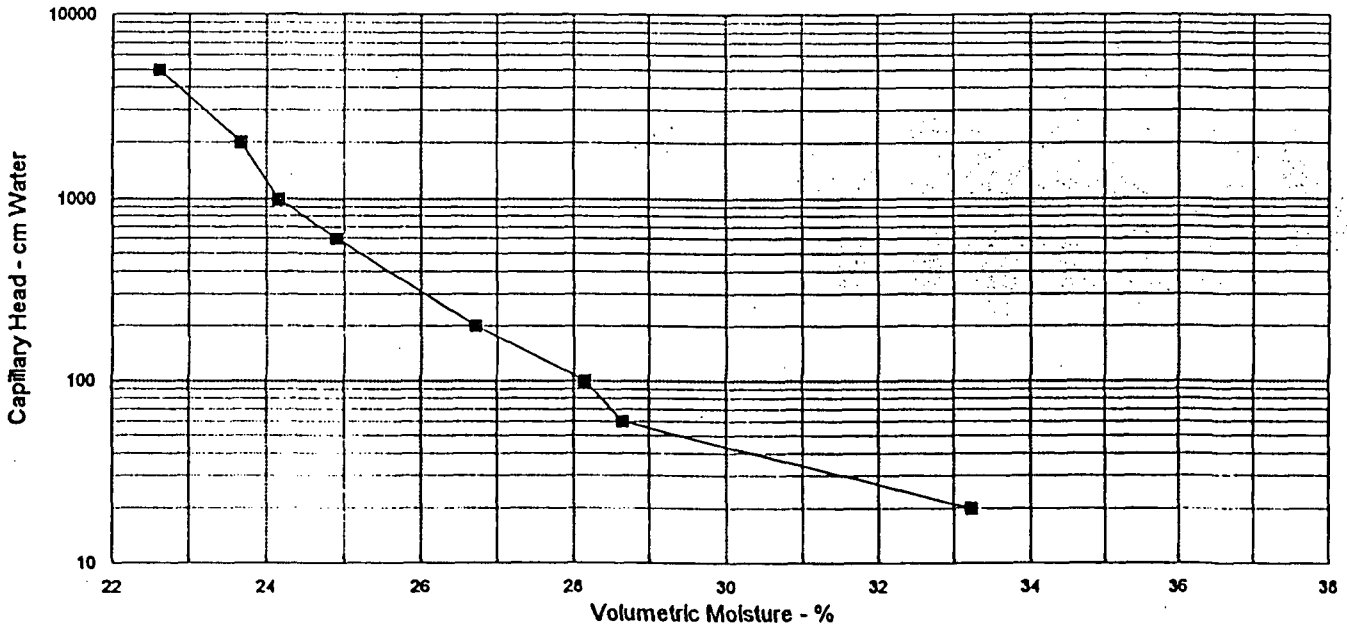
CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk (R)



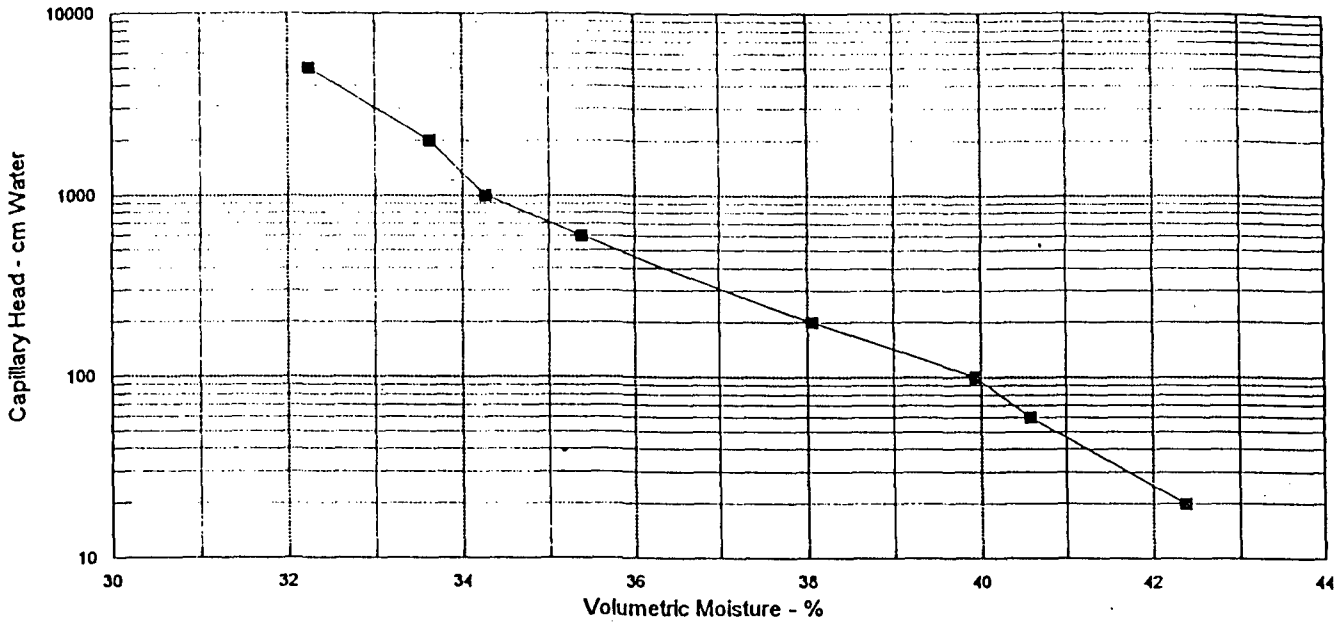
CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk



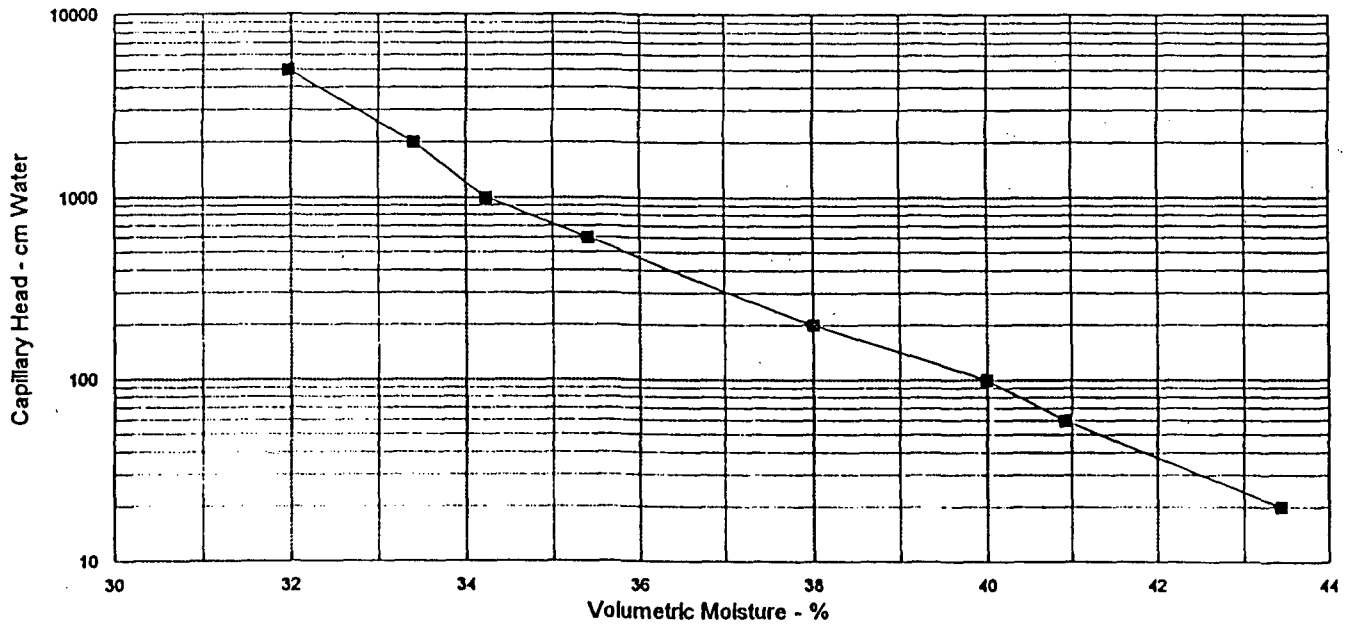
CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk (R)



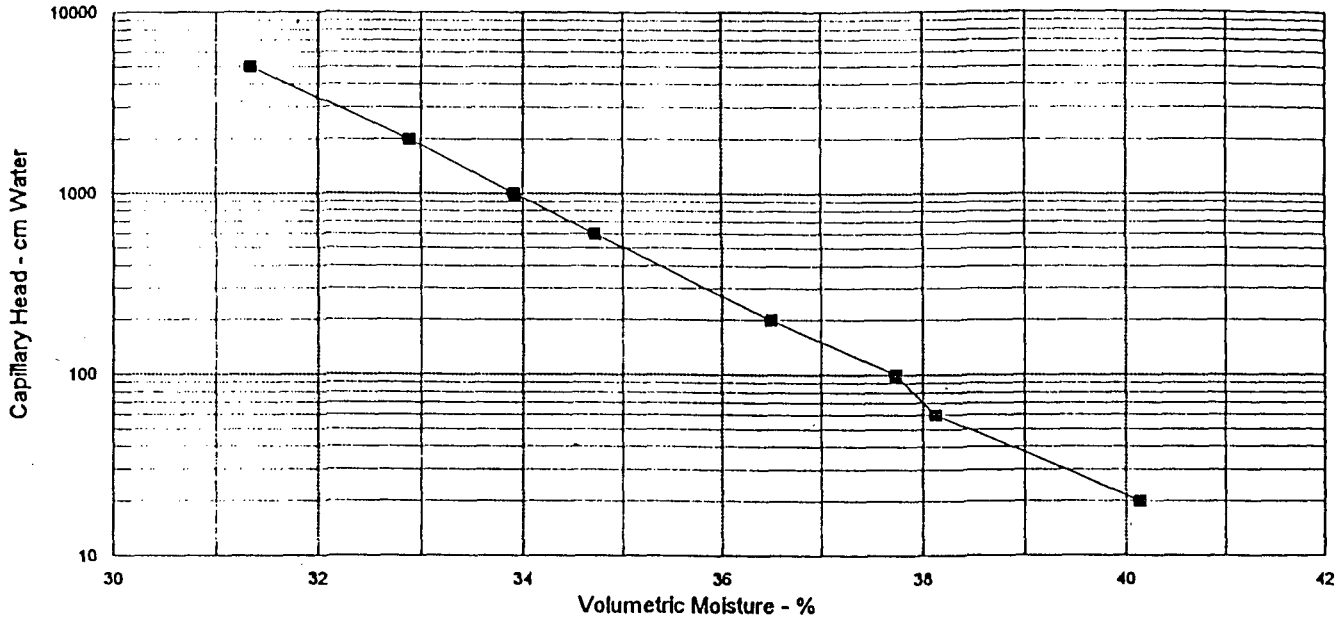
CAPILLARY MOISTURE RETENTION CURVE
97-AL-1



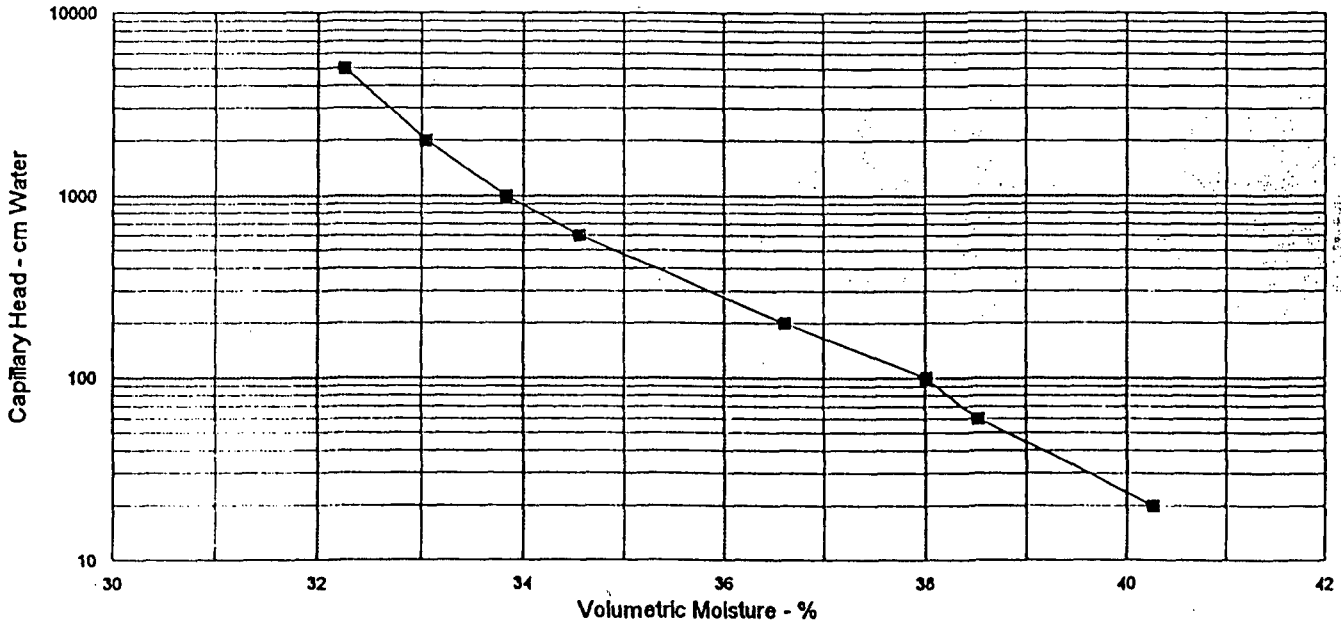
CAPILLARY MOISTURE RETENTION CURVE
97-AL-1 (R)



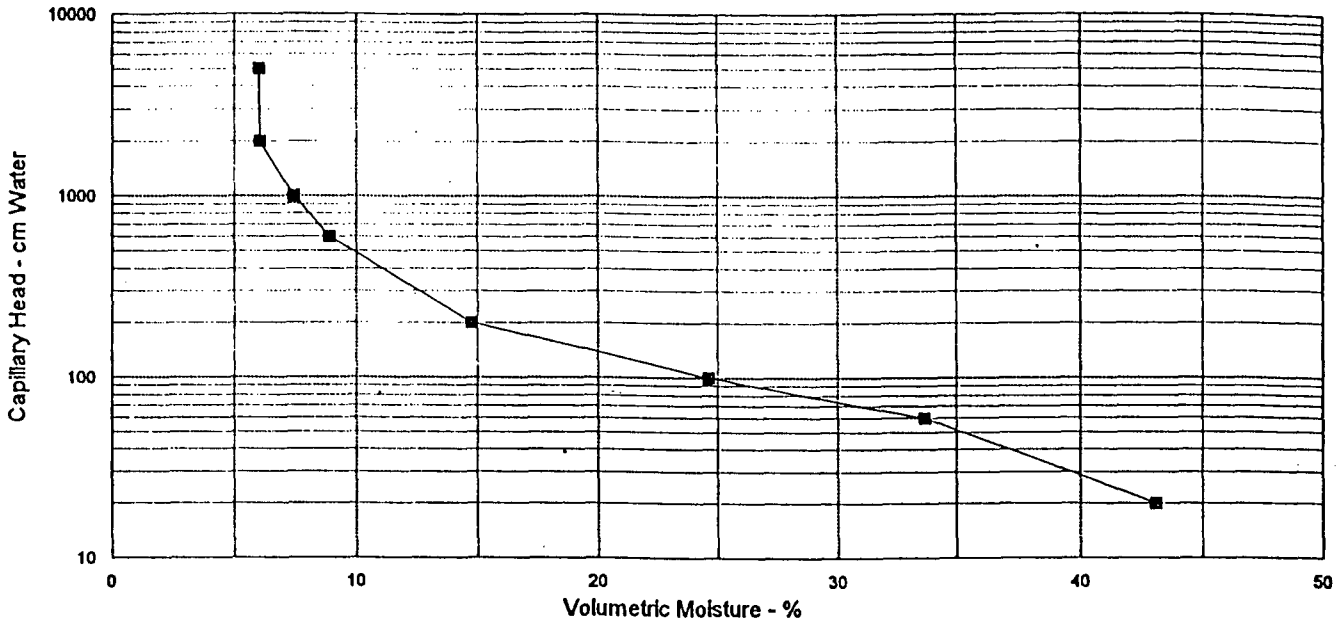
CAPILLARY MOISTURE RETENTION CURVE
97-AL-2



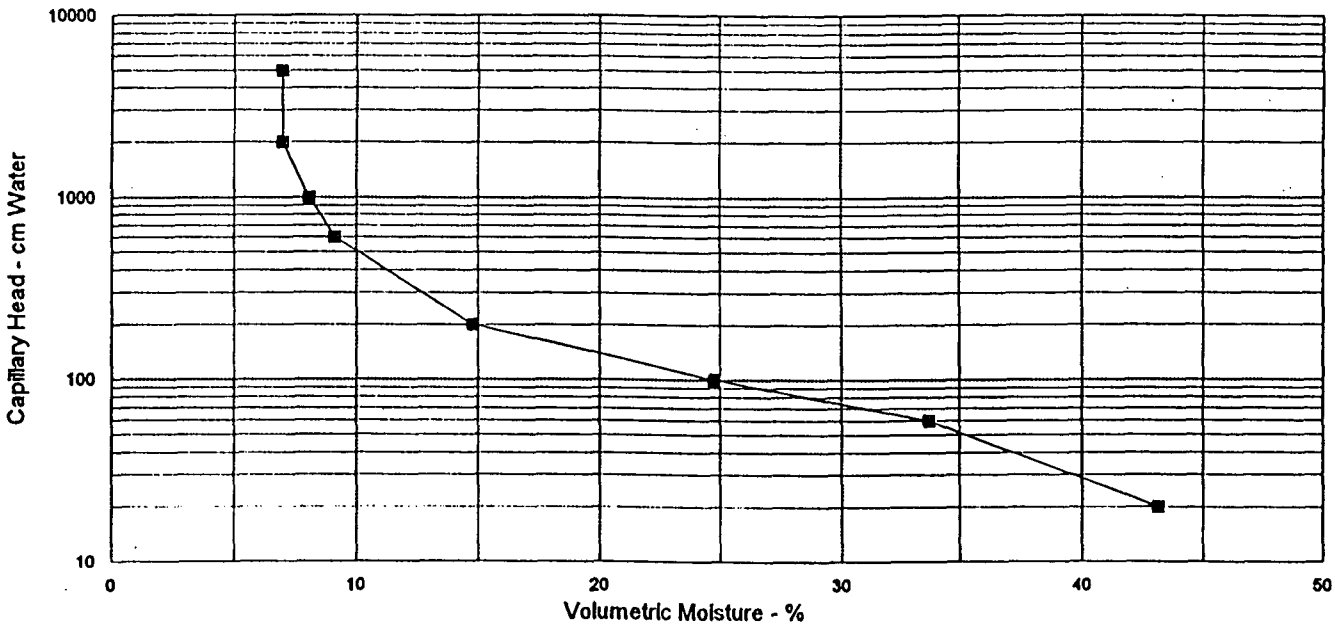
CAPILLARY MOISTURE RETENTION CURVE
97-AL-2 (R)



CAPILLARY MOISTURE RETENTION CURVE
97-T-7



CAPILLARY MOISTURE RETENTION CURVE
97-T-7 (R)



CONSTANT HEAD PERMEABILITY TEST
FLEXIBLE WALL (ASTM D 5084)

Project	Questa	Project No.	9208.04
Sample No.	T-2, Bulk (Clayey Tailing)	Tested By	SDD
Depth	N/A	Checked By	GM
Sample Type	Remold	Date	04/26/96

INITIAL SAMPLE DATA

Sample Dia (cm)	7.28	Specific Gravity	2.69
Init. Ht. (cm)	14.50	Assumed?	No
Init. Vol (cm^3)	604.38	Init. Void Ratio	0.729
Init. Sample Wet Wt. (g)	1173.91	Init. Dry Density (pcf)	97.1
Init. Moisture Content	24.9%	Initial Calculated Saturation	91.8%

CONSOLIDATION DATA

Back Pressure (psi)	40.0	Final Area (cm^2)	41.09
Confining Pressure (psi)	2.0	Height Change (cm)	0.046
Volume Change (cc)	10.465	Final Ht. (cm)	14.455

FINAL SAMPLE DATA

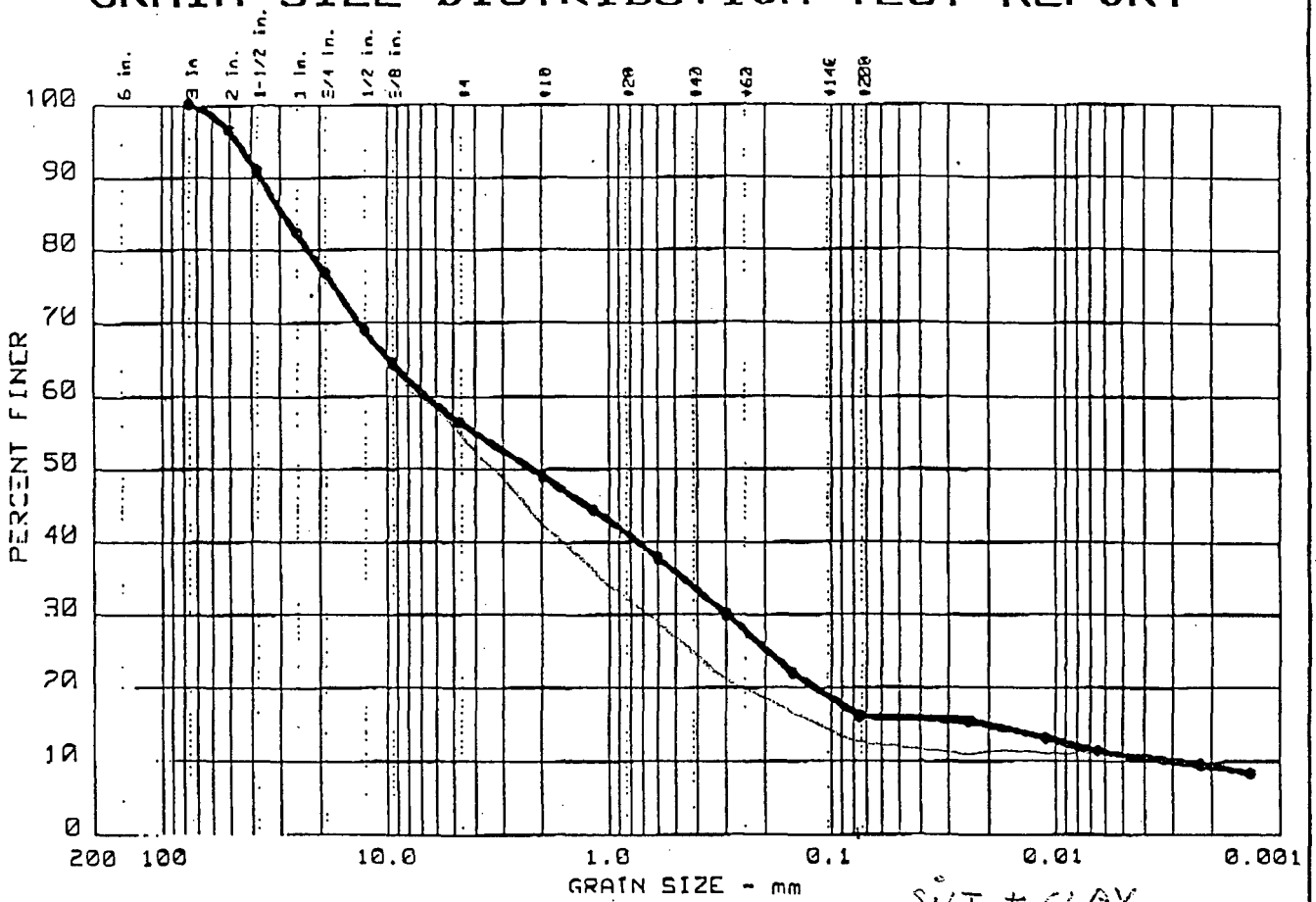
Final Wet Wt. + Pan (g)	1395.00	Final Void Ratio	0.699
Final Dry Wt. + Pan (g)	1131.93	Final Volume (cm^3)	593.91
Pan Wt. Only (g)	191.68	Final Dry Density (pcf)	98.8
Final Moisture Content	28.0%	Final Calculated Saturation	100.0%

Burrette Calibration (cc/cm)	0.91
Constant Pressure Head (psi)	0.97

TEST DATA

Elapsed Time (min)	Head Burrette Reading (cm)	Tail Burrette Reading (cm)	Flow Q (cc)	Average Total Head (cm)	Average Total Head (psi)	Permeability k (cm/sec)
	4.3	41.6				
945	12.6	33.0	7.69	97.04	1.38	4.9E-07
99	13.3	32.2	0.68	87.84	1.25	4.6E-07
145	14.3	31.0	1.00	85.99	1.22	4.7E-07
					Average =	4.7E-07

GRAIN SIZE DISTRIBUTION TEST REPORT



SILT + CLAY

	% +3"	% GRAVEL	% SAND	% FINES
●	0.0	43.5	40.4	16.1

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	29	15	29.1	6.59	2.26	0.301	0.0195	0.0026	5.37	2570.4

MATERIAL DESCRIPTION	USCS	AASHTO
● Clayey gravel with sand	GC	

Project No.: 09208.04
Project: Questa
● Location: T-3 Bulk, Cover Material

Date: 4/1/96

Remarks:
Specific gravity = 2.67

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: _____

CONSTANT HEAD PERMEABILITY
RIGID WALL

Project	Questa	Project No.	09208.04
Sample No.	T-3, Bulk (Cover Material)	Tested By	SDD
Depth	N/A	Checked By	GM
Sample Type	Remolded (6" mold)	Date	04/26/96

INITIAL SAMPLE DATA			
Sample Dia (cm)	15.24	Specific Gravity	2.67
Init. Ht. (cm)	10.602	Assumed?	No
Init. Vol (cm^3)	1933.95	Init. Void Ratio	0.323
Init. Sample Wet Wt. (g)	4055.00	Init. Dry Density (pcf)	126.0
Init. Moisture Content	3.9%	Initial Calculated Saturation	32.4%

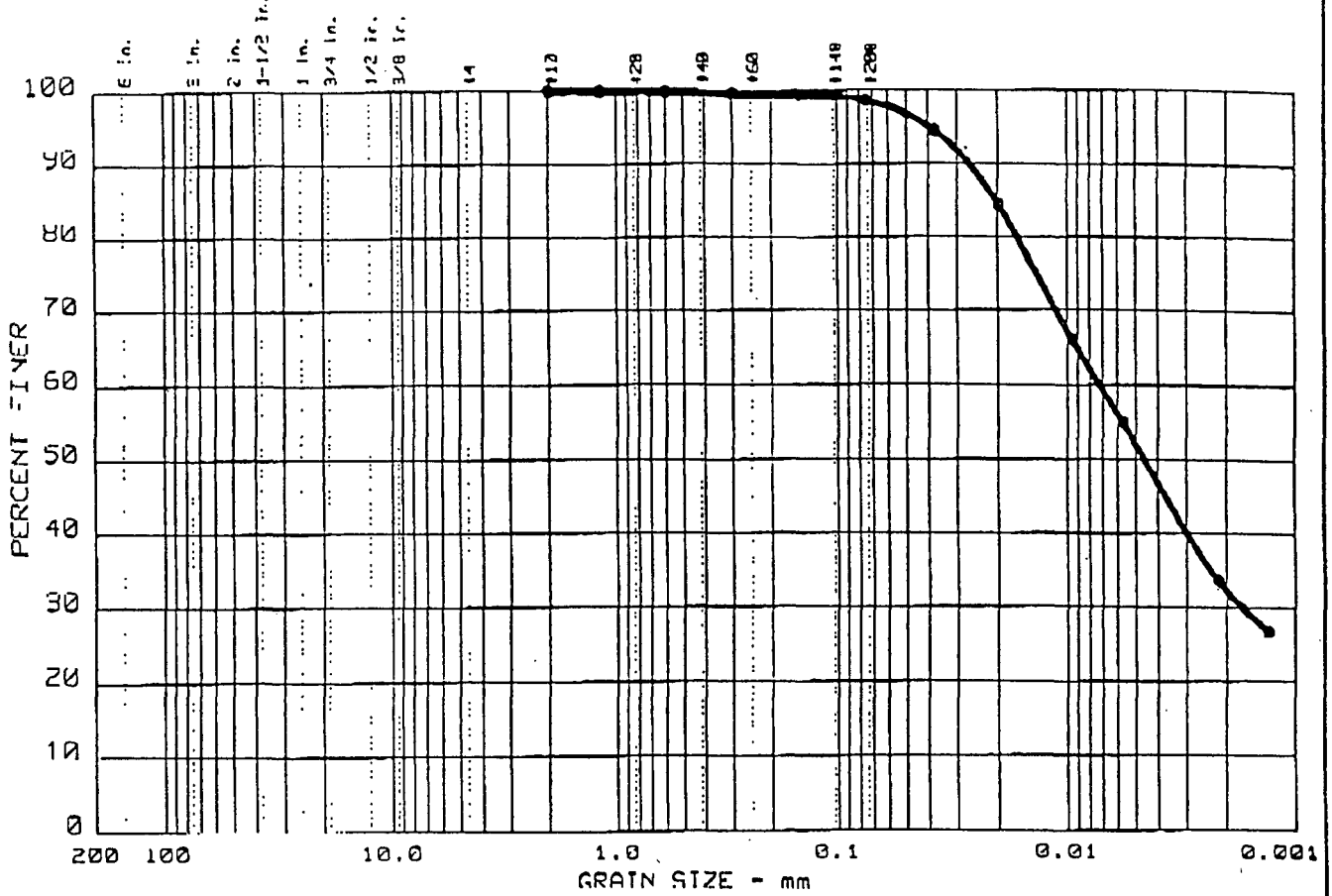
CONSOLIDATION DATA	
Area (cm^2)	182.415
Final Ht. (cm)	10.660

FINAL SAMPLE DATA			
Final Wet Wt. + Pan (g)	4538.0	Final Void Ratio	0.330
Final Dry Wt. + Pan (g)	4182.0	Final Volume (cm^3)	1944.61
Pan Wt. Only (g)	280.0	Final Dry Density (pcf)	125.3
Final Moisture Content	9.1%	Final Calculated Saturation	73.8%

TEST DATA

Date	Elapsed Time (min)	Elapsed Time (sec)	Total Head (cm)	Length (cm) Flow Q (cc)	10.660 Permeability k (cm/sec)
04/19/96	32	1920	36.30	19.3	1.6E-05
04/19/96	36	2160	36.30	22.3	1.7E-05
04/19/96	62	3720	36.30	39.5	1.7E-05
				Average =	1.7E-05

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
●	0.0	0.0	1.4	98.6

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●					0.0045	0.0017				

MATERIAL DESCRIPTION	USCS	AASHTO
● Silt	ML	

Project No.: 09208.04
Project: Questa
● Location: T-2 Bulk, tailing

Date: 4/1/96

Remarks:
Specific gravity = 2.69

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: ____

CONSTANT HEAD PERMEABILITY
RIGID WALL

Project	Questa	Project No.	09208.04
Sample No.	T-21, Bulk (Cover Material)	Tested By	SDD
Depth	N/A	Checked By	GM
Sample Type	Remolded (6" mold)	Date	04/26/96

INITIAL SAMPLE DATA

Sample Dia (cm)	15.24	Specific Gravity	2.69
Init. Ht. (cm)	10.610	Assumed?	No
Init. Vol (cm^3)	1935.34	Init. Void Ratio	0.473
Init. Sample Wet Wt. (g)	3843.40	Init. Dry Density (pcf)	114.0
Init. Moisture Content	8.7%	Initial Calculated Saturation	49.6%

CONSOLIDATION DATA

Area (cm^2)	182.415
Final Ht. (cm)	10.605

FINAL SAMPLE DATA

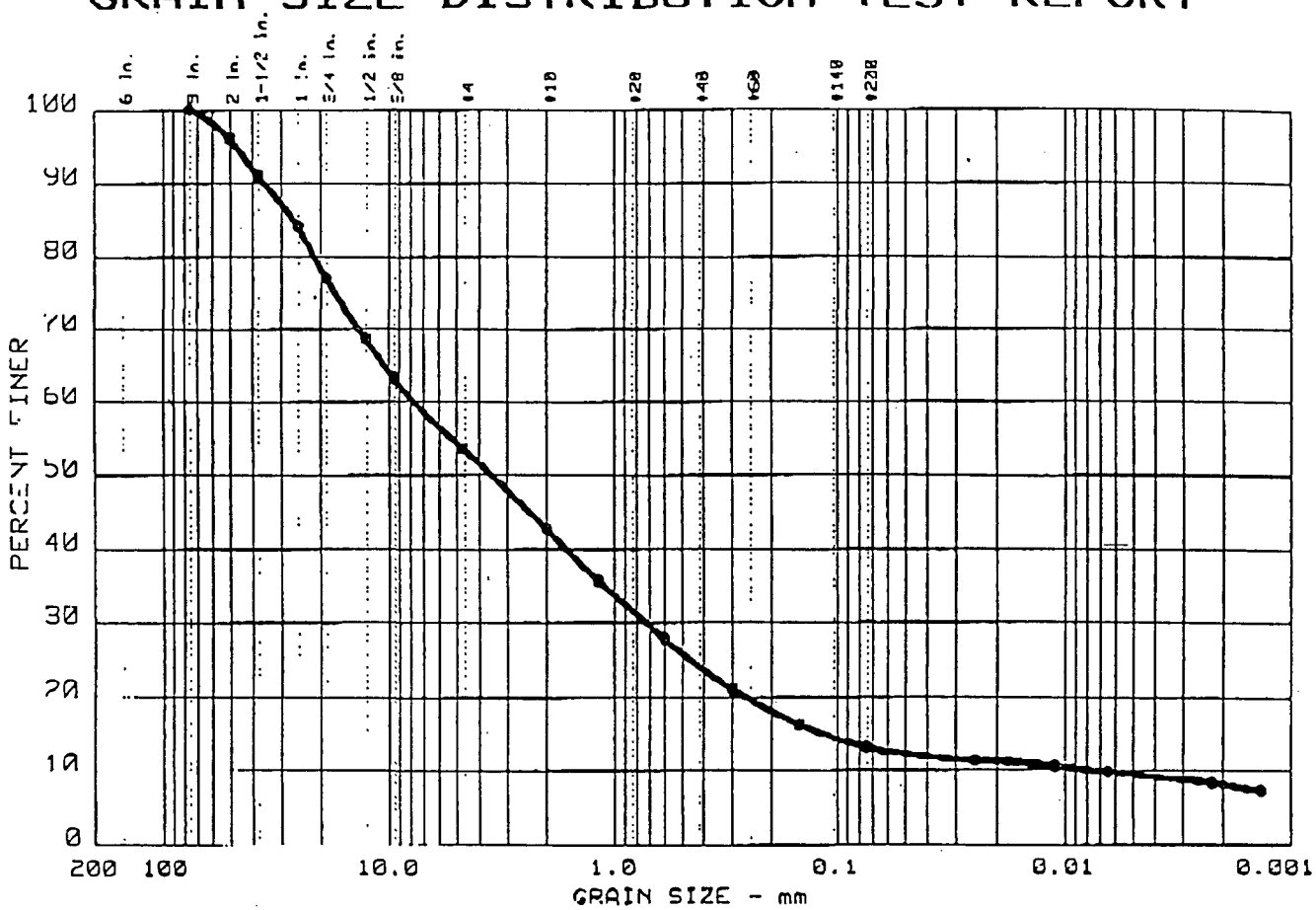
Final Wet Wt. + Pan (g)	4213.00	Final Void Ratio	0.471
Final Dry Wt. + Pan (g)	3732.00	Final Volume (cm^3)	1934.42
Pan Wt. Only (g)	197.00	Final Dry Density (pcf)	114.1
Final Moisture Content	13.6%	Final Calculated Saturation	77.7%

TEST DATA

Length (cm) 10.605

Date	Elapsed Time (min)	Elapsed Time (sec)	Total Head (cm)	Flow Q (cc)	Permeability k (cm/sec)
04/12/96	5	300	2.0	20.2	2.0E-03
04/12/96	5	300	2.0	20.2	2.0E-03
04/12/96	5	300	2.0	20.2	2.0E-03
				Average =	2.0E-03

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
●	0.0	46.4	40.5	13.1

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	33	19	26.3	7.70	3.55	0.733	0.117	0.0070	9.89	1109.2

MATERIAL DESCRIPTION	USCS	AASHTO
● Clayey gravel with sand	GC	

Project No.: 09208.04
Project: Questa
● Location: T-21 Bulk, cover material

Date: 3/26/96

Remarks:
Specific gravity = 2.69

GRAIN SIZE DISTRIBUTION TEST REPORT
STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.
Consulting Engineers and Scientists

Fig. No.: ___

CONSTANT HEAD PERMEABILITY
RIGID WALL

Project	Questa	Project No.	9208.04
Sample No.	T-24, Bulk (Tailing Sand)	Tested By	SDD
Depth	N/A	Checked By	GM
Sample Type	Remolded (6" mold)	Date	04/26/96

INITIAL SAMPLE DATA

Sample Dia (cm)	15.24	Specific Gravity	2.63
Init. Ht. (cm)	10.711	Assumed?	No
Init. Vol (cm^3)	1953.88	Init. Void Ratio	0.827
Init. Sample Wet Wt. (g)	3173.20	Init. Dry Density (pcf)	89.9
Init. Moisture Content	12.8%	Initial Calculated Saturation	40.7%

CONSOLIDATION DATA

Area (cm^2)	182.415
Final Ht. (cm)	10.645

FINAL SAMPLE DATA

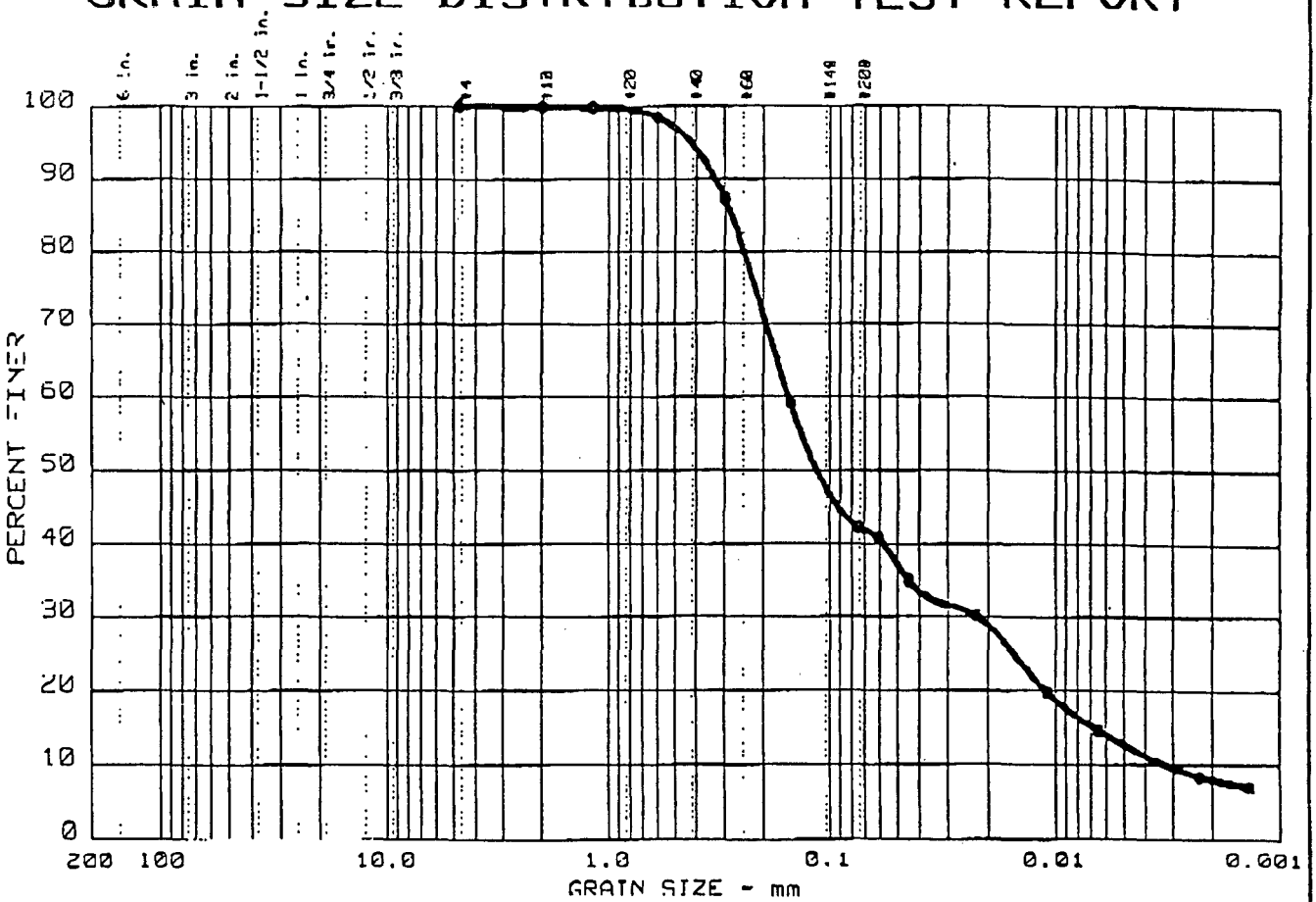
Final Wet Wt. + Pan (g)	3846.00	Final Void Ratio	0.814
Final Dry Wt. + Pan (g)	3156.00	Final Volume (cm^3)	1941.83
Pan Wt. Only (g)	342.60	Final Dry Density (pcf)	90.4
Final Moisture Content	24.5%	Final Calculated Saturation	79.2%

TEST DATA

Length (cm) 10.645

Date	Elapsed Time (min)	Elapsed Time (sec)	Total Head (cm)	Flow Q (cc)	Permeability k (cm/sec)
04/12/96	5	300	3.8	22.9	1.2E-03
04/12/96	5	300	3.8	22.9	1.2E-03
04/12/96	5	300	3.8	22.9	1.2E-03
				Average =	1.2E-03

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
●	0.0	0.0	57.8	42.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.279	0.153	0.115	0.0221	0.0068	0.0032	0.99	47.4

MATERIAL DESCRIPTION	USCS	AASHTO
● Silty sand	SM	

Project No.: 09208.04

Project: Questa

● Location: T-24 Bulk, tailing sand

Date: 4/1/96

Remarks:

Specific gravity = 2.63

GRAIN SIZE DISTRIBUTION TEST REPORT

STEFFEN ROBERTSON AND KIRSTEN (U.S.) INC.

Consulting Engineers and Scientists

Fig. No.: _____

CAPILLARY MOISTURE RETENTION TEST
ASTM D 2325

Project: Questa
Project No: 09208.04

Started: 03/04/96
Finished: 03/11/96

Tested By: BDD/LMS
Checked By: CM

Ring No.	1	2	3	4	5	6	7	8
Ring Vol: (cc)	19.04177	18.894286	19.058155	19.169252	19.2546	19.041768	19.123704	19.158262

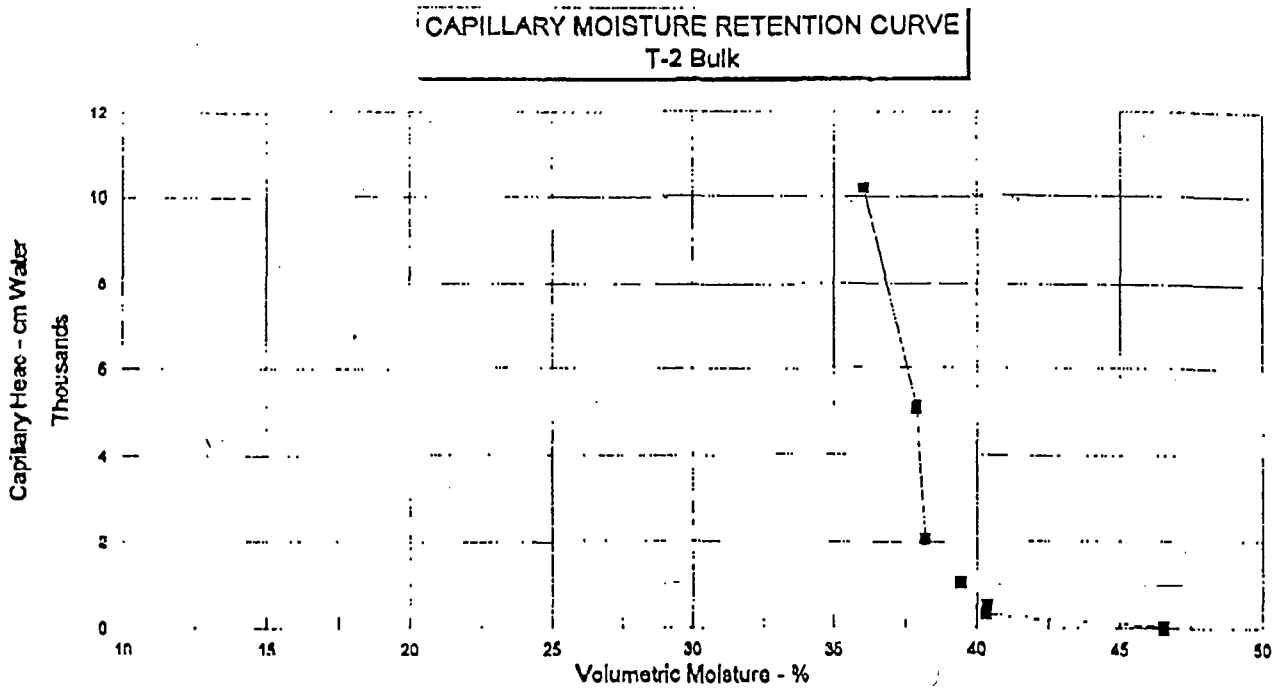
Sample	Ring Mass g.	Initial Mass g.	Sat. Mass g.	0.3 Bar Mass g	0.5 Bar Mass g	1 Bar Mass g	2 Bar Mass g	5 Bar Mass g	10 Bar Mass g	Dry Mass Filter + Ring + Dish g	Dish Wt. g.
Filter Only		0.000	0.867	0.628	0.647	0.633	0.623	0.506	0.464	70.928	70.528
T-2 Bulk	10.461	47.862	49.564	48.166	48.083	47.900	47.667	47.670	47.218	116.771	78.647
T-2 Bulk (R)	10.412	47.562	49.082	48.012	47.647	47.660	47.440	47.075	47.040	118.408	78.618
T-3 Bulk	10.547	53.164	55.581	54.366	54.171	53.987	53.761	53.736	53.475	122.805	74.770
T-3 Bulk (R)	10.525	54.078	55.818	54.682	54.465	54.291	54.094	54.026	53.761	123.432	75.333
T-21 Bulk	10.569	50.546	52.553	50.966	50.769	50.579	50.392	50.333	50.081	117.209	72.002
T-21 Bulk (R)	10.684	48.983	51.718	49.976	49.786	49.578	49.377	49.282	48.982	117.278	72.338
T-24 Bulk	10.514	43.134	48.898	43.098	42.859	42.650	42.411	42.308	41.918	114.030	75.282
T-24 Bulk (R)	10.571	42.233	47.978	42.832	42.354	42.181	41.987	41.903	41.631	134.629	95.741

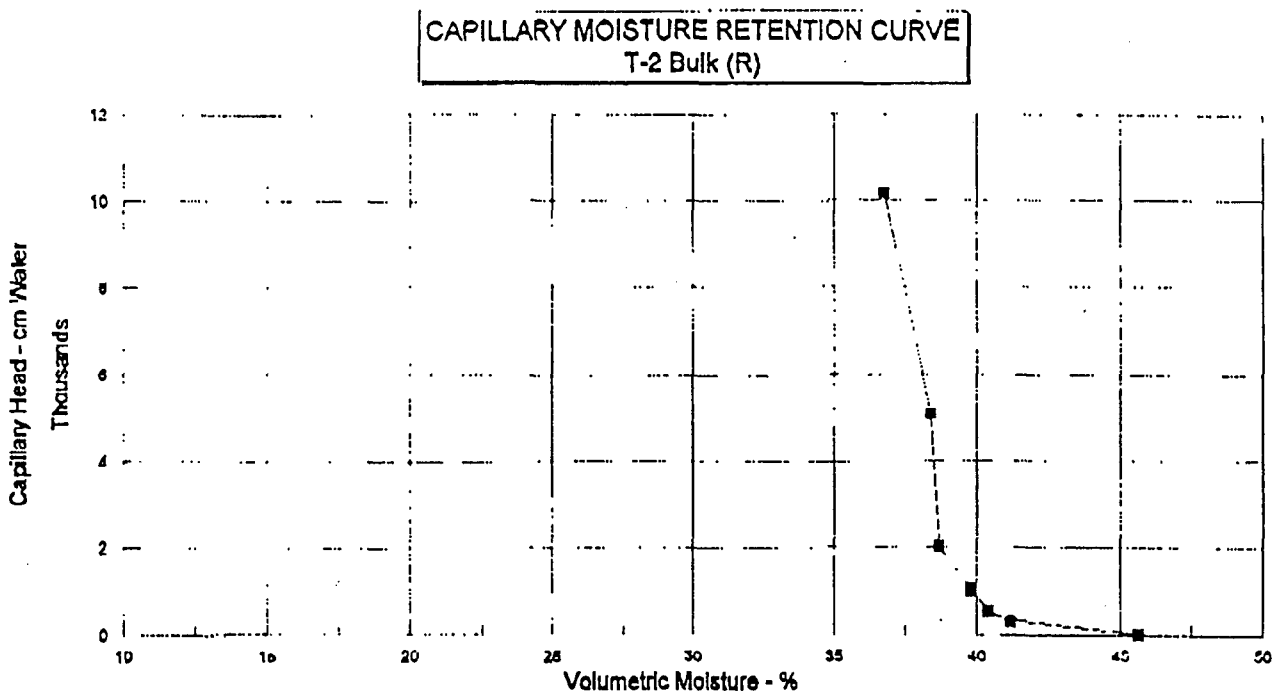
Sample	Dry Mass g	Unit Wt. g/cc	Sat. Mass g	Total H20 g	Sat. MC % DM	Sat. MC % Vol.	0.3 Bar Ret H20	0.3 Bar % DM	0.3 Bar % Vol.	0.5 Bar Ret H20	0.5 Bar % DM	0.5 Bar % Vol.
T-2 Bulk	29.377	1.64277	38.248	8.869	30.19%	49.58%	7.680	26.14%	40.33%	7.686	26.17%	40.37%
T-2 Bulk (R)	29.200	1.54544	37.823	8.623	29.53%	45.64%	7.772	26.62%	41.13%	7.688	26.33%	40.37%
T-3 Bulk	37.199	1.94783	44.167	7.035	18.95%	36.91%	6.059	16.32%	31.79%	5.955	16.04%	31.27%
T-3 Bulk (R)	37.208	1.93900	44.434	7.226	19.42%	37.66%	6.321	16.99%	32.94%	6.205	16.68%	32.59%
T-21 Bulk	34.272	1.77002	41.127	6.856	20.00%	35.60%	5.486	16.01%	28.49%	5.371	15.67%	28.21%
T-21 Bulk (R)	33.890	1.76502	40.277	6.387	18.60%	33.02%	4.773	14.04%	25.07%	4.646	13.87%	24.39%
T-24 Bulk	27.666	1.46726	33.327	7.468	28.77%	39.00%	4.660	14.87%	21.38%	3.030	14.10%	20.64%
T-24 Bulk (R)	27.951	1.40600	35.948	7.997	28.61%	41.07%	3.462	12.40%	16.15%	0.285	11.76%	17.26%

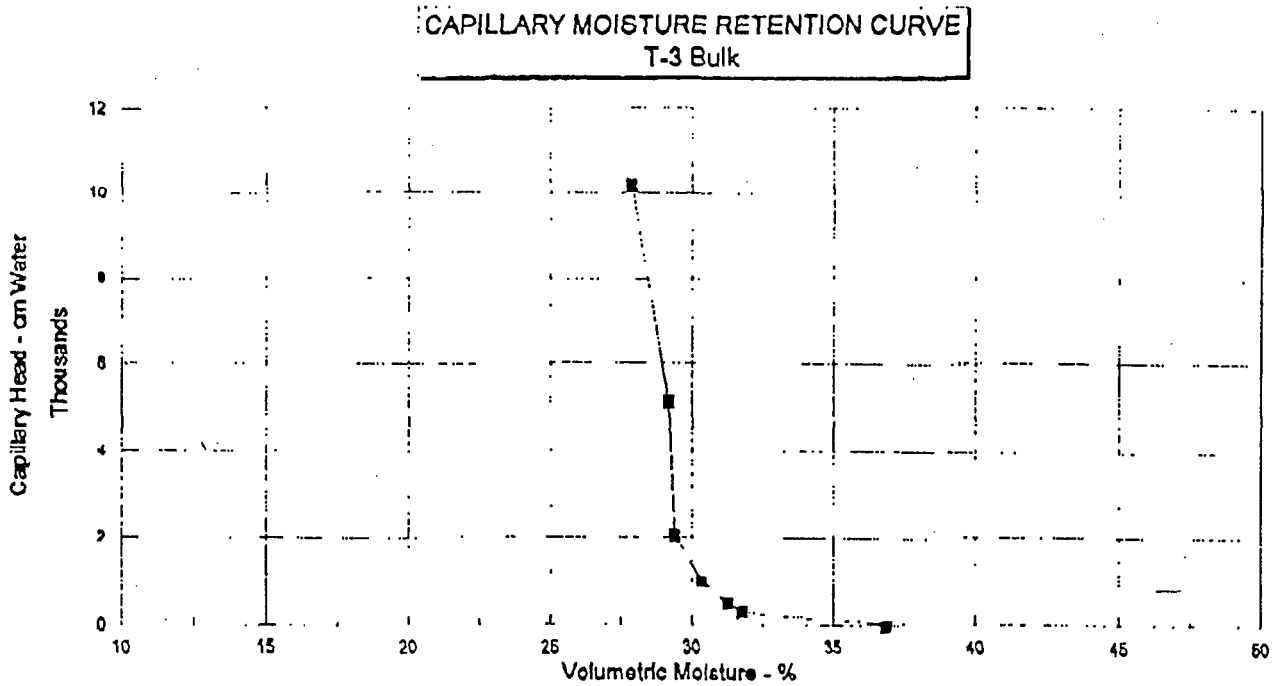
Sample	1 Bar Ret H20	1 Bar % DM	1 Bar % Vol.	2 Bar Ret H20	2 Bar % DM	2 Bar % Vol.	5 Bar Ret H20	5 Bar % DM	5 Bar % Vol.	10 Bar Ret H20	10 Bar % DM	10 Bar % Vol.
T-2 Bulk	7.509	25.66%	39.43%	7.276	24.77%	38.21%	7.215	24.56%	37.89%	6.886	23.37%	36.06%
T-2 Bulk (R)	7.521	25.76%	39.61%	7.311	25.04%	38.69%	7.267	24.85%	38.41%	6.943	23.78%	36.75%
T-3 Bulk	6.700	15.56%	30.35%	5.600	16.06%	29.38%	5.581	14.98%	29.18%	5.312	14.31%	27.87%
T-3 Bulk (R)	6.023	16.18%	31.40%	5.030	16.60%	30.42%	5.787	15.55%	30.18%	5.554	14.93%	28.94%
T-21 Bulk	5.205	15.19%	27.03%	5.026	14.67%	26.11%	4.986	14.55%	25.89%	4.746	13.85%	24.65%
T-21 Bulk (R)	4.471	13.15%	23.48%	4.280	12.59%	22.48%	4.212	12.39%	22.12%	3.894	11.45%	20.45%
T-24 Bulk	3.735	13.40%	19.53%	3.506	12.58%	18.33%	3.418	12.26%	17.87%	3.042	10.92%	15.91%
T-24 Bulk (R)	3.128	11.18%	16.29%	2.942	10.53%	15.33%	2.875	10.29%	14.98%	2.615	9.36%	13.63%

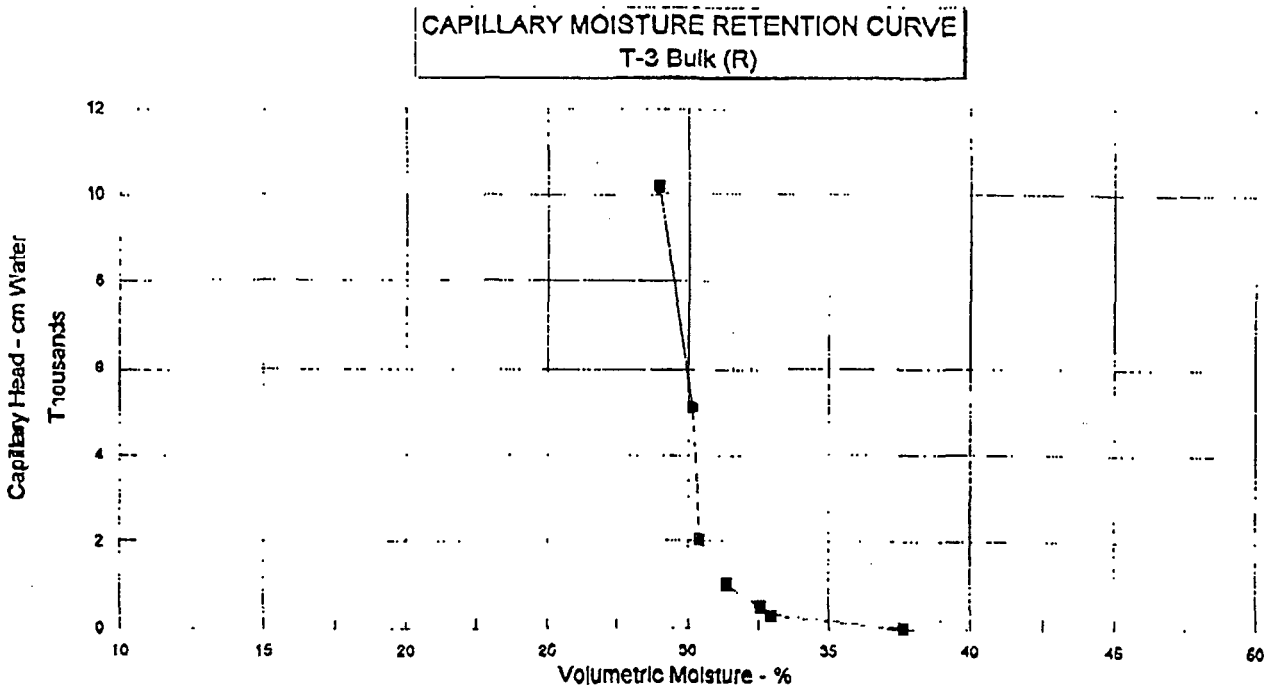
Sample	Vol. MC (%) Sat.	Vol. MC (%) 0.3 Bar	Vol. MC (%) 0.5 Bar	Vol. MC (%) 1 Bar	Vol. MC (%) 2 Bar	Vol. MC (%) 5 Bar	Vol. MC (%) 10 Bar
T-2 Bulk	49.58	40.33	40.37	39.43	38.21	37.89	36.06
T-2 Bulk (R)	45.64	41.13	40.37	39.61	38.69	38.41	36.75
T-3 Bulk	36.91	31.79	31.27	30.35	29.38	29.18	27.87
T-3 Bulk (R)	37.66	32.94	32.59	31.40	30.42	30.18	28.94
T-21 Bulk	35.60	28.49	28.21	27.03	26.11	25.89	24.65
T-21 Bulk (R)	33.02	25.07	24.39	23.48	22.48	22.12	20.45
T-24 Bulk	30.00	21.38	20.64	19.53	18.33	17.87	15.91
T-24 Bulk (R)	41.07	16.15	17.26	16.29	15.33	14.98	13.63

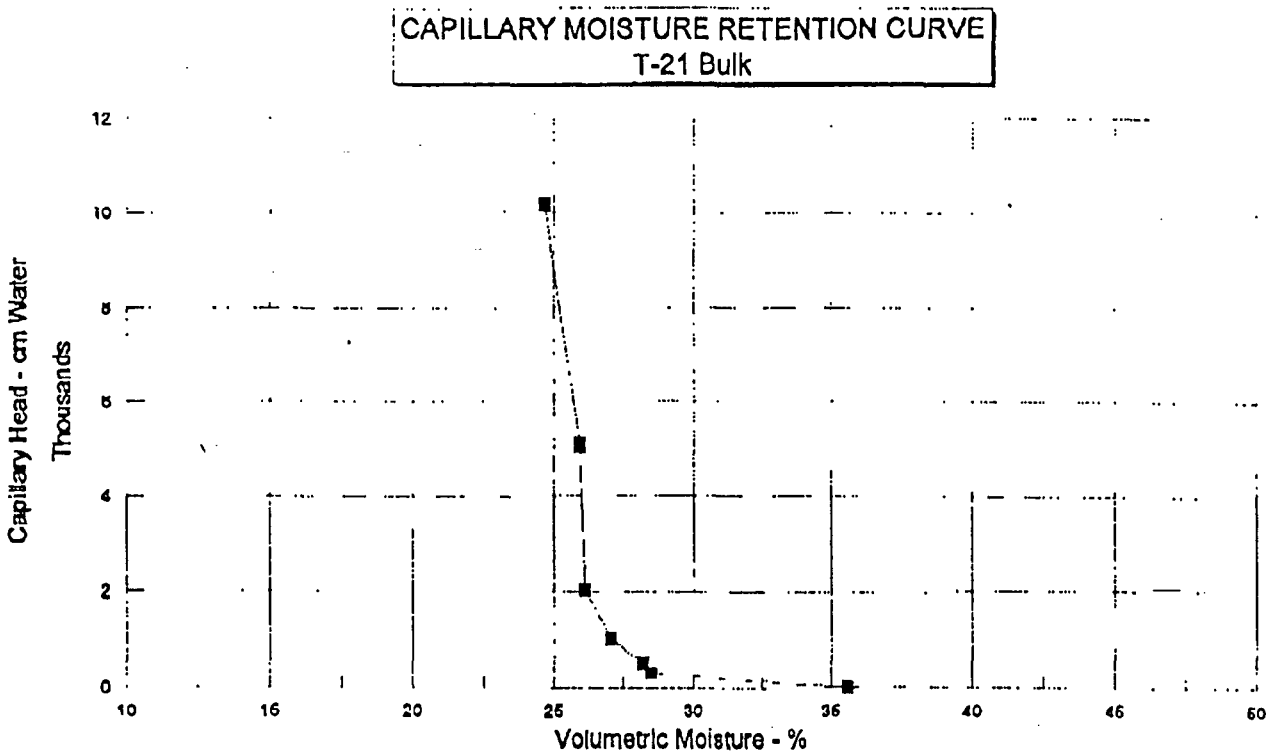
Heads Used							
Bar	0.0	0.3	0.5	1.0	2.0	5.0	10.0
cm H20	0	305.9	509.9	1019.7	2039.4	5098.6	10197.2

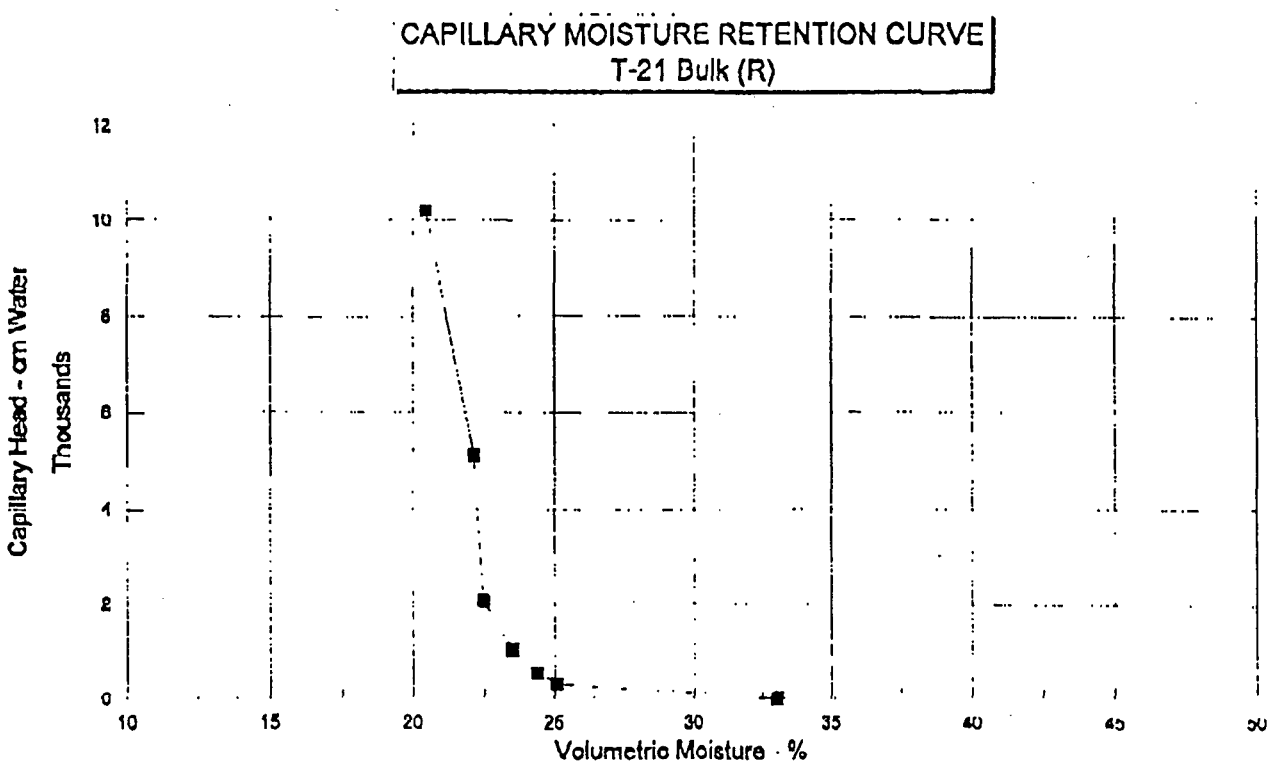

CAPILLARY MOISTURE RETENTION CURVE
T-2 Bulk
Capilary Heac - cm Water
Thousands
12
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
Volumetric Moisture - %


CAPILLARY MOISTURE RETENTION CURVE
T-2 Bulk (R)
Capilary Head - cm Water
Thousands
12
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
Volumetric Moisture - %

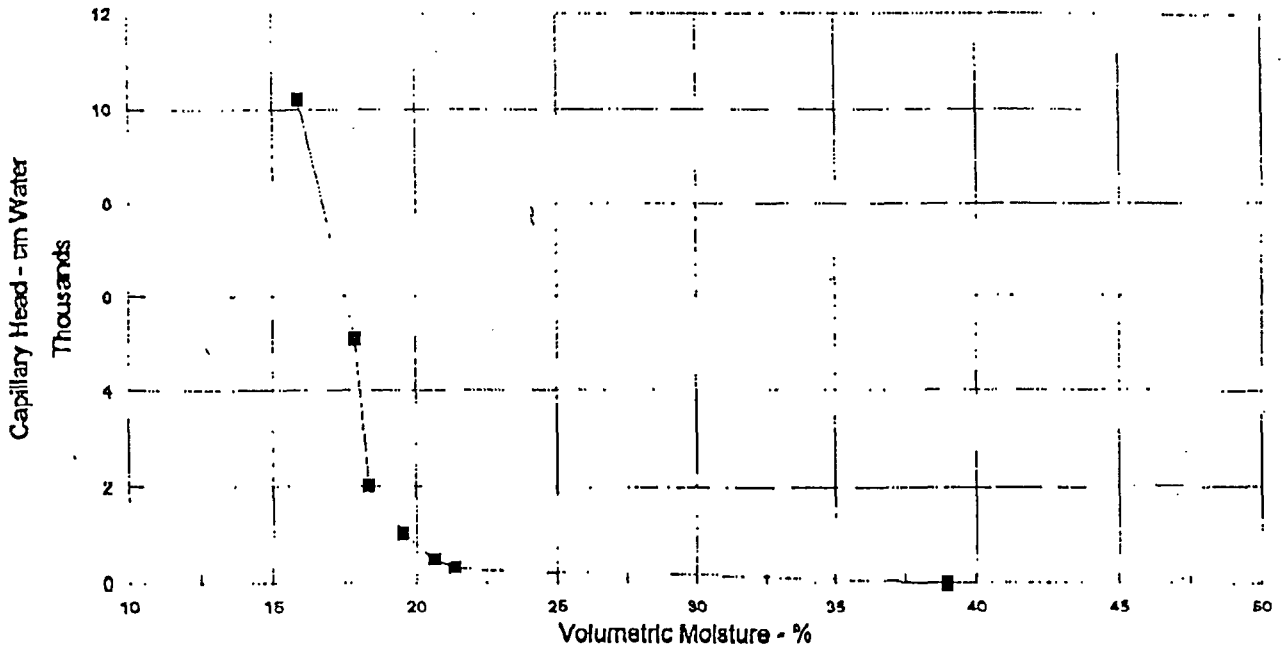

CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk
Capillary Head - cm Water
Thousands
Volumetric Moisture - %


CAPILLARY MOISTURE RETENTION CURVE
T-3 Bulk (R)
Capillary Head - cm Water
Thousands
Volumetric Moisture - %

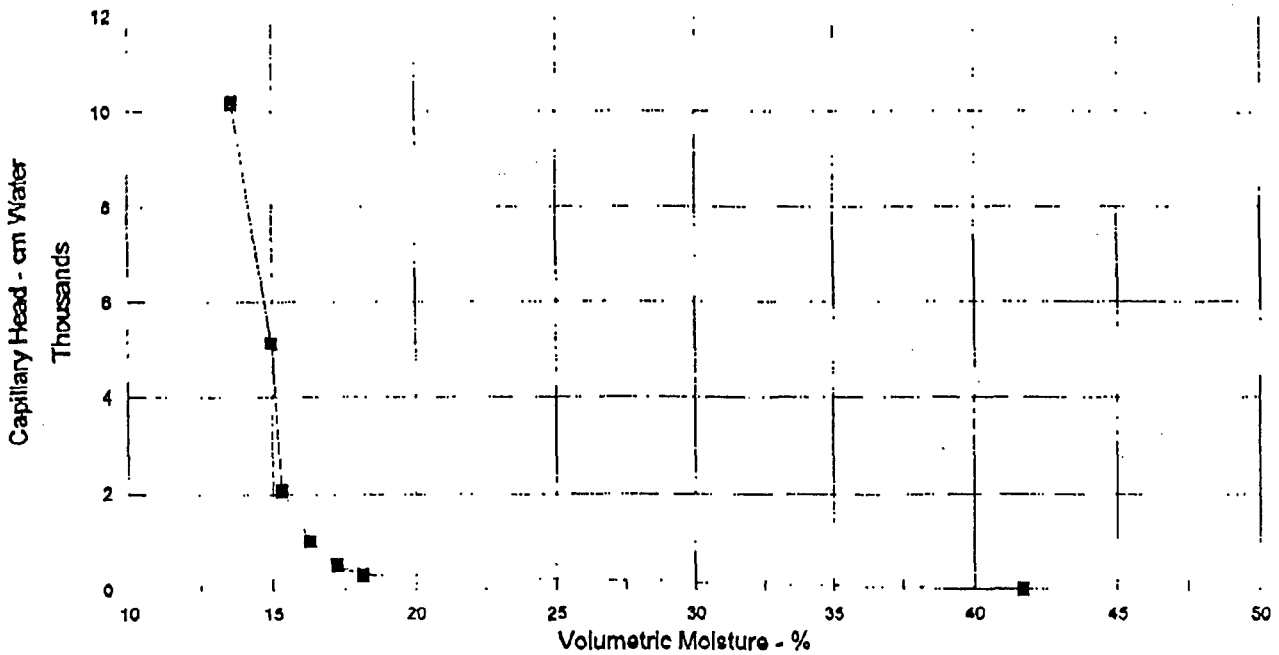

CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk
Capillary Head - cm Water
Thousands
12
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
Volumetric Moisture - %


CAPILLARY MOISTURE RETENTION CURVE
T-21 Bulk (R)
Capillary Head - cm Water
Thousands
12
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
Volumetric Moisture - %

CAPILLARY MOISTURE RETENTION CURVE
T-24 Bulk



CAPILLARY MOISTURE RETENTION CURVE
T-24 Bulk (R)



SPECIFIC GRAVITY BY PYCNOMETER METHOD (ASTM D854)
QUESTA - 09208.04

Sample ID	Flask No.	Dry Soil Wt. (g)	Flask + Water + Soil (g)	Temp. Degrees C	Flask + Water + (g)	Corr. Factor K	Specific Gravity at 20 Degrees C
T - 3 Bulk	2	22.64	373.30	22.0	359.12	0.9996	2.676
T - 3 Bulk	6	22.70	376.10	22.0	361.93	0.9996	2.660
						Average =	2.67
T - 24 Bulk	5	23.43	375.50	22.0	360.97	0.9996	2.632
T - 24 Bulk	3	24.19	374.20	22.0	359.23	0.9996	2.622
						Average =	2.63
T - 2 Bulk	5	22.83	375.30	22.0	360.97	0.9996	2.684
T - 2 Bulk	3	25.85	375.50	22.0	359.23	0.9996	2.697
						Average =	2.69
T - 21 Bulk	6	22.17	375.90	22.0	361.93	0.9996	2.704
T - 21 Bulk	2	21.52	372.60	22.0	359.12	0.9996	2.677
						Average =	2.69

Appendix D

APPENDIX D

Column Seepage Modeling

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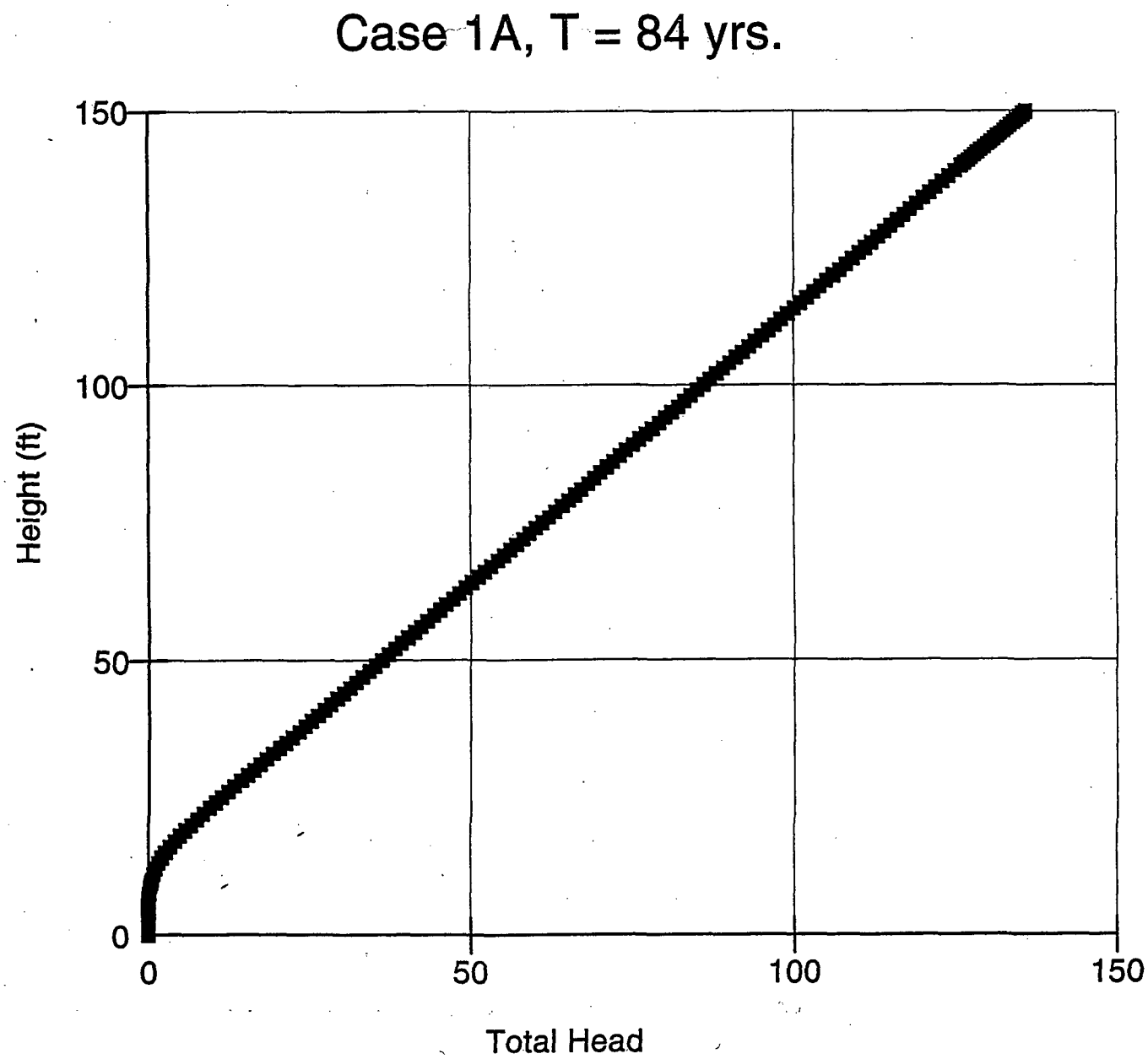
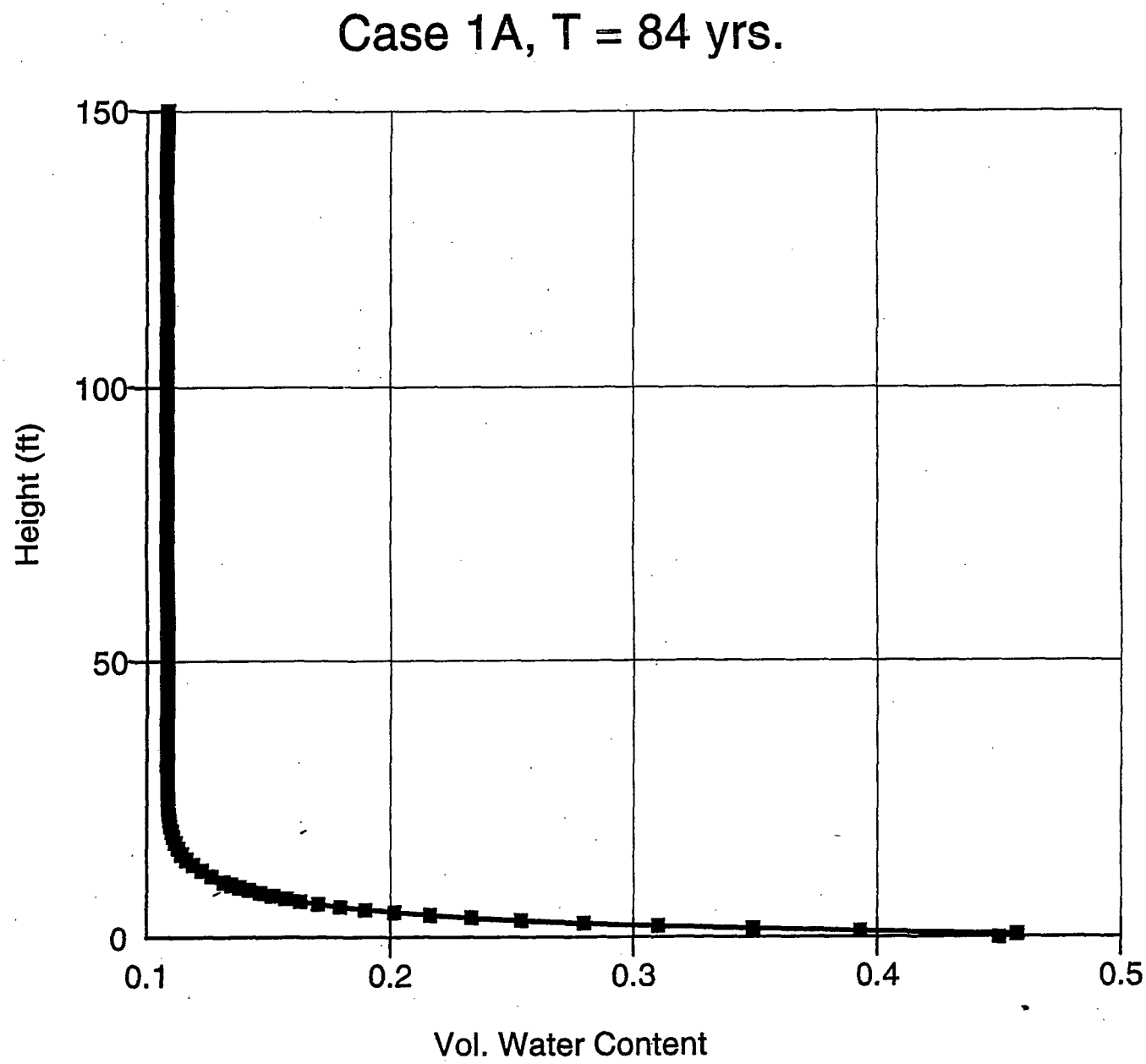
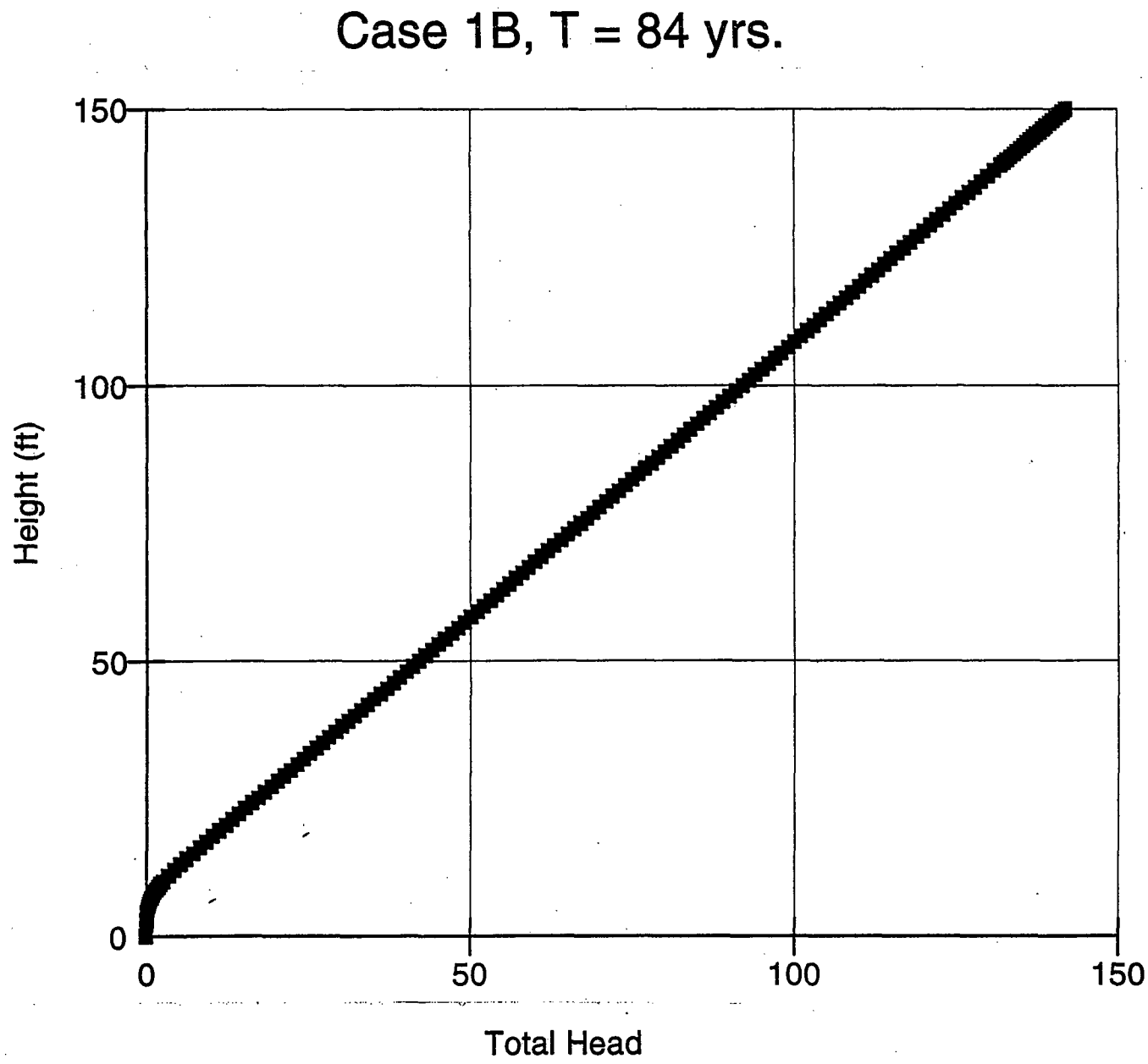
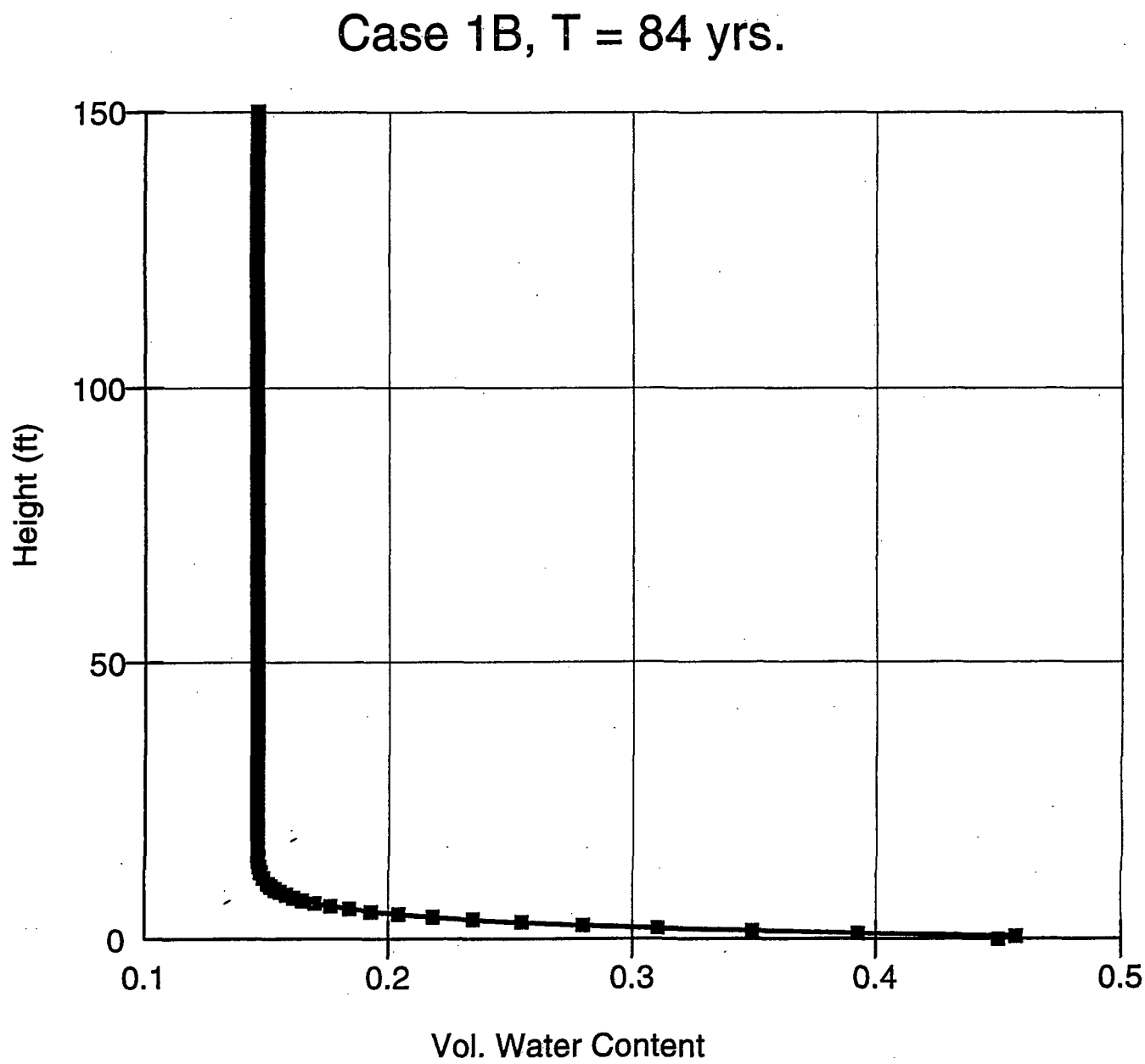
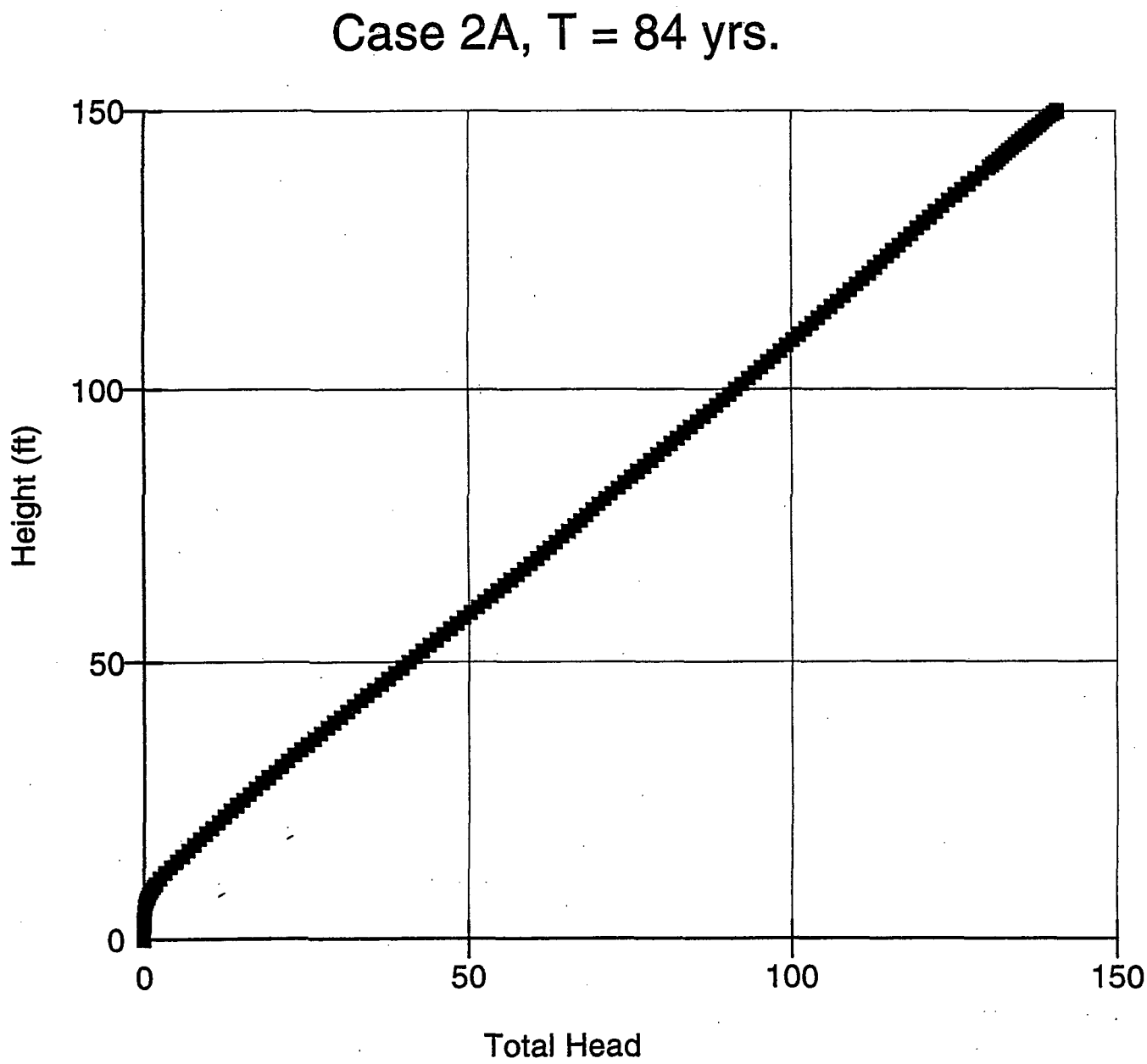
Steady-State Profiles of Total Head and Volumetric Moisture Content

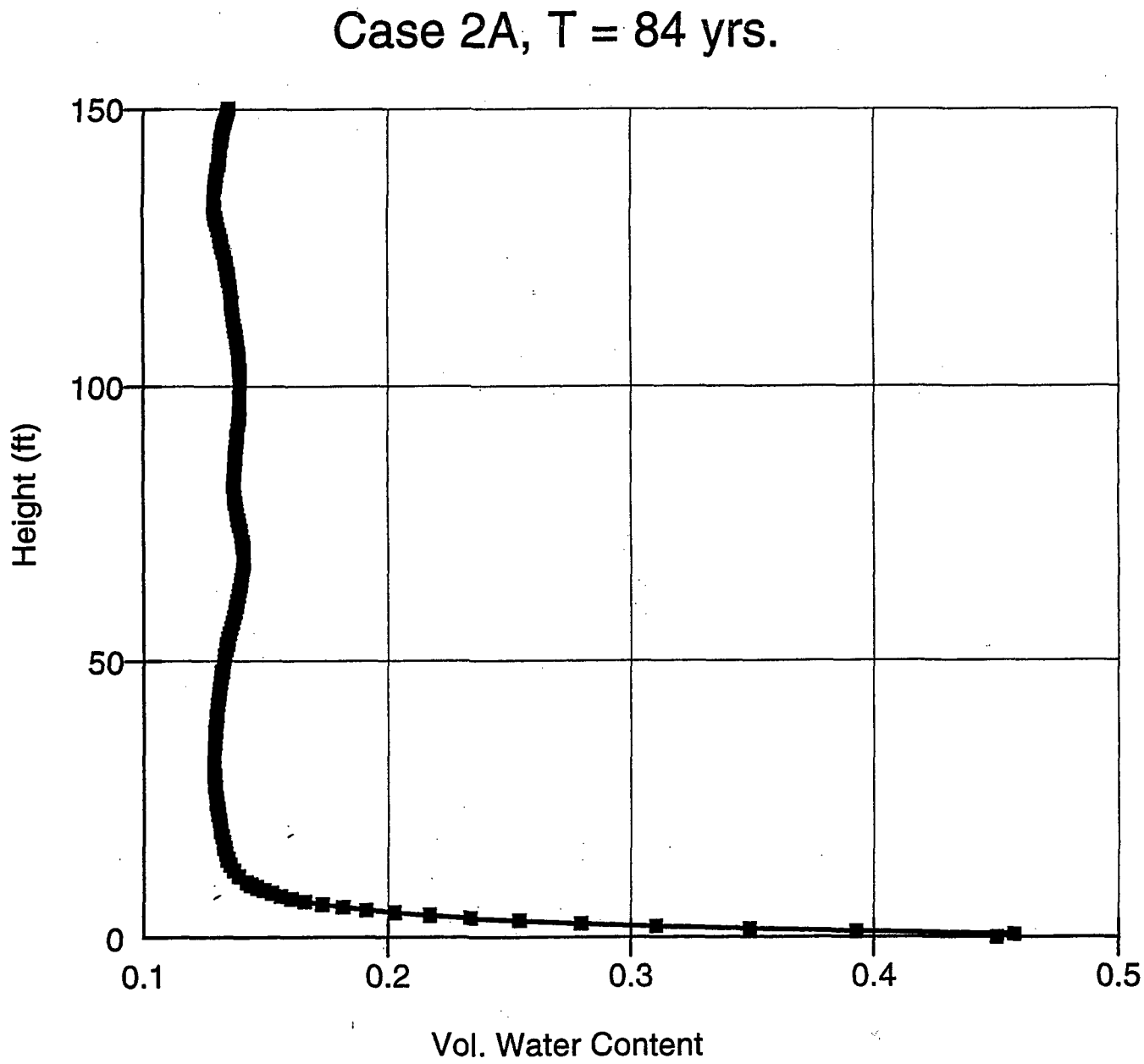

Case 1A, T = 84 yrs.
150
100
50
0
Height (ft)
0
50
100
150
Total Head

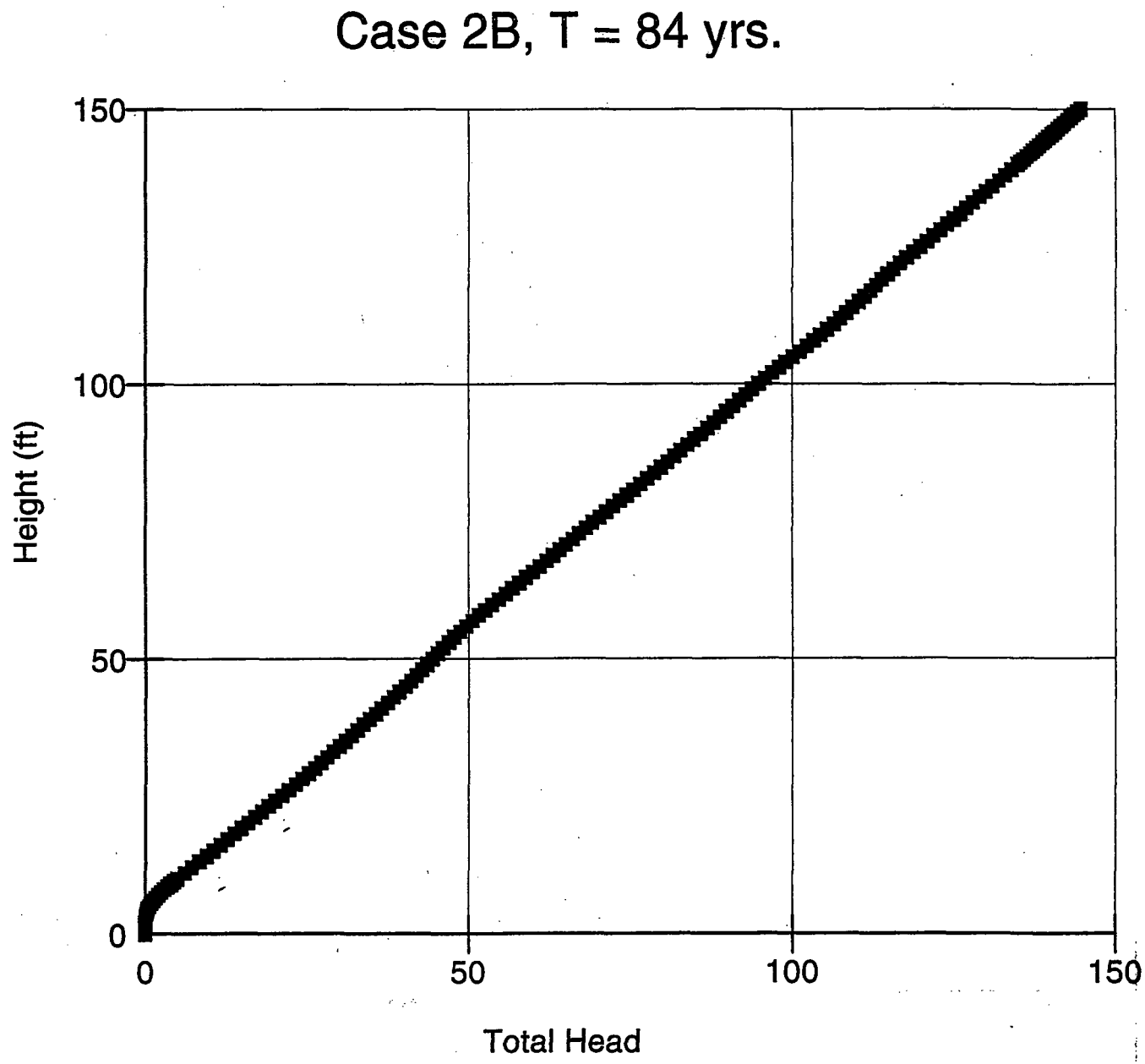

Case 1A, T = 84 yrs.
150
100
50
0
Height (ft)
0.1
0.2
0.3
0.4
0.5
Vol. Water Content

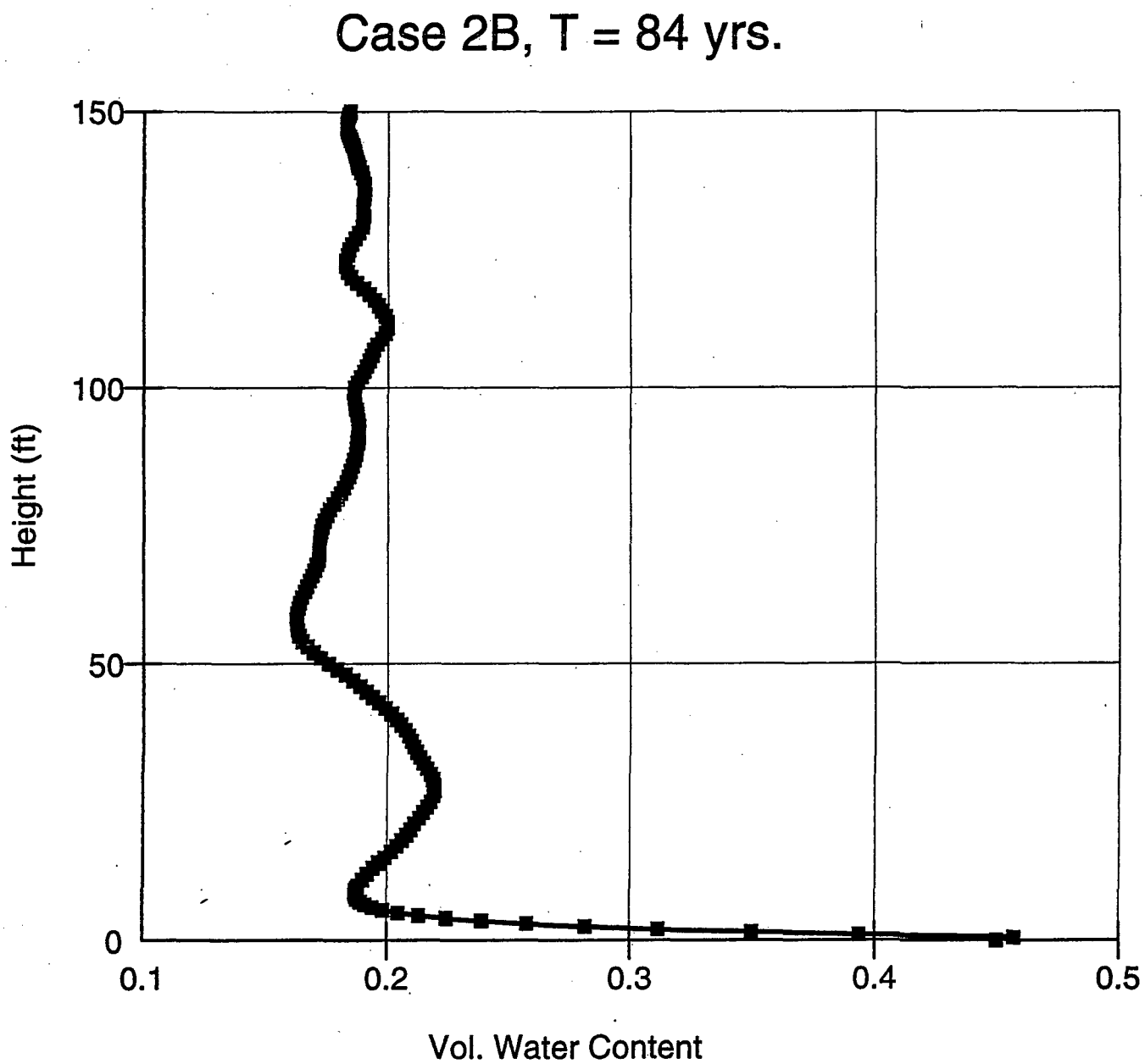

Case 1B, T = 84 yrs.
150
100
50
0
Height (ft)
0
50
100
150
Total Head

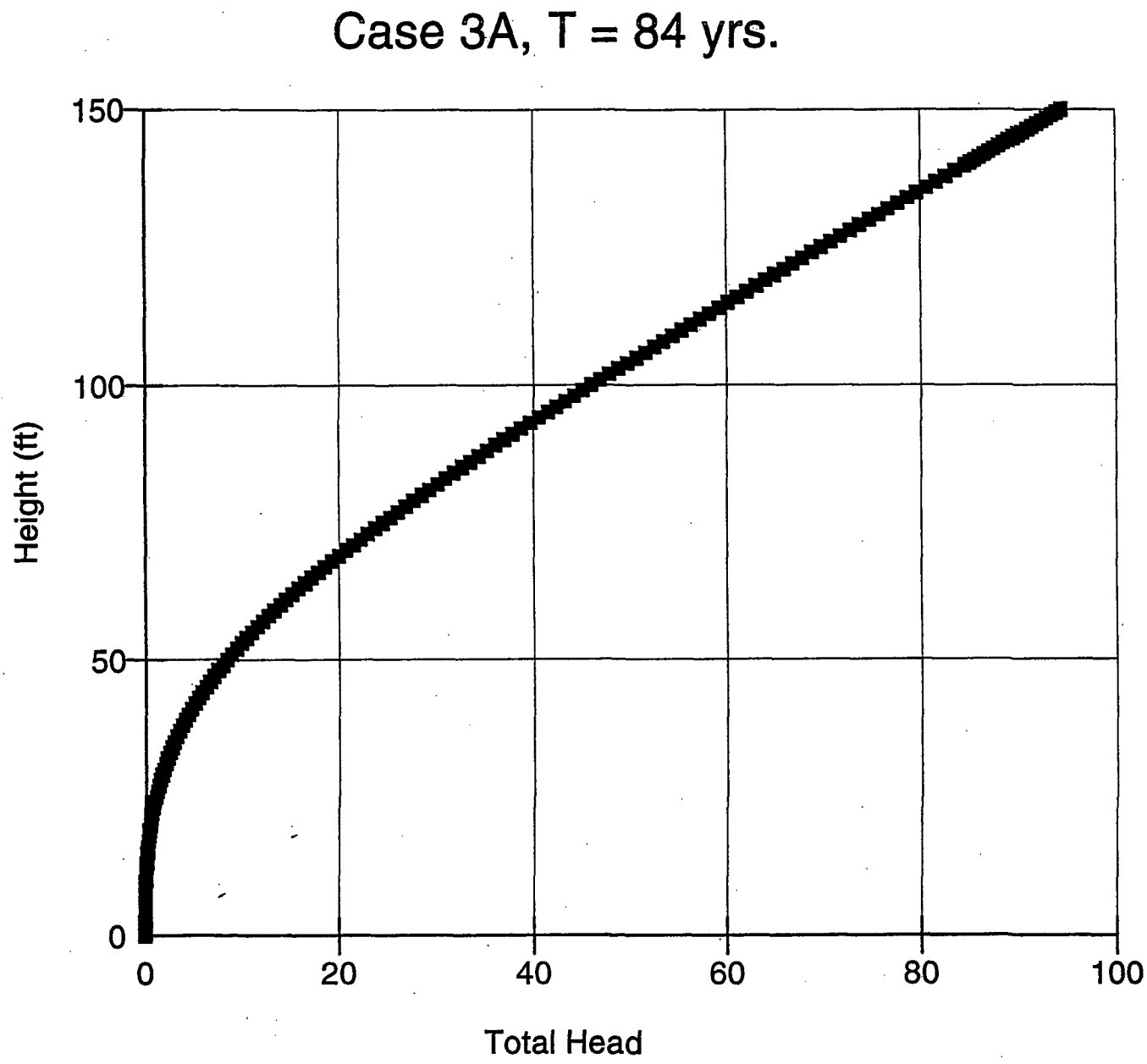

Case 1B, T = 84 yrs.
150
100
50
0
Height (ft)
0.1
0.2
0.3
0.4
0.5
Vol. Water Content

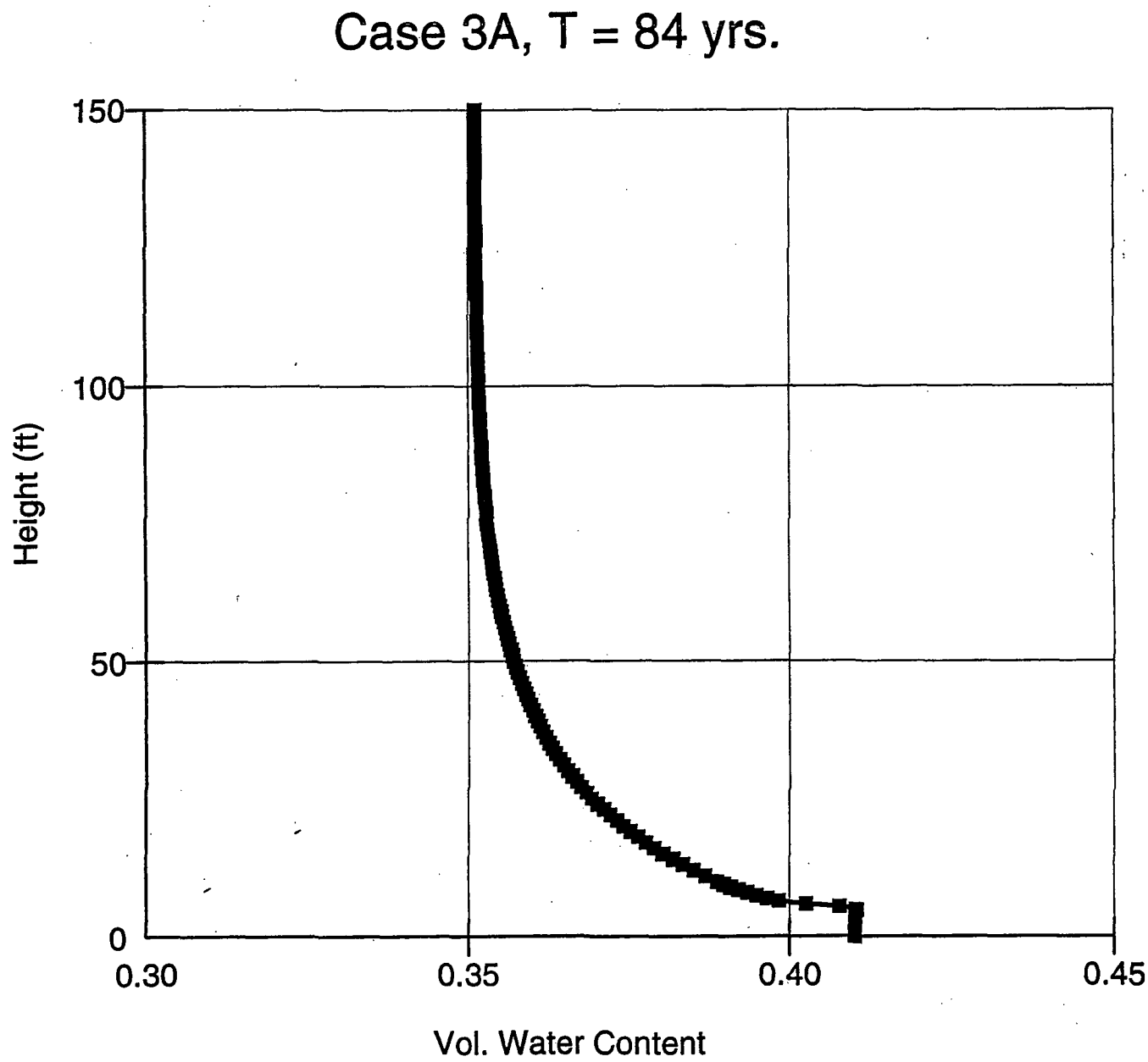

Case 2A, T = 84 yrs.
150
100
50
0
Height (ft)
0
50
100
150
Total Head

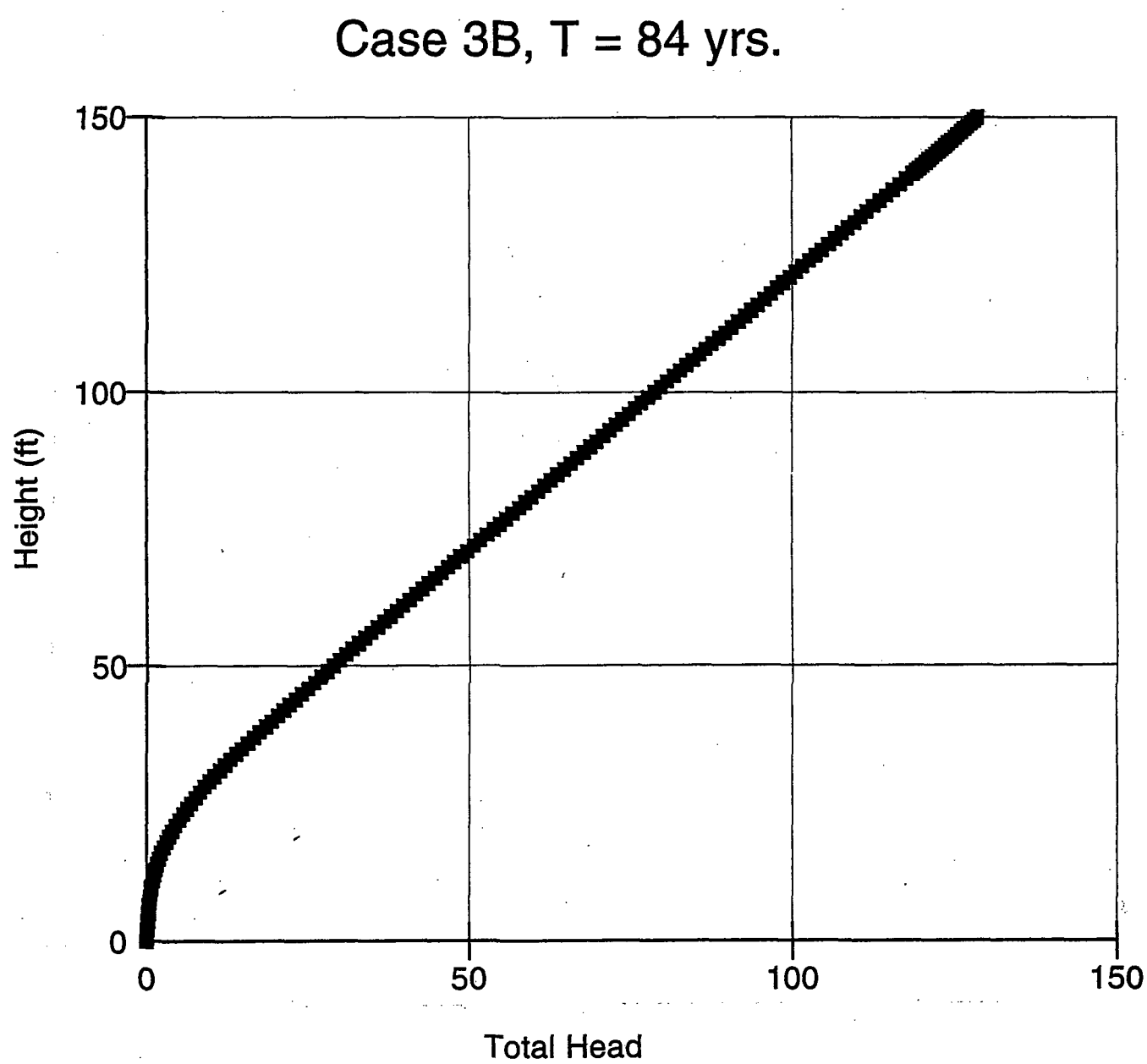

Case 2A, T = 84 yrs.
150
100
50
0
Height (ft)
0.1
0.2
0.3
0.4
0.5
Vol. Water Content


Case 2B, T = 84 yrs.
150
100
50
0
Height (ft)
0
50
100
150
Total Head


Case 2B, T = 84 yrs.
150
100
50
0
Height (ft)
0.1
0.2
0.3
0.4
0.5
Vol. Water Content


Case 3A, T = 84 yrs.
150
100
50
0
Height (ft)
0
20
40
60
80
100
Total Head


Case 3A, T = 84 yrs.
150
100
50
0
Height (ft)
0.30
0.35
0.40
0.45
Vol. Water Content


Case 3B, T = 84 yrs.
150
100
50
0
Height (ft)
0
50
100
150
Total Head

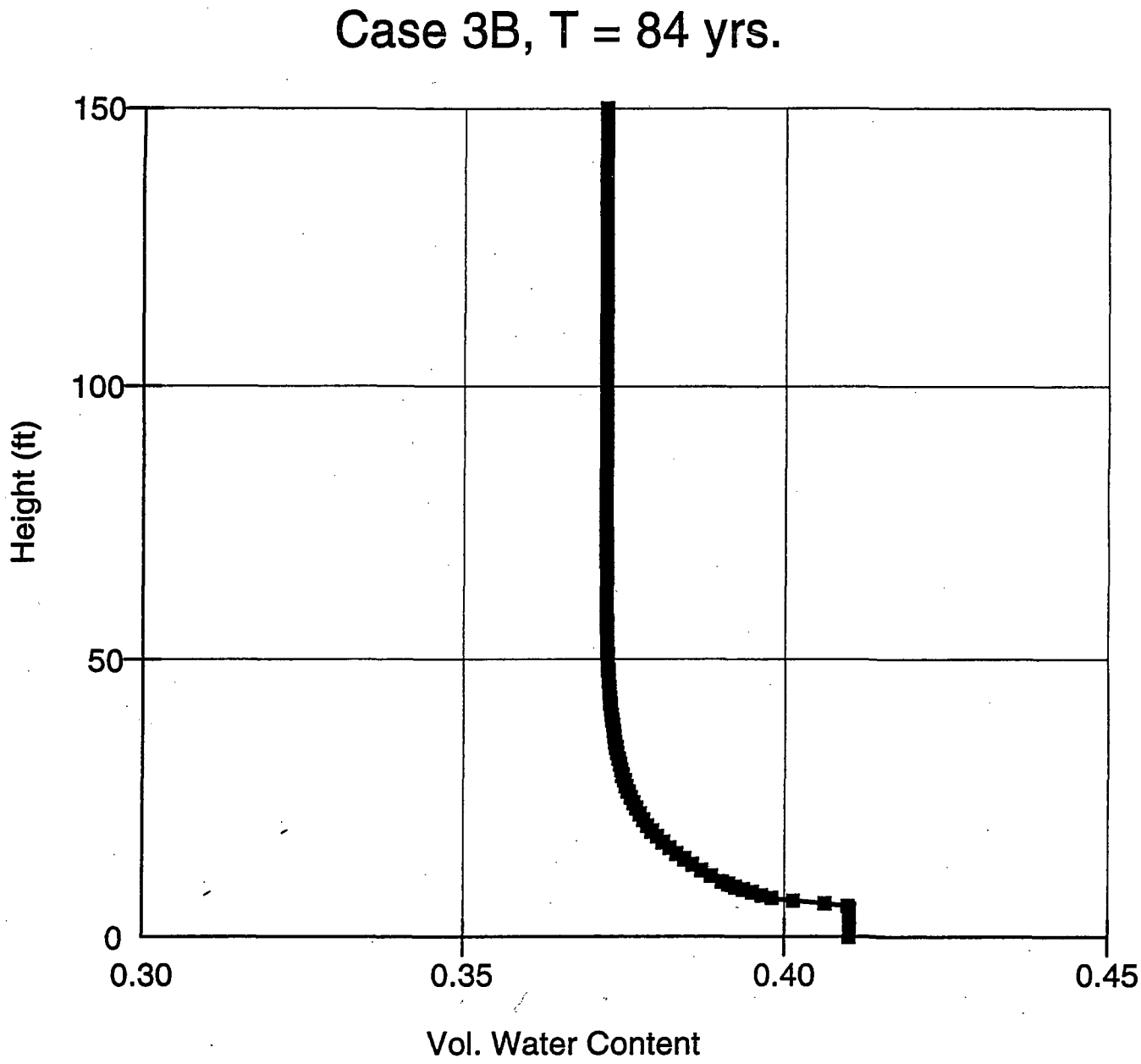

Case 3B, T = 84 yrs.
150
100
50
0
Height (ft)
0.30
0.35
0.40
0.45
Vol. Water Content

Table E1.
List of Figures Summarizing Cover Performance Analysis

Run	Description	Flux plot	Head plot	Figure No.
quest 1_84b	9" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E1
quest 1_93a	9" alluvial cover on sandy tailings - 1993 w/ short growing season	x		Figure E2
quest 1_93b	9" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E3a & 3b
quest 1_93c	9" alluvial cover on sandy tailings - 1993 w/ long growing season	x		Figure E4
quest 2_84b	9" alluvial cover on fine tailings - 1984 w/ intermediate growing season	x	x	Figure E5a & 5b
quest 2_93a	9" alluvial cover on fine tailings - 1993 w/ short growing season	x		Figure E6
quest 2_93b	9" alluvial cover on fine tailings - 1993 w/ intermediate growing season	x	x	Figure E7a & 7b
quest 2_93c	9" alluvial cover on fine tailings - 1993 w/ long growing season	x		Figure E8
quest 3_84b	18" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E9
quest 3_93b	18" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E10a & 10b
quest 4_84b	36" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E11
quest 4_93b	36" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E12a & 12b
quest 5_84b	18" alluvium plus 6" silt on sandy tailings - 1984 w/ intermediate growing season	x		Figure E13
quest 5_93b	18" alluvium plus 6" silt on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E14a & 14b
sens 1a	9" alluvial cover on sandy tailings - Drainable porosity = 30%	x		Figure E15
sens 1b	18" alluvial cover on sandy tailings - Drainable porosity = 30%	x		Figure E16
sens 2a	9" alluvial cover on sandy tailings - K_cover = 3*10-5 cm/s	x		Figure E17
sens 2b	18" alluvial cover on sandy tailings - K_cover = 3*10-5 cm/s	x		Figure E18
sens 3a	9" alluvial cover on sandy tailings - K_sandy tails = 1*10-4 cm/s	x		Figure E19
sens 3b	18" alluvial cover on sandy tailings - K_sandy tails = 1*10-4 cm/s	x		Figure E20
sens 4a	9" alluvial cover on sandy tailings - wet soil profile (WT at 6.8 m bgs)	x	x	Figure E21a & 21b
sens 4b	18" alluvial cover on sandy tailings - wet soil profile (WT at 6.8 m bgs)	x	x	Figure E22a & 22b
sens 5a	18" alluvial cover on sandy tailings - root zone depth = 0.5 m	x	x	Figure E23a & 23b
sens 5b	18" alluvial cover on sandy tailings - root zone depth = 1.0 m	x	x	Figure E24a & 24b
sens 5c	18" alluvial cover on sandy tailings - root zone depth = 1.5 m	x	x	Figure E25a & 25b
sens 5d	18" alluvial cover on sandy tailings - root zone depth = 2.5 m	x	x	Figure E26a & 26b

Appendix E

APPENDIX E

Summary Plots of Cover Modeling

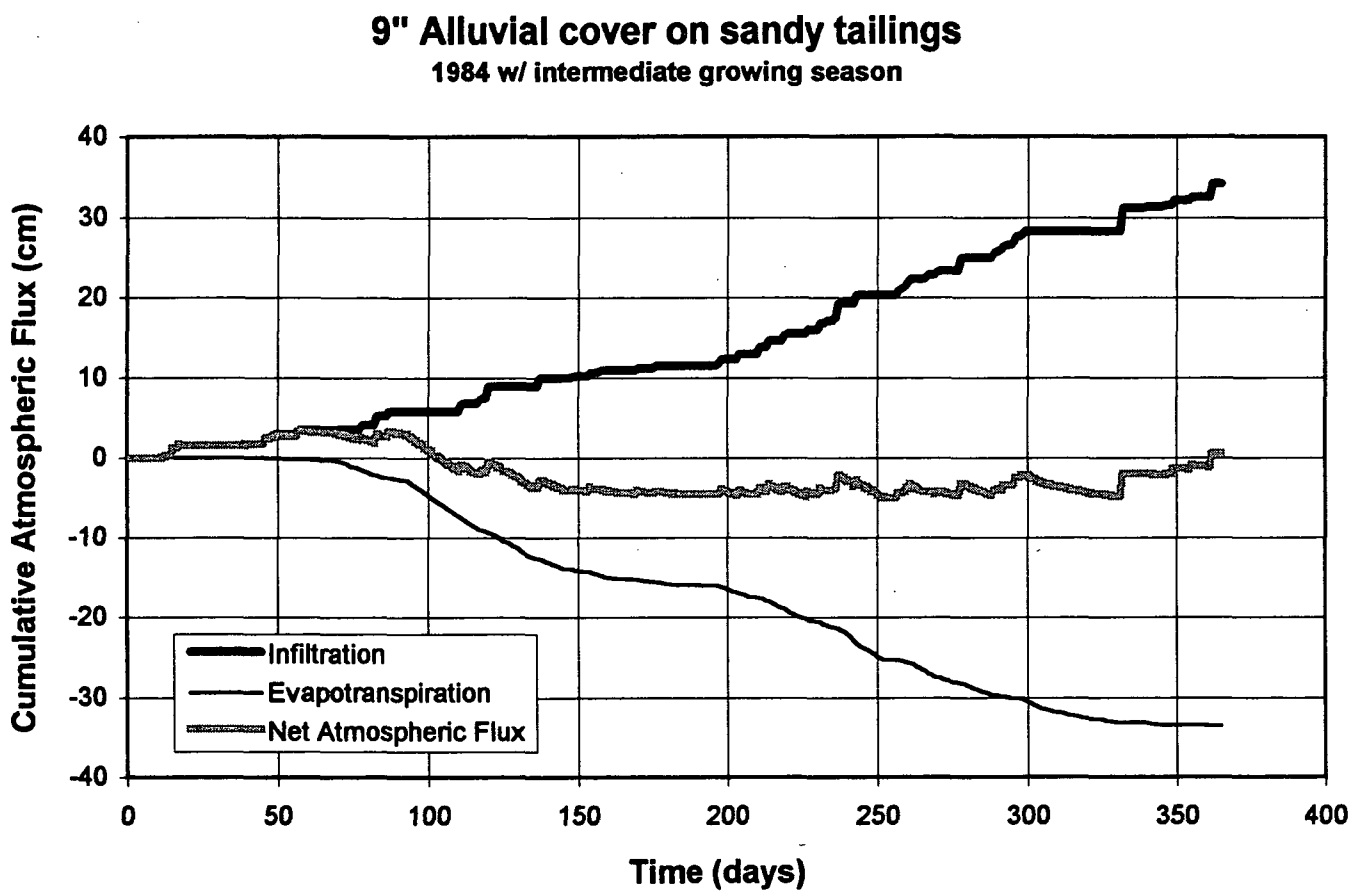


Figure E1.
Simulated Atmospheric Fluxes for Scenario "quest1_84b"

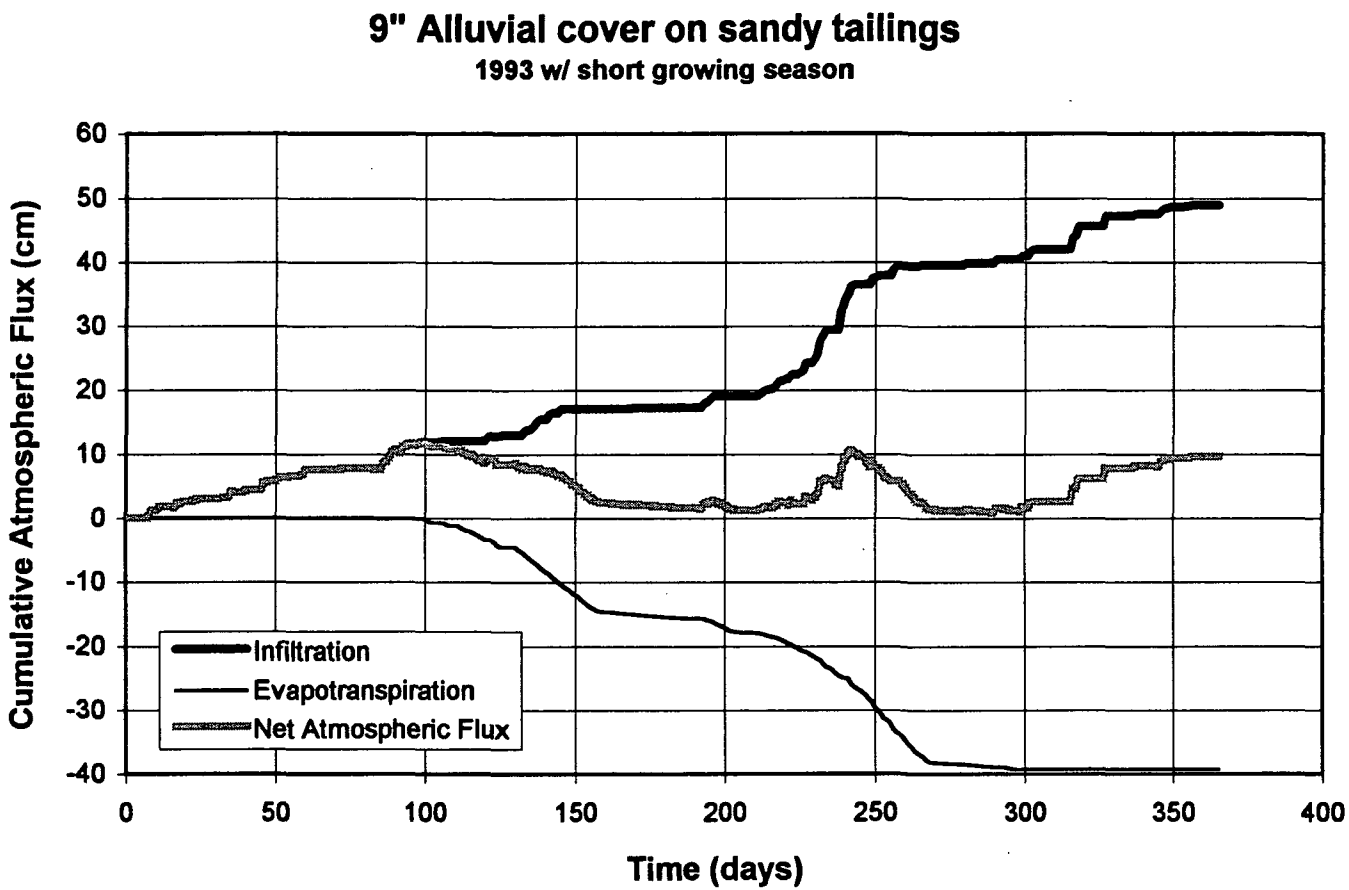


Figure E2.
Simulated Atmospheric Fluxes for Scenario "quest1_93a"

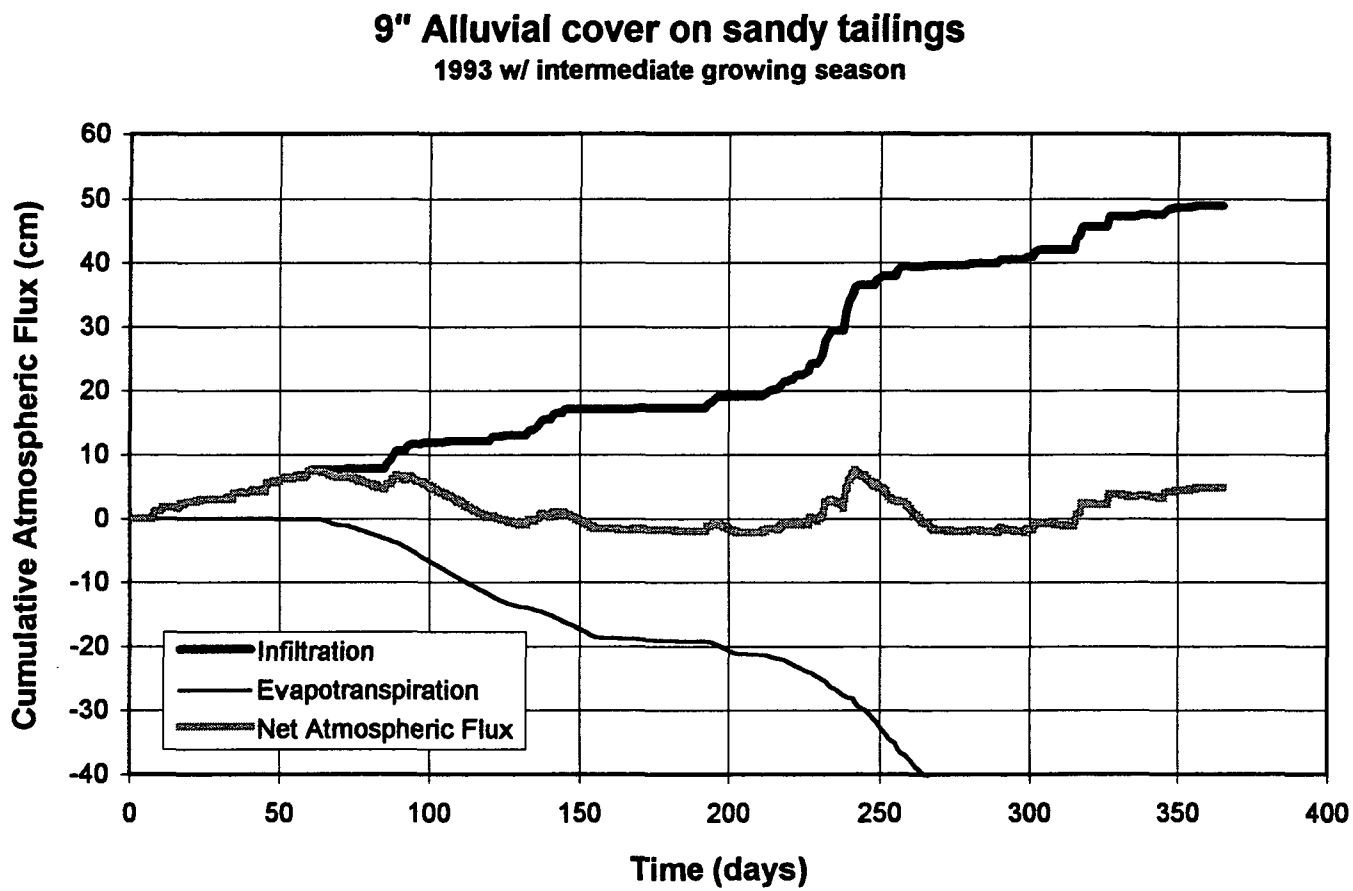


Figure E3a.
Simulated Atmospheric Fluxes for Scenario "quest1_93b"

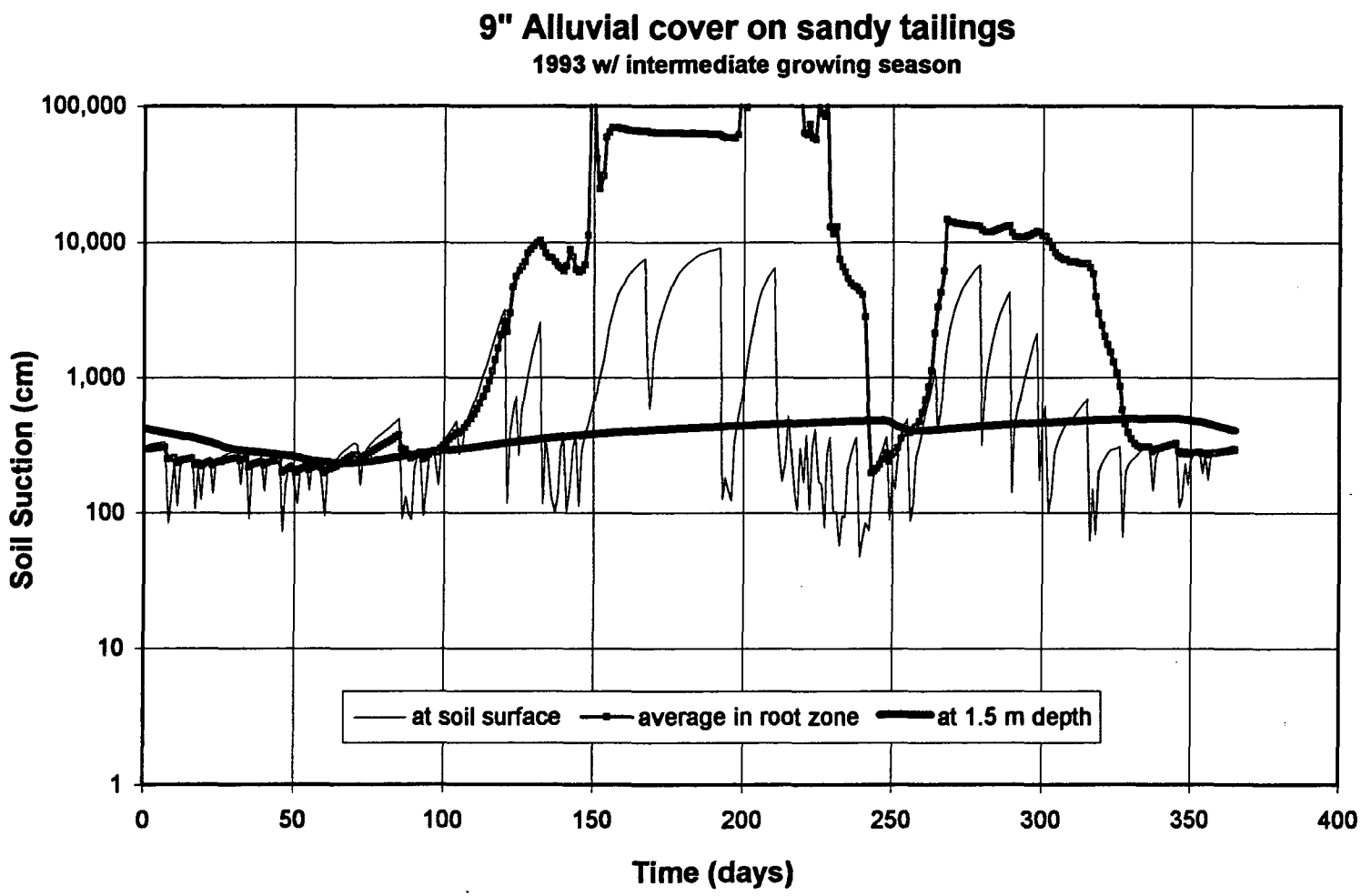


Figure E3b.
Simulated Soil Suction for Scenario "quest_93b"

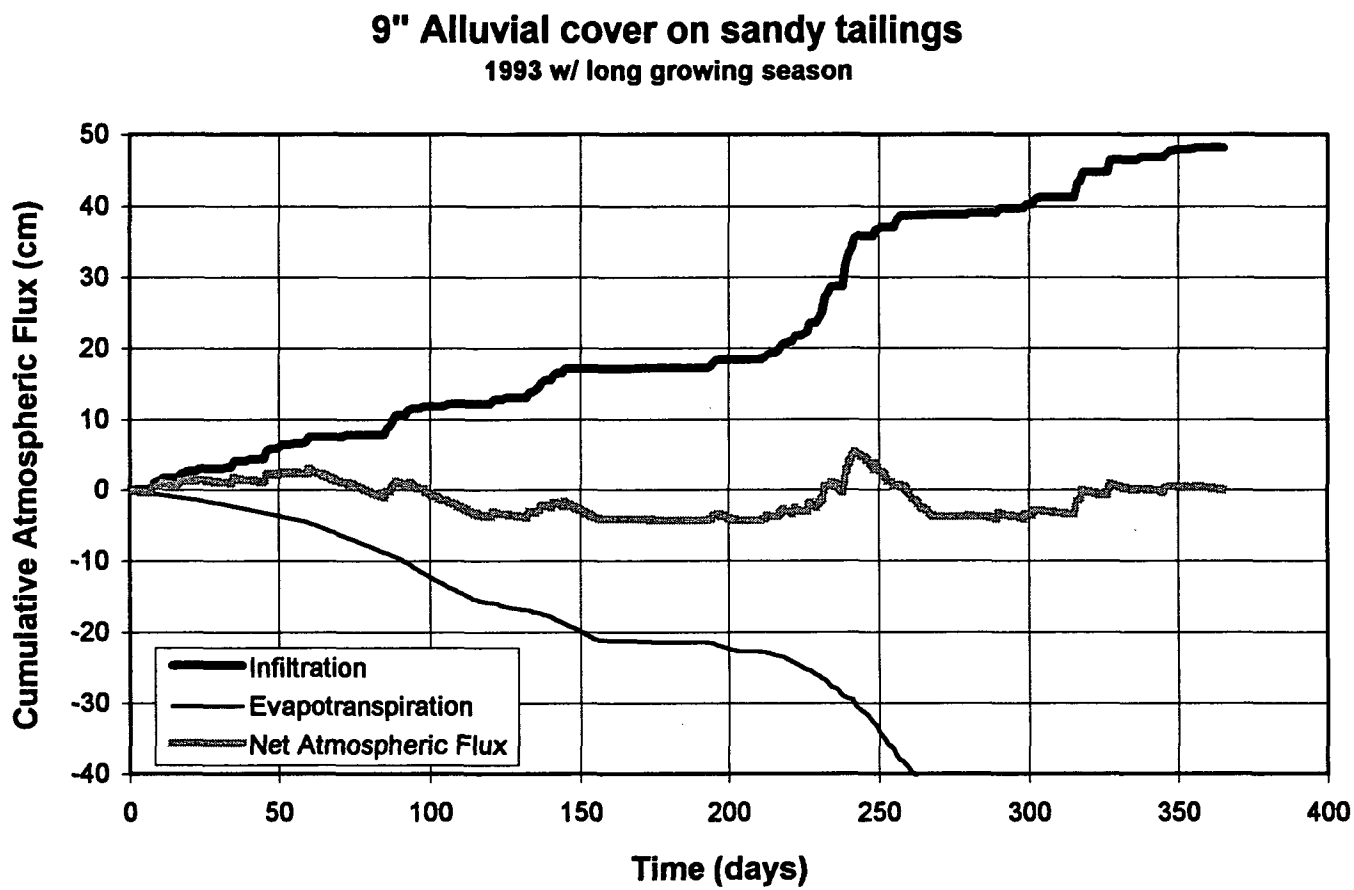


Figure E4.
Simulated Atmospheric Fluxes for Scenario "quest1_93c"

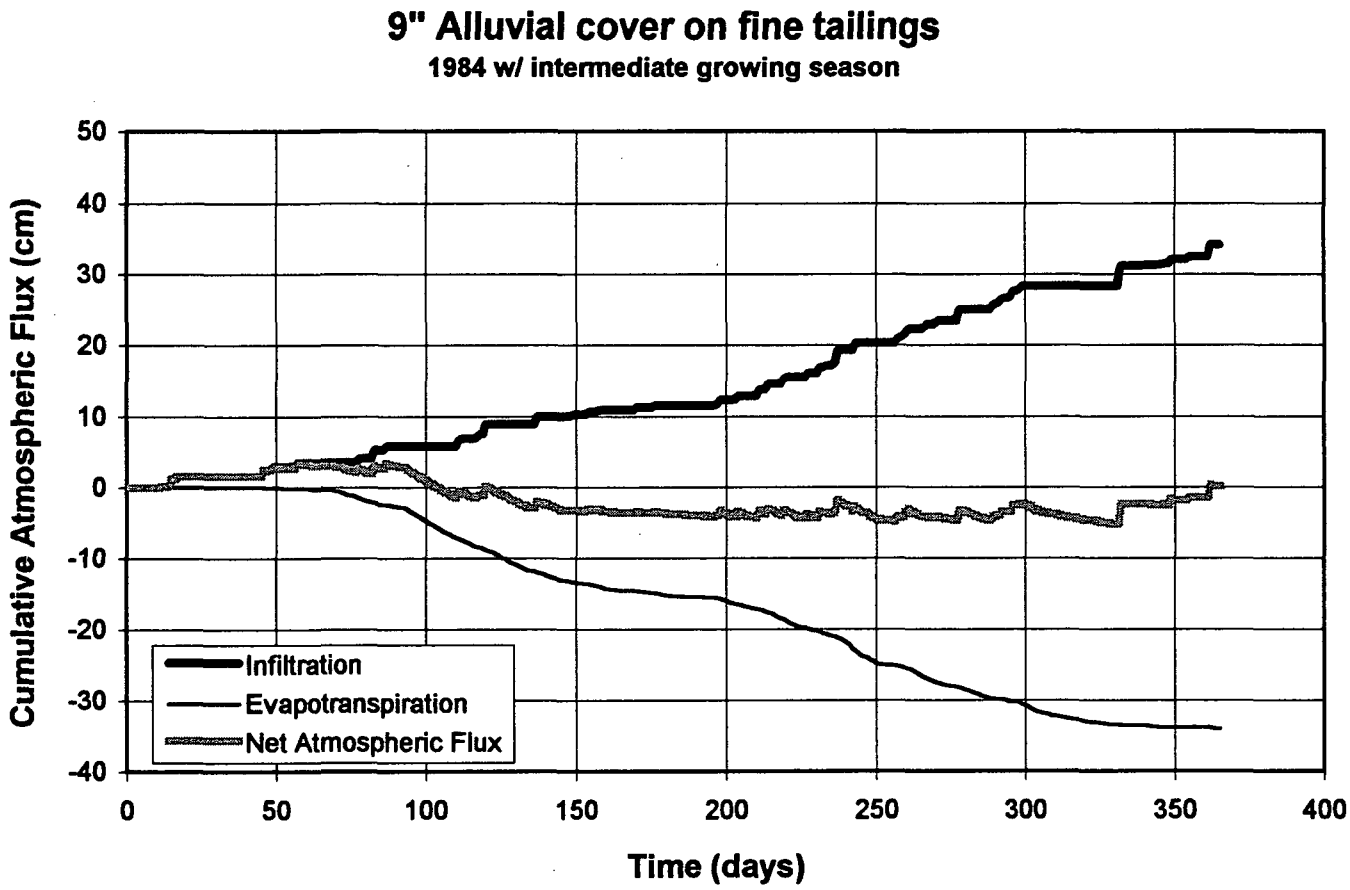


Figure E5a.
Simulated Atmospheric Fluxes for Scenario "quest2_84b"

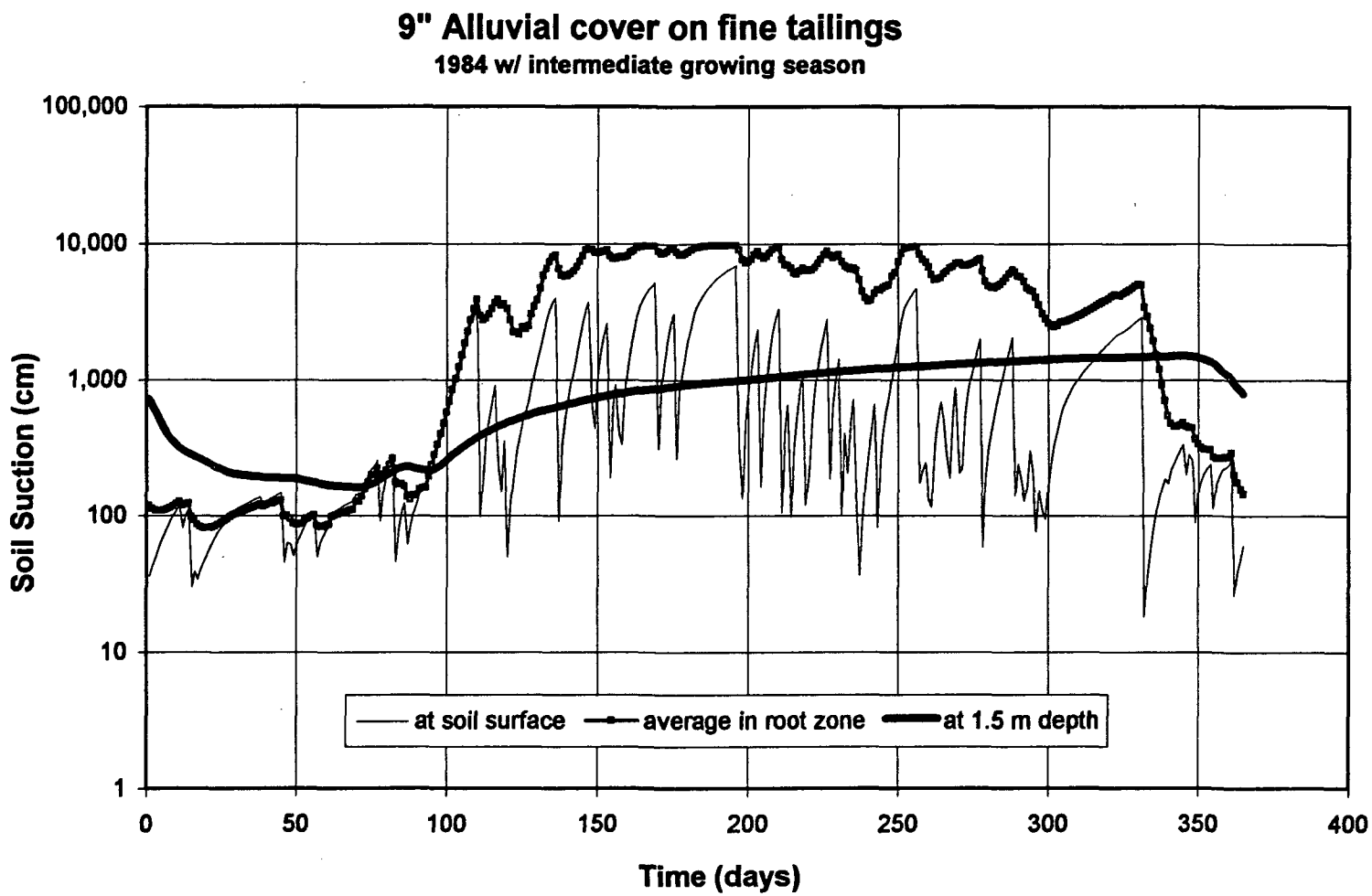


Figure E5b.
Simulated Soil Suction for Scenario "quest2_84b"

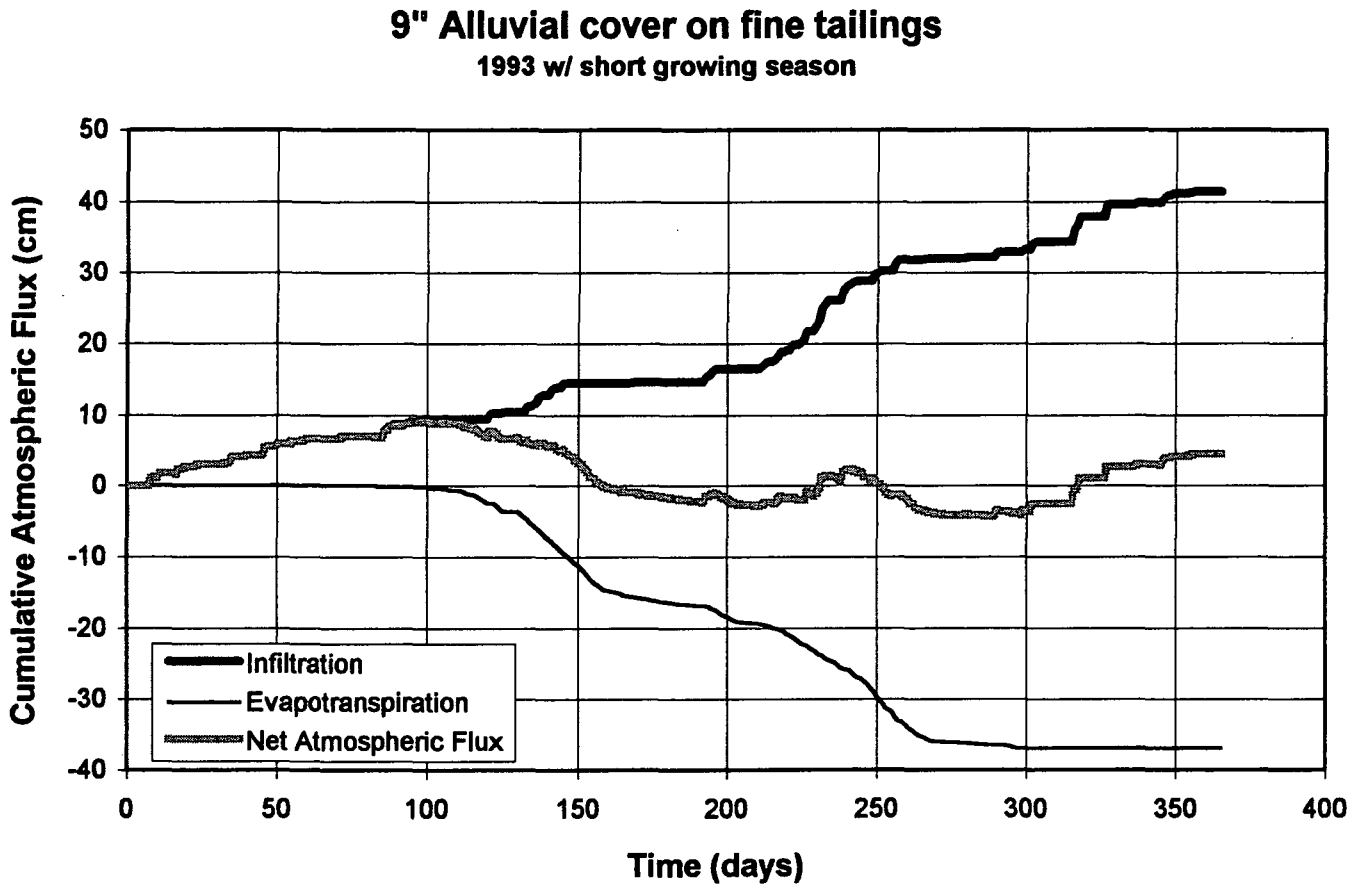


Figure E6.
Simulated Atmospheric Fluxes for Scenario "quest2_93a"

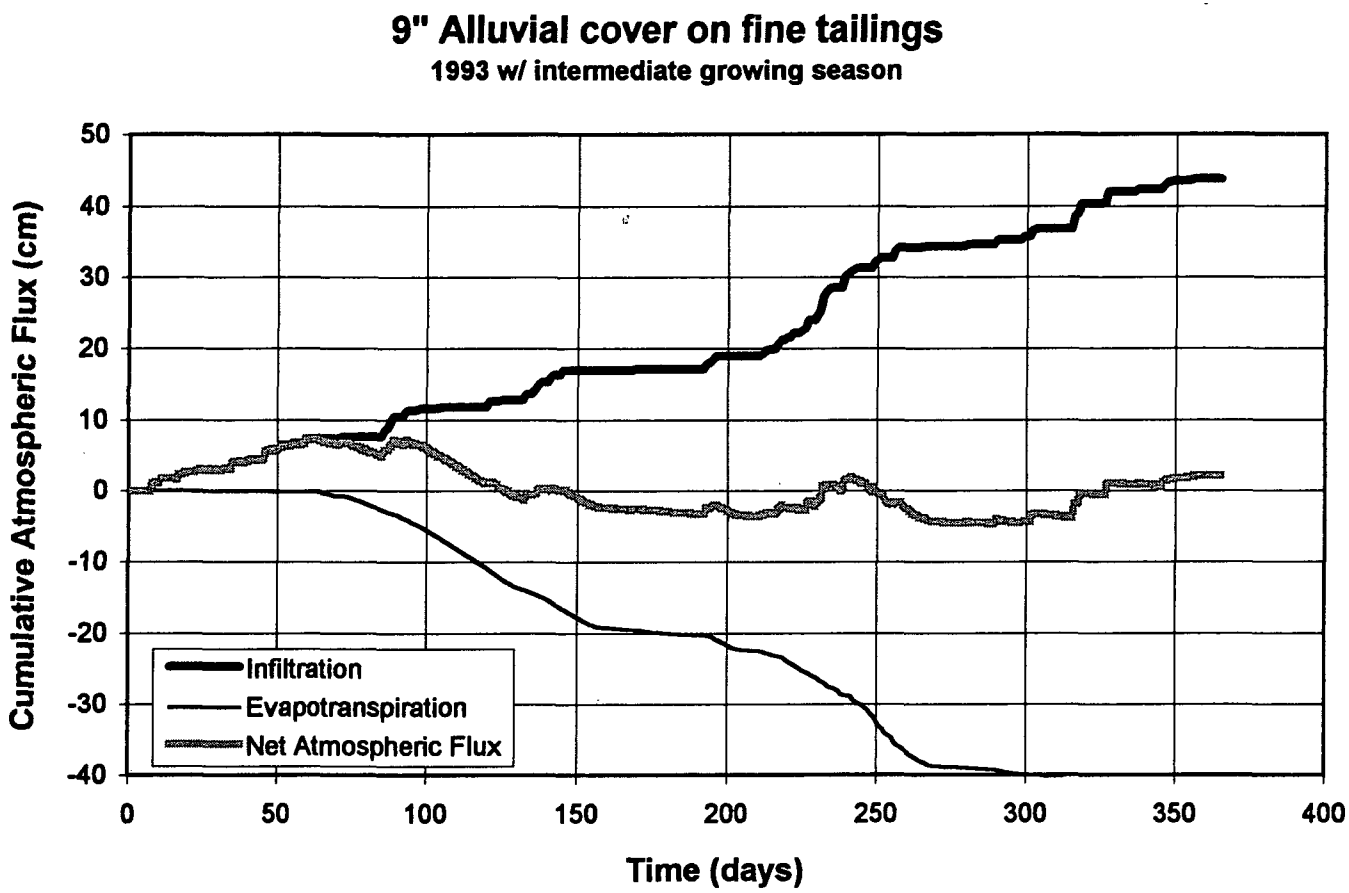


Figure E7a.
Simulated Atmospheric Fluxes for Scenario "quest2_93b"

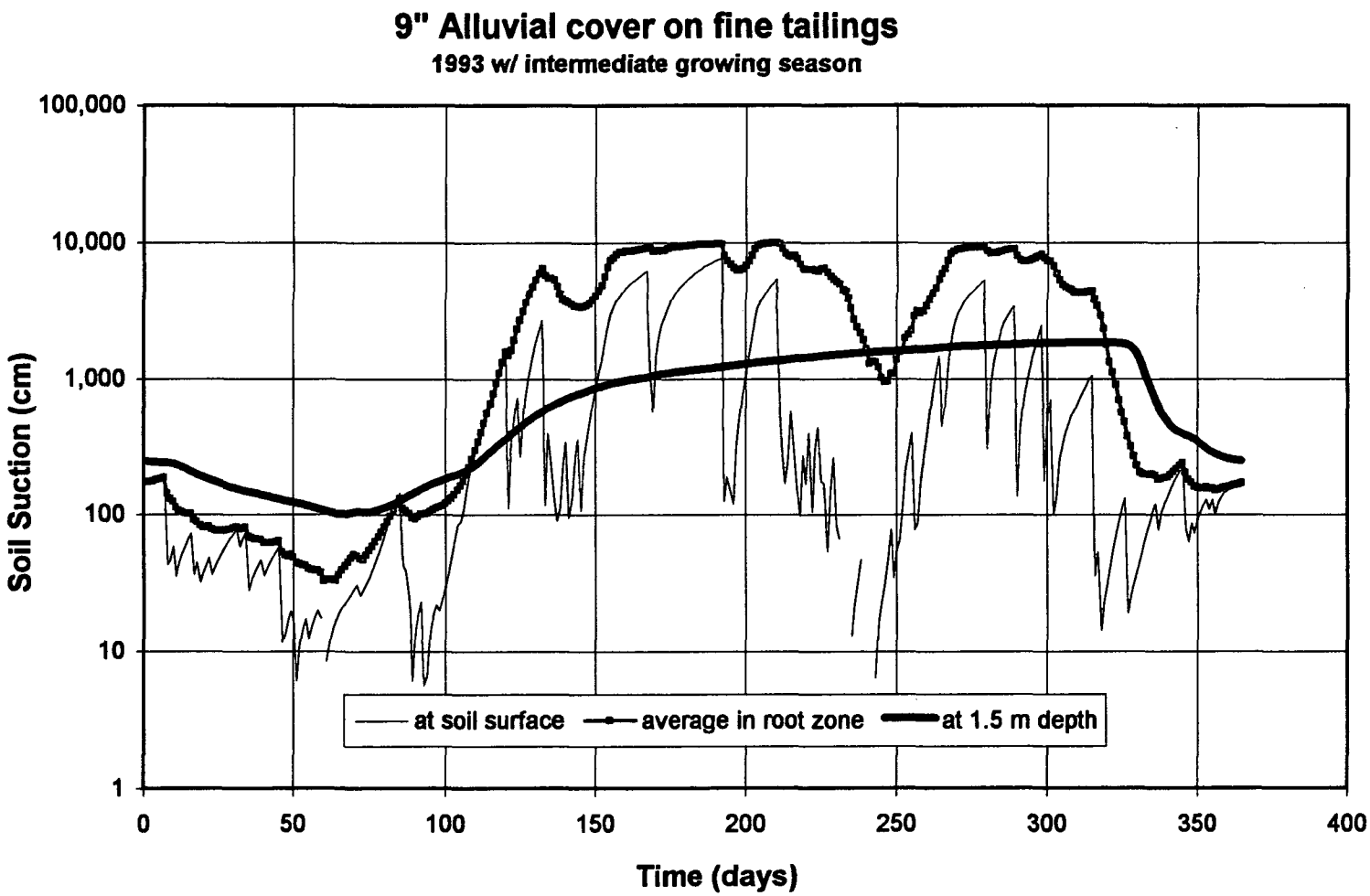


Figure E7b.
Simulated Soil Suction for Scenario "quest2_93b"

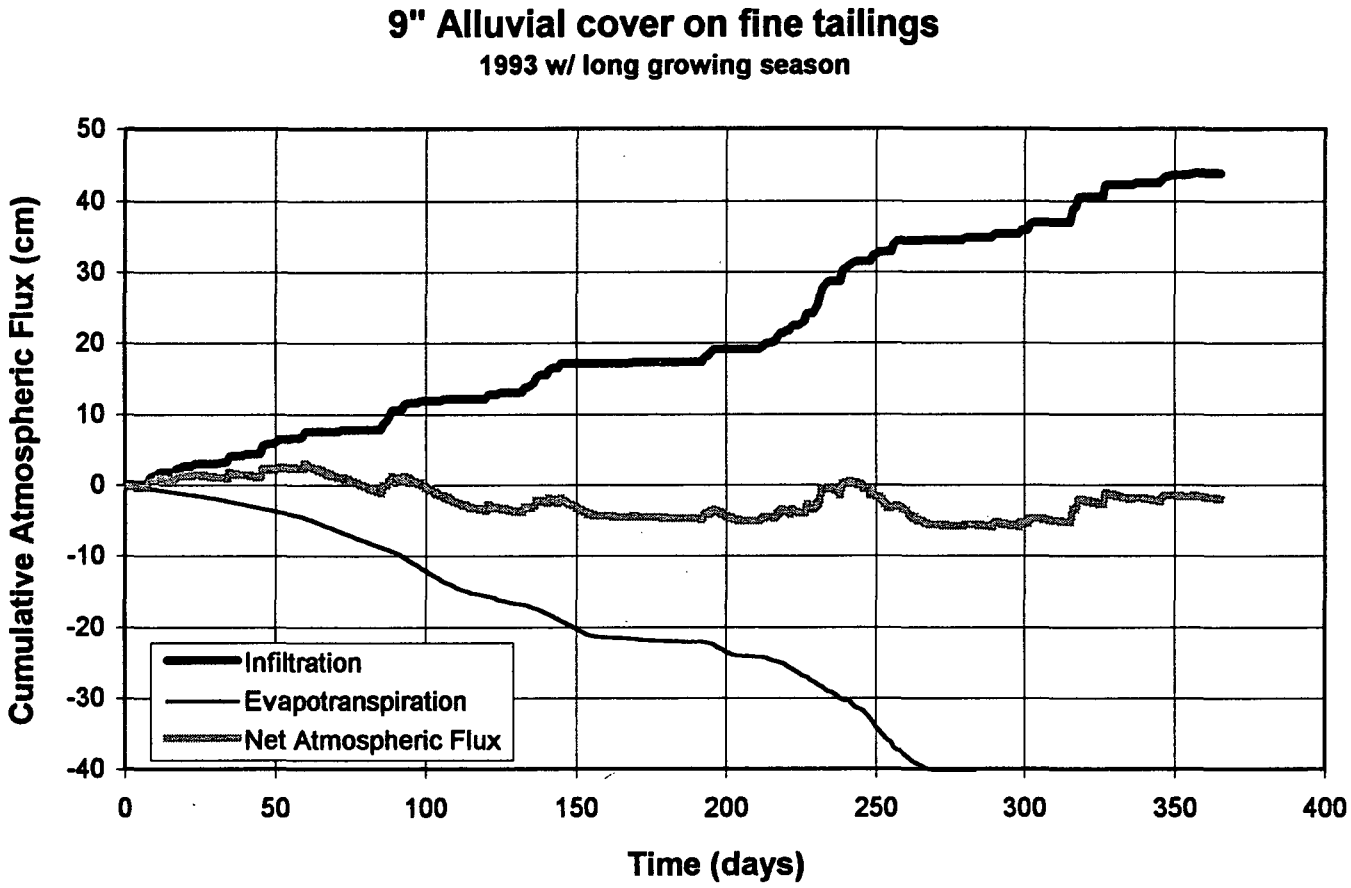


Figure E8.
Simulated Atmospheric Fluxes for Scenario "quest2_93c"

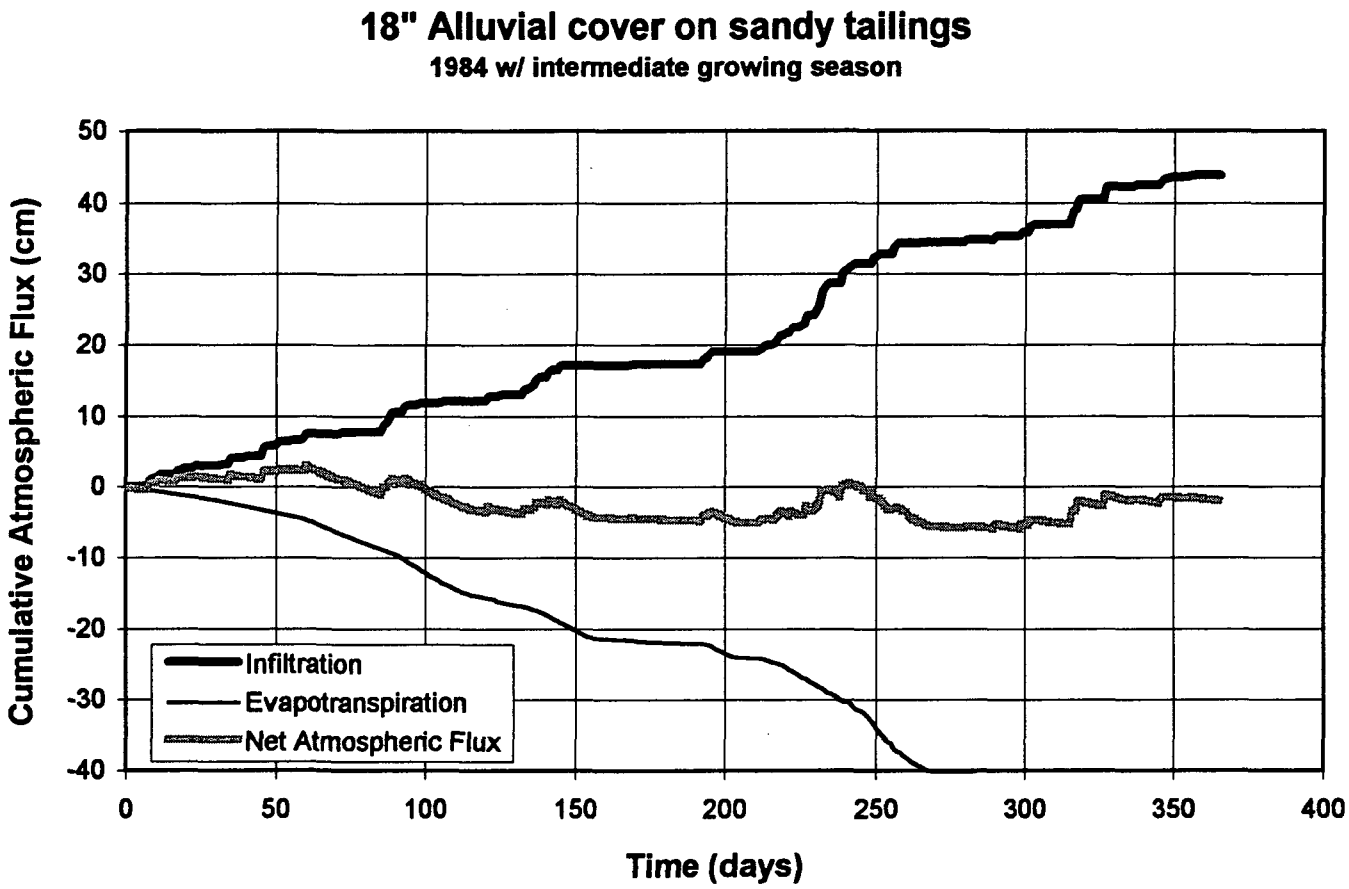


Figure E9.
Simulated Atmospheric Fluxes for Scenario "quest3_84b"

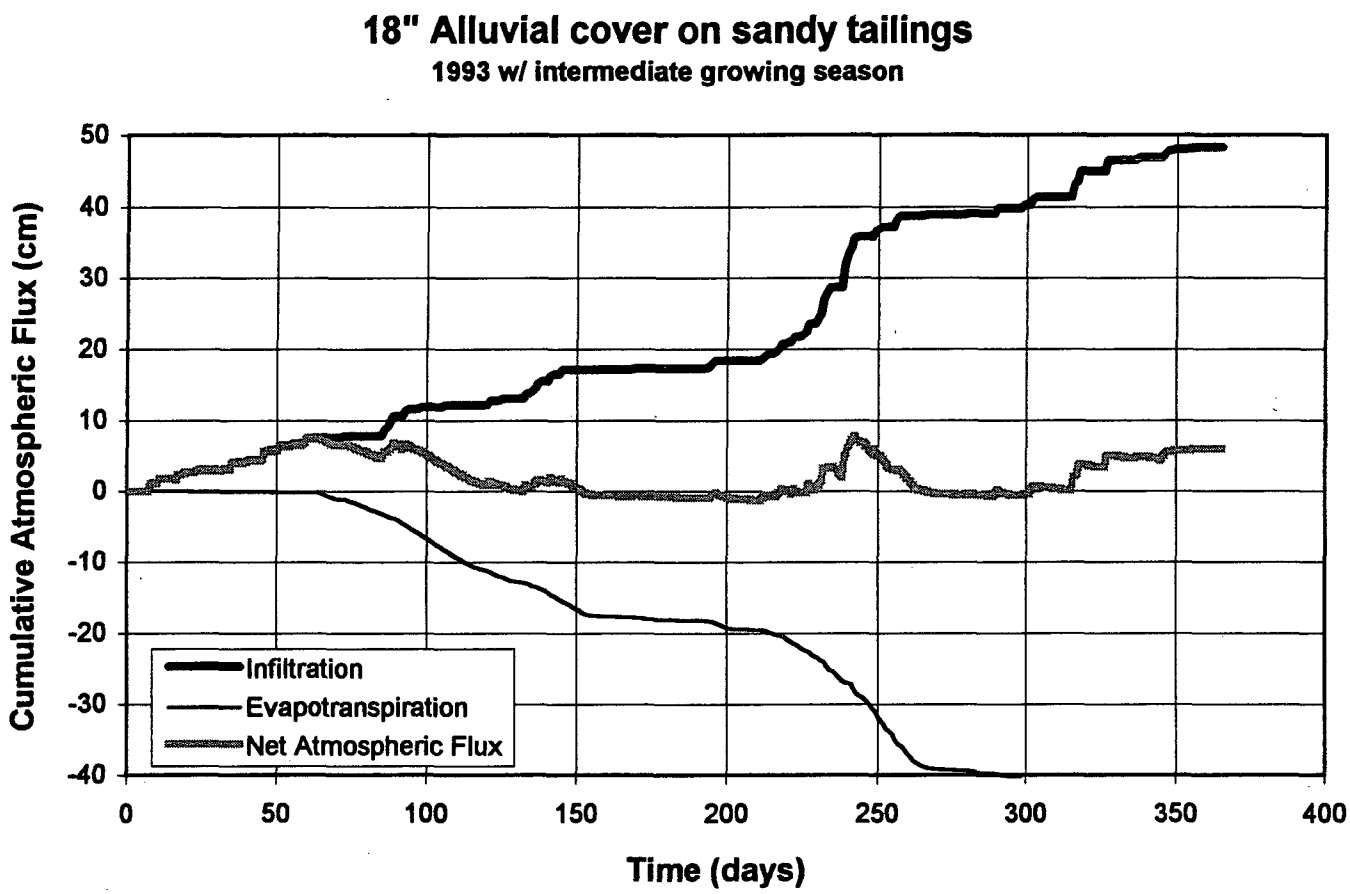


Figure E10a.
Simulated Atmospheric Fluxes for Scenario "quest3_93b"

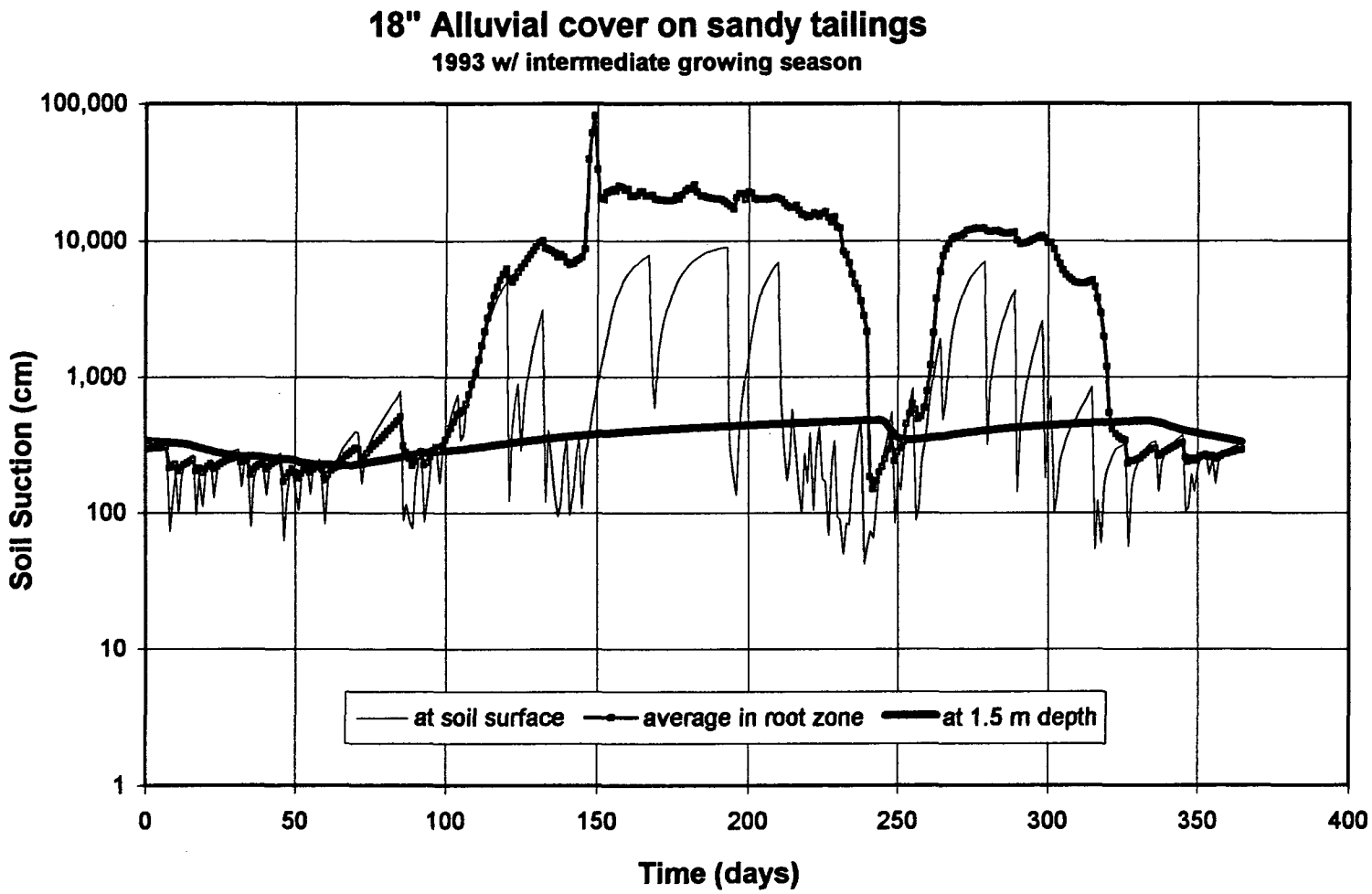


Figure E10b.
Simulated Soil Suction for Scenario "quest3_93b"

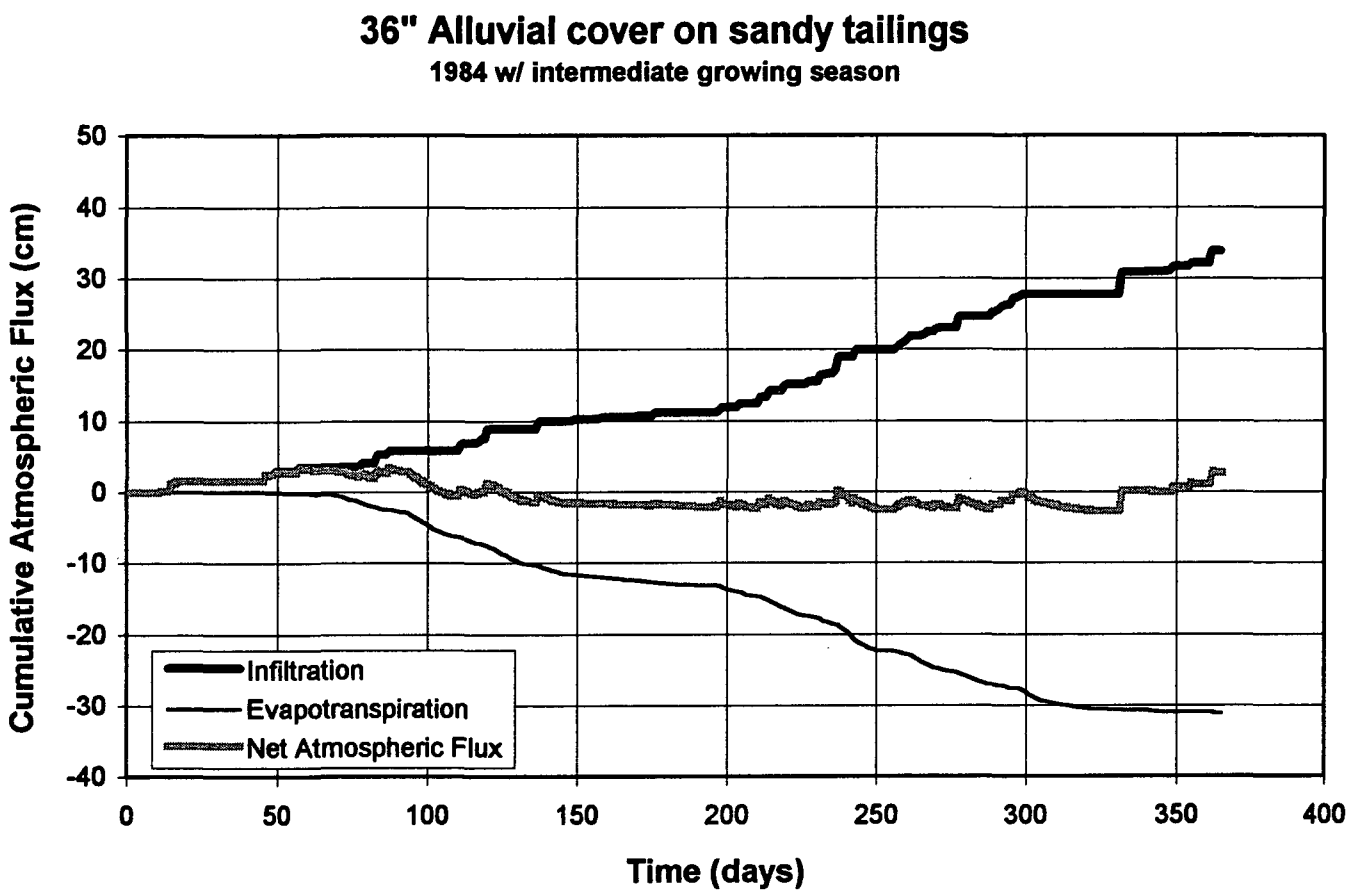


Figure E11.
Simulated Atmospheric Fluxes for Scenario "quest4_84b"

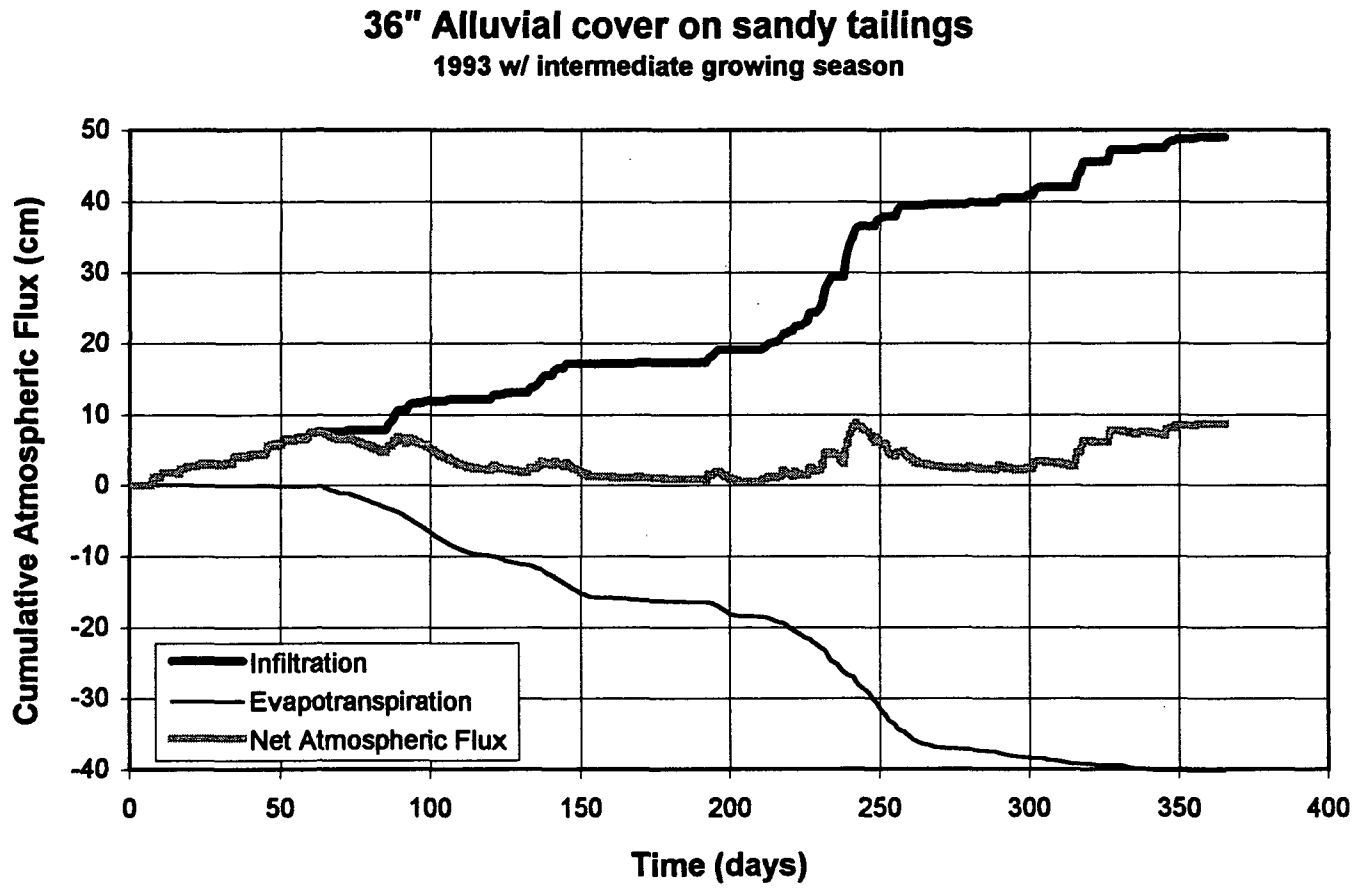


Figure E12a.
Simulated Atmospheric Fluxes for Scenario "quest4_93b"

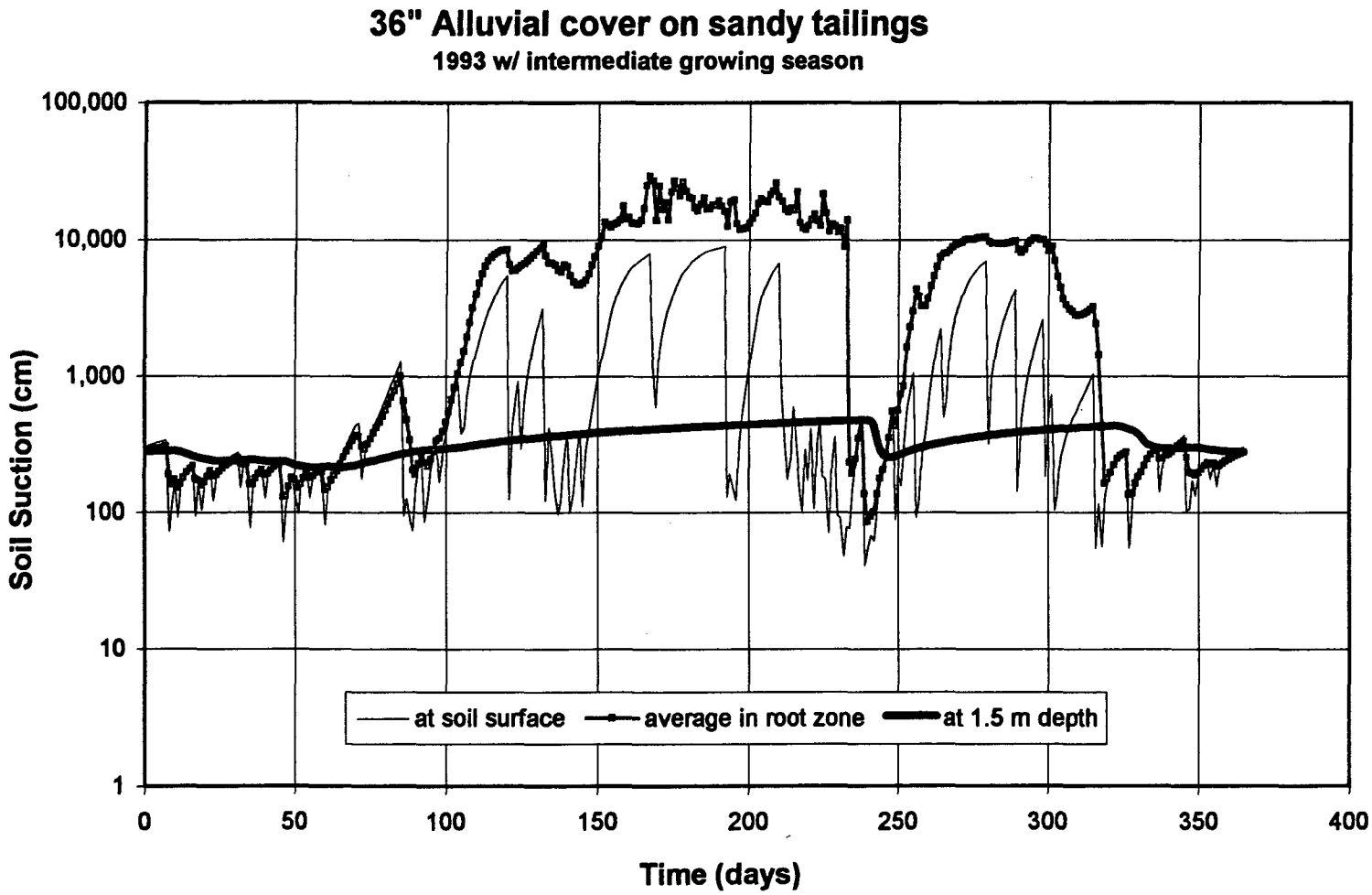


Figure E12b.
Simulated Soil Suction for Scenario "quest4_93b"

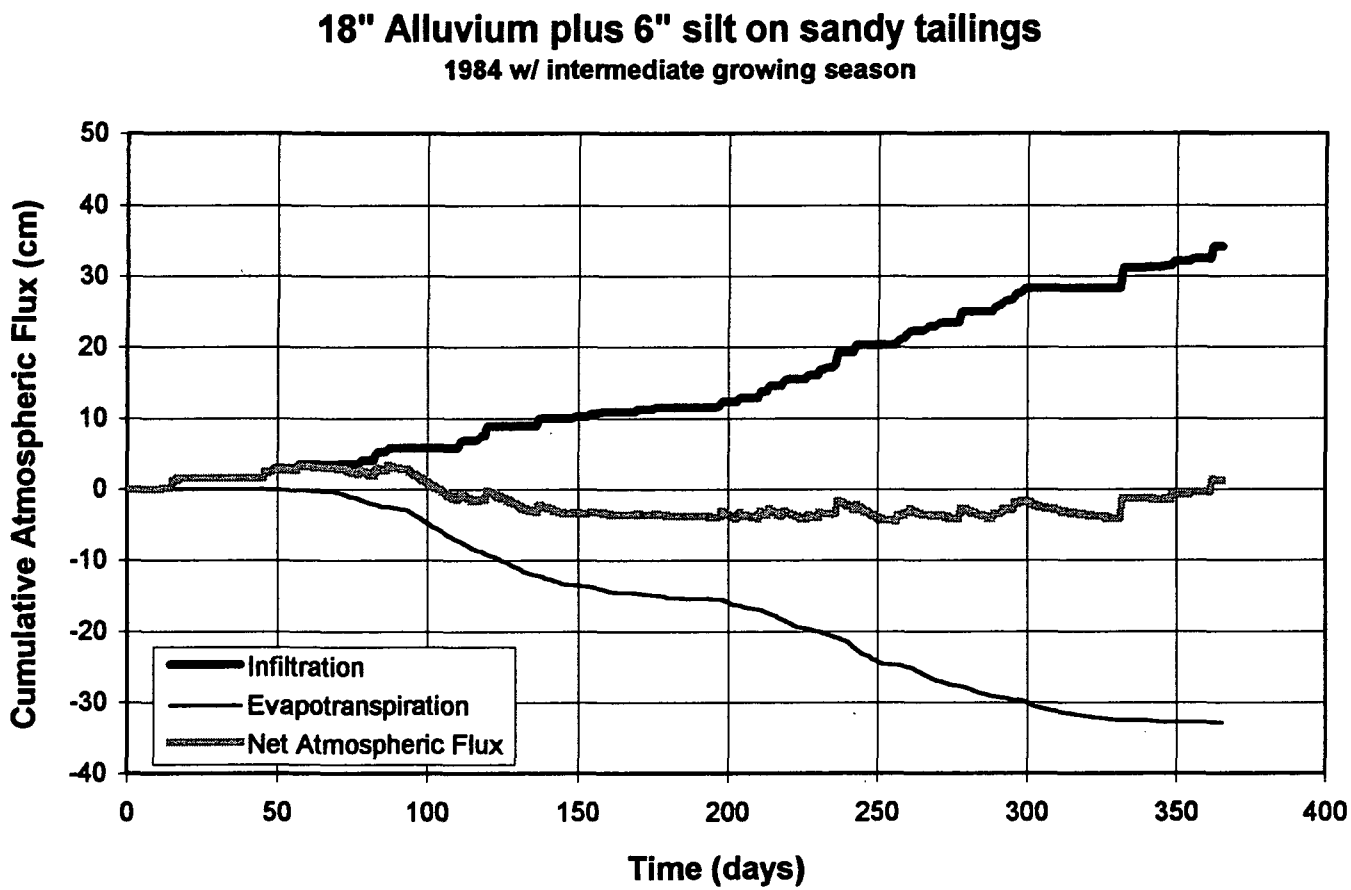


Figure E13.
Simulated Atmospheric Fluxes for Scenario "quest5_84b"

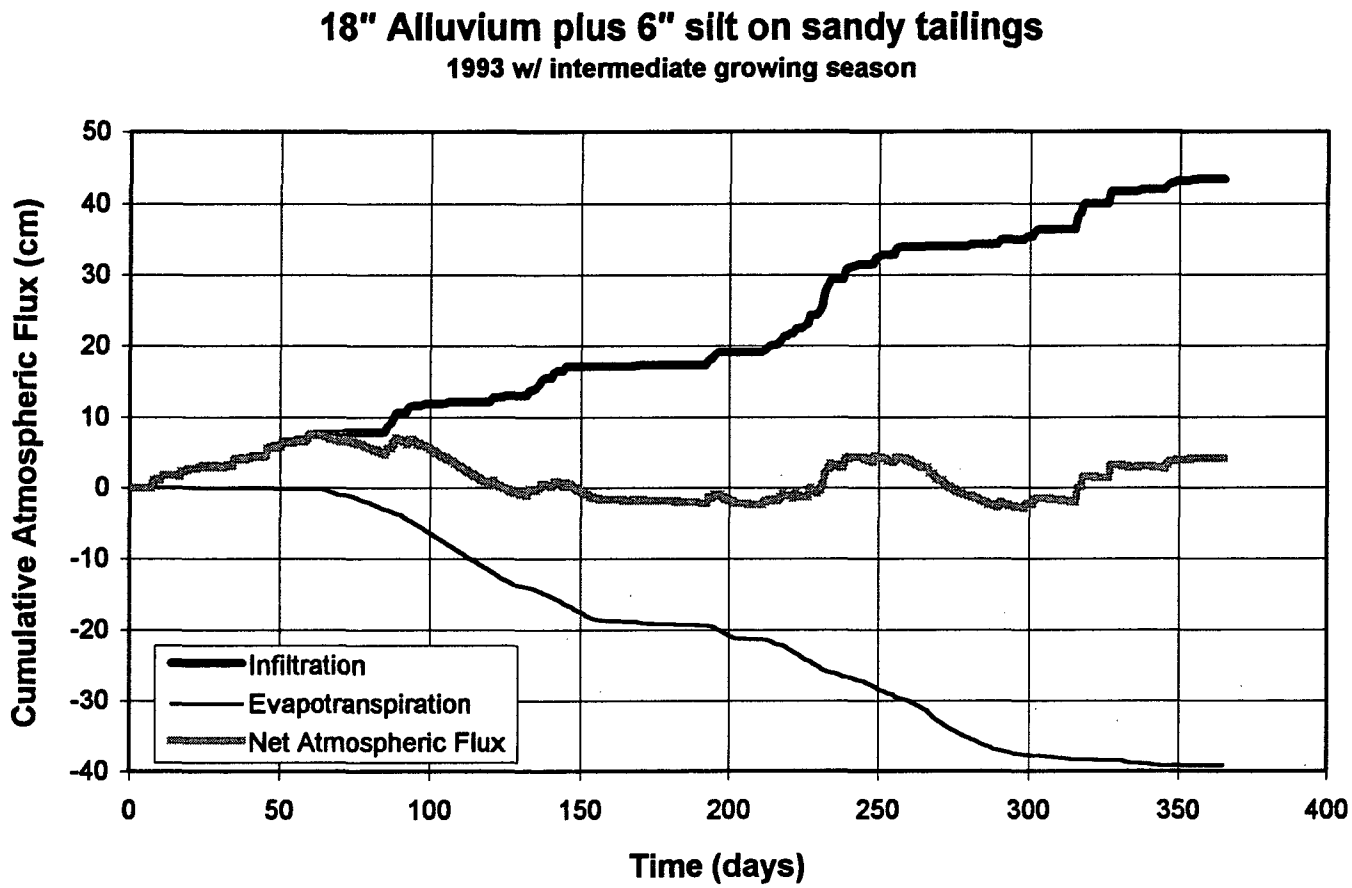


Figure E14a.
Simulated Atmospheric Fluxes for Scenario "quest5_93b"

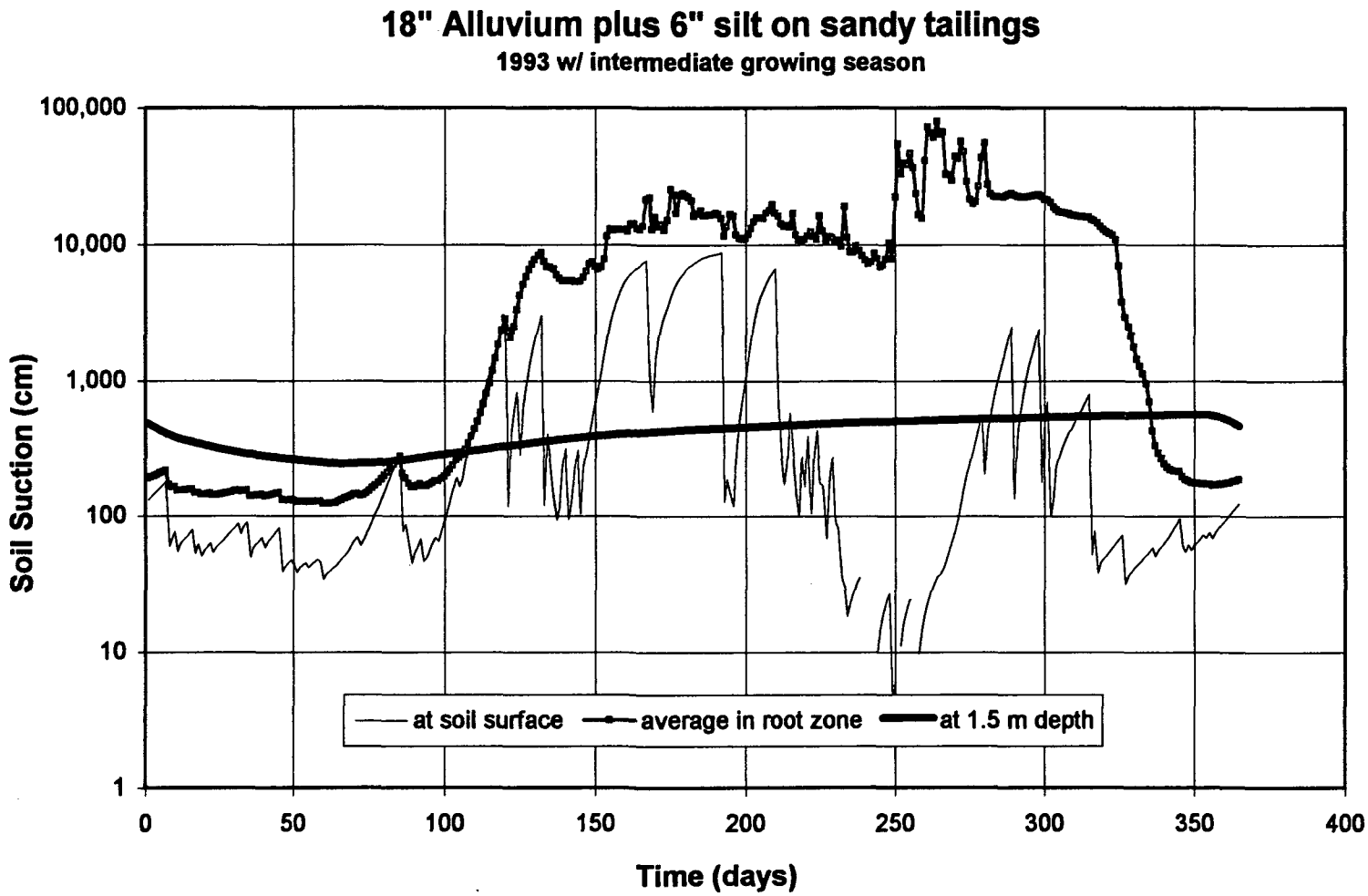


Figure E14b.
Simulated Soil Suction for Scenario "quest5_93b"

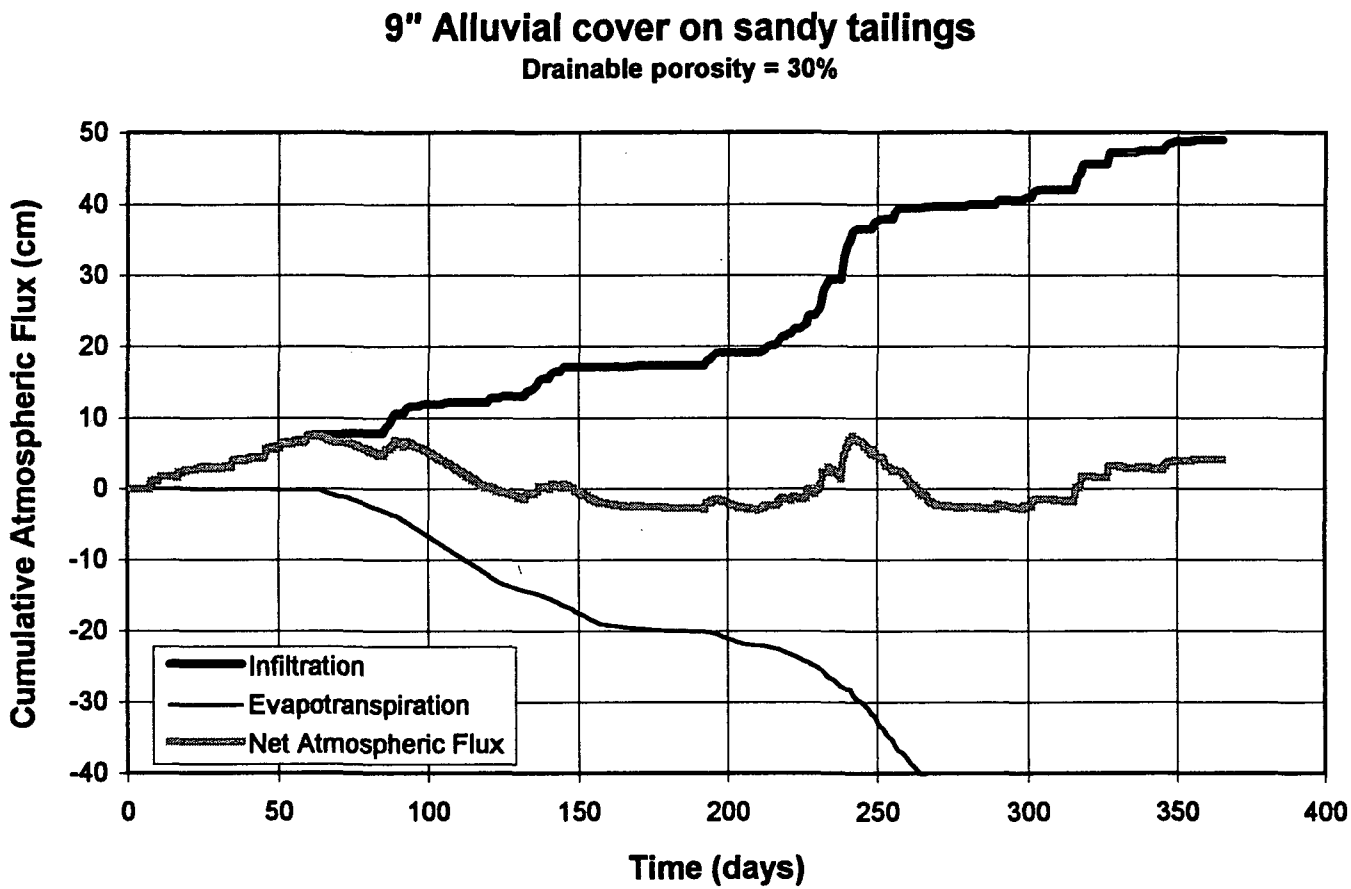


Figure E15.
Simulated Atmospheric Fluxes for Scenario "sens 1a"

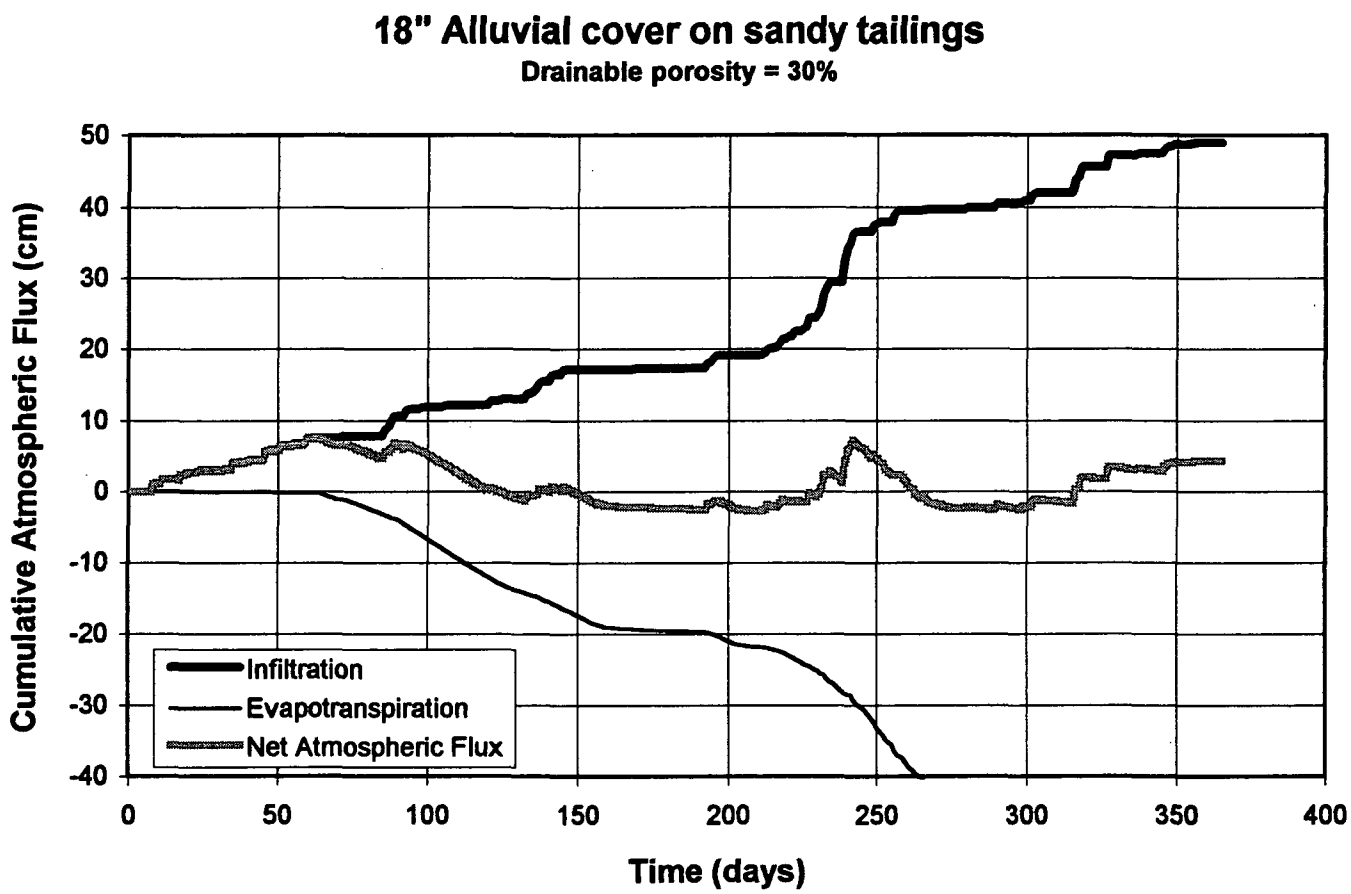


Figure E16.
Simulated Atmospheric Fluxes for Scenario "sens 1b"

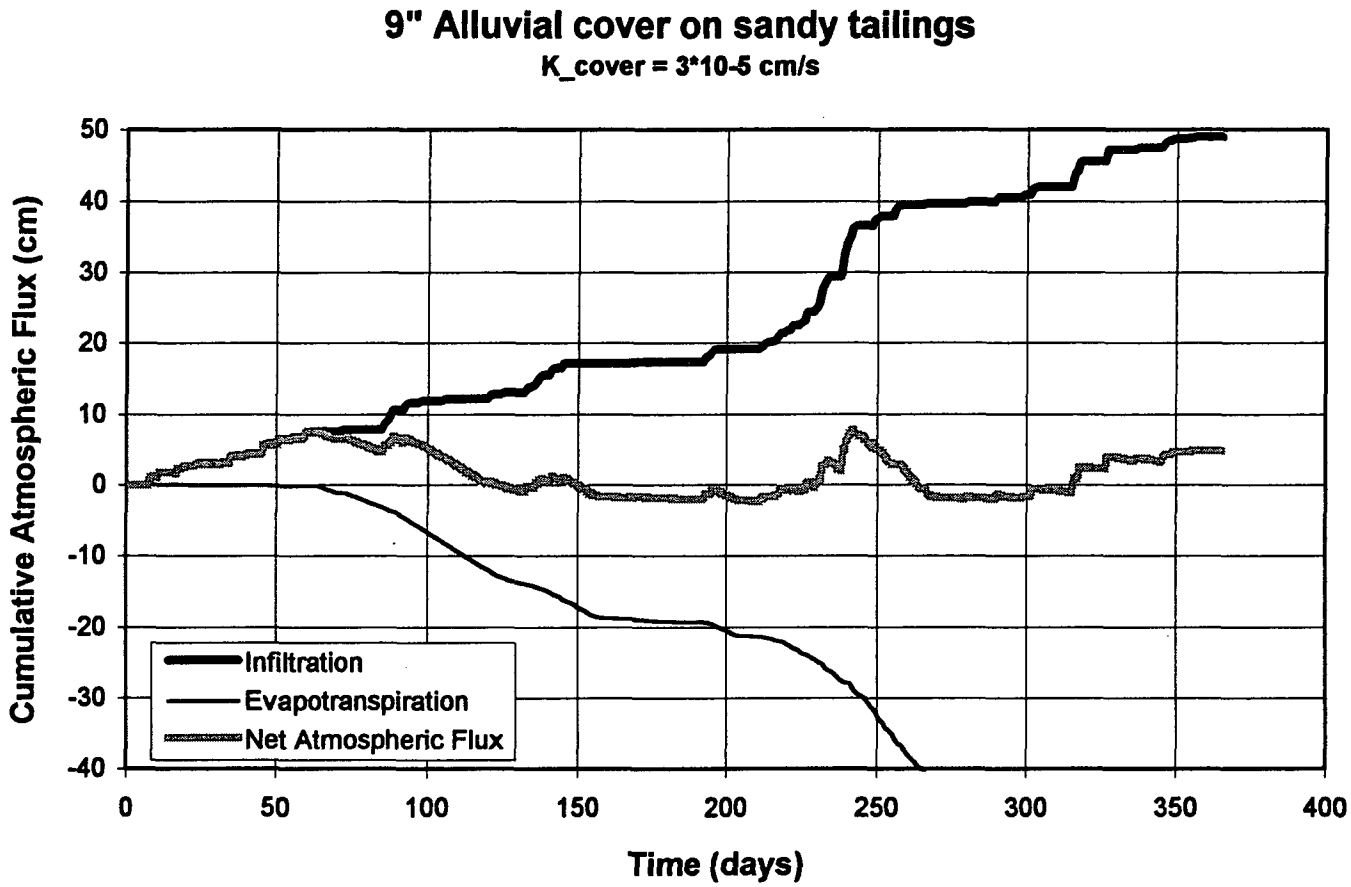


Figure E17.
Simulated Atmospheric Fluxes for Scenario "sens 2a"

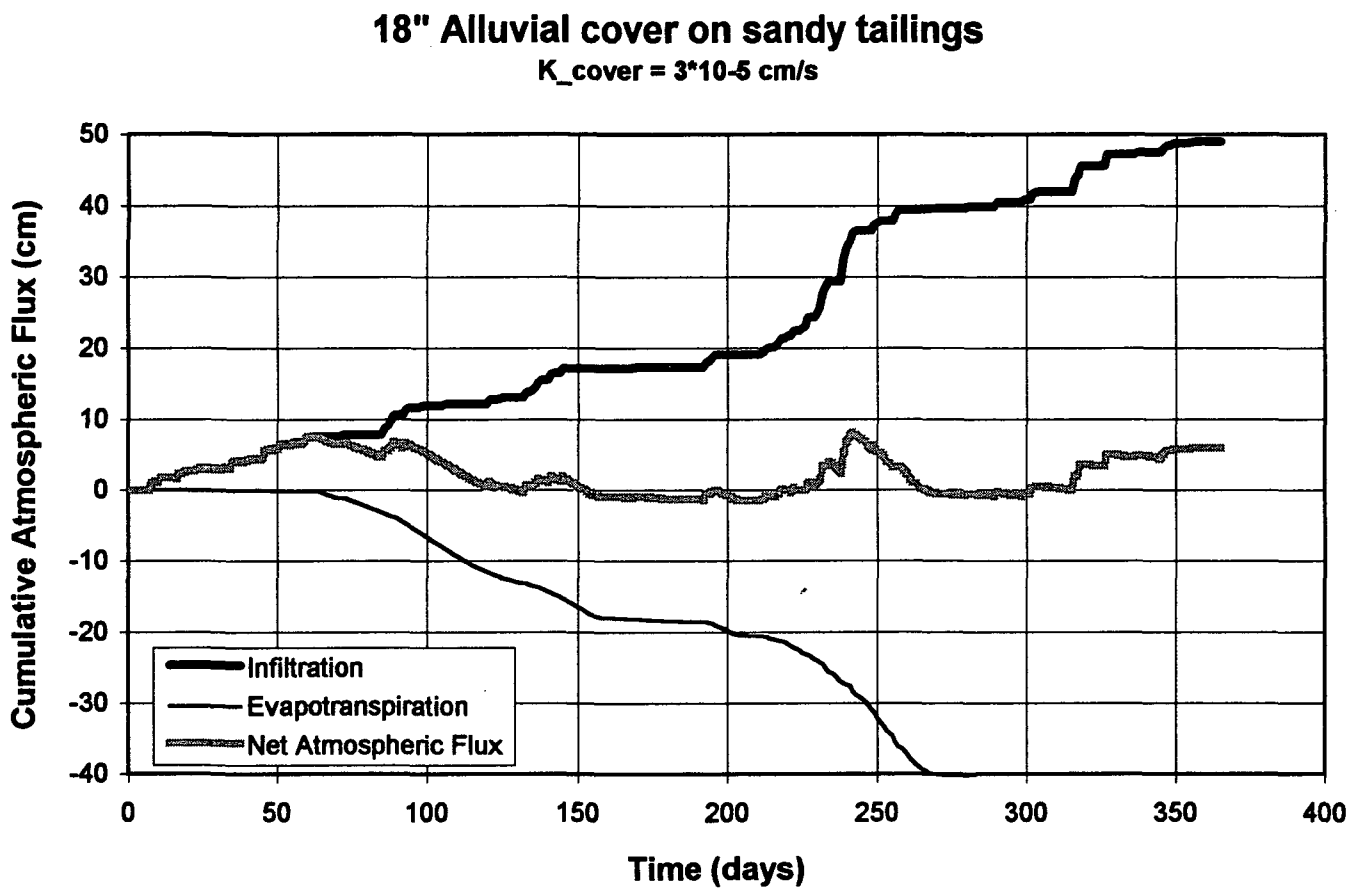


Figure E18.
Simulated Atmospheric Fluxes for Scenario "sens 2b"

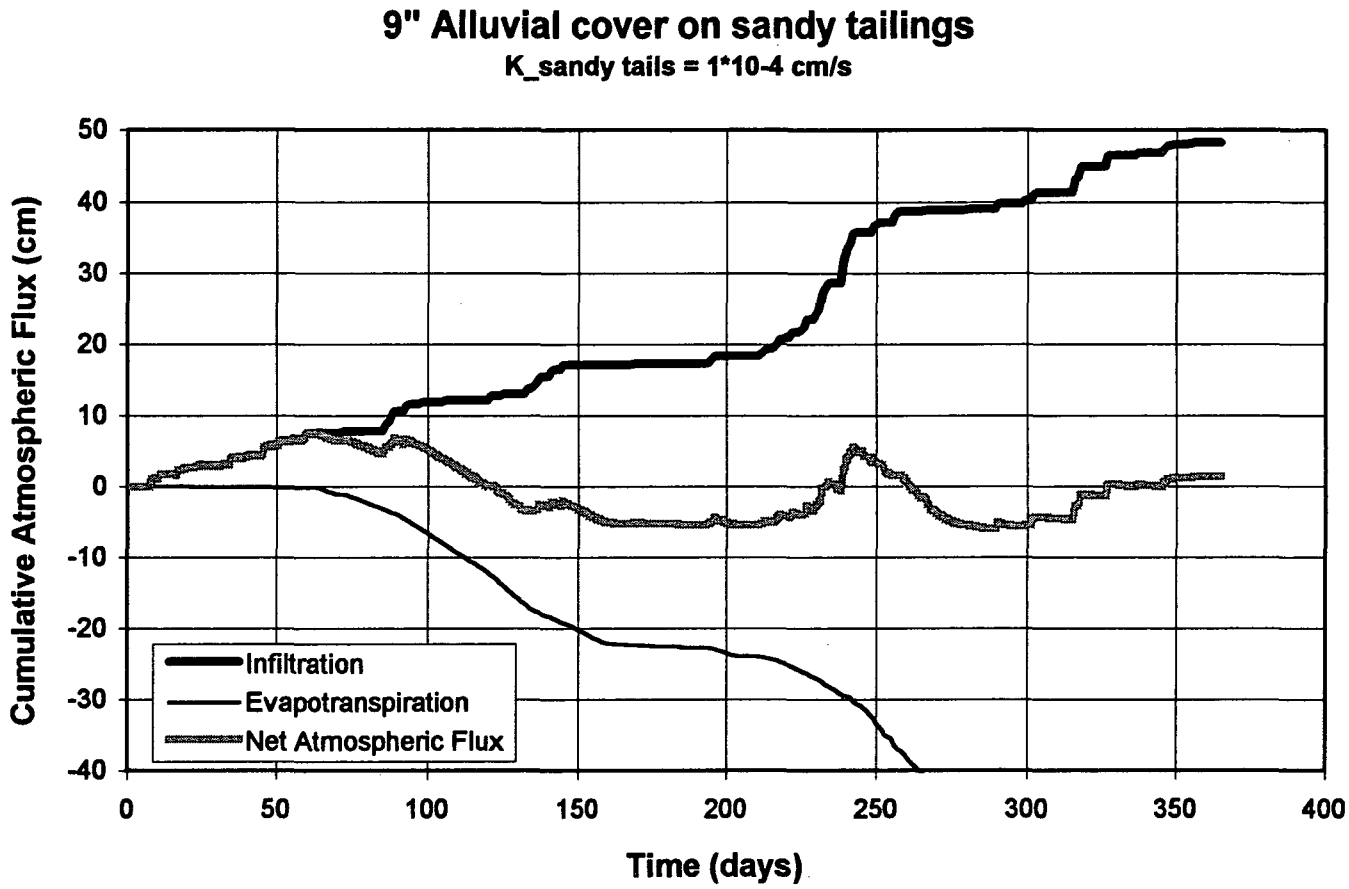


Figure E19.
Simulated Atmospheric Fluxes for Scenario "sens 3a"

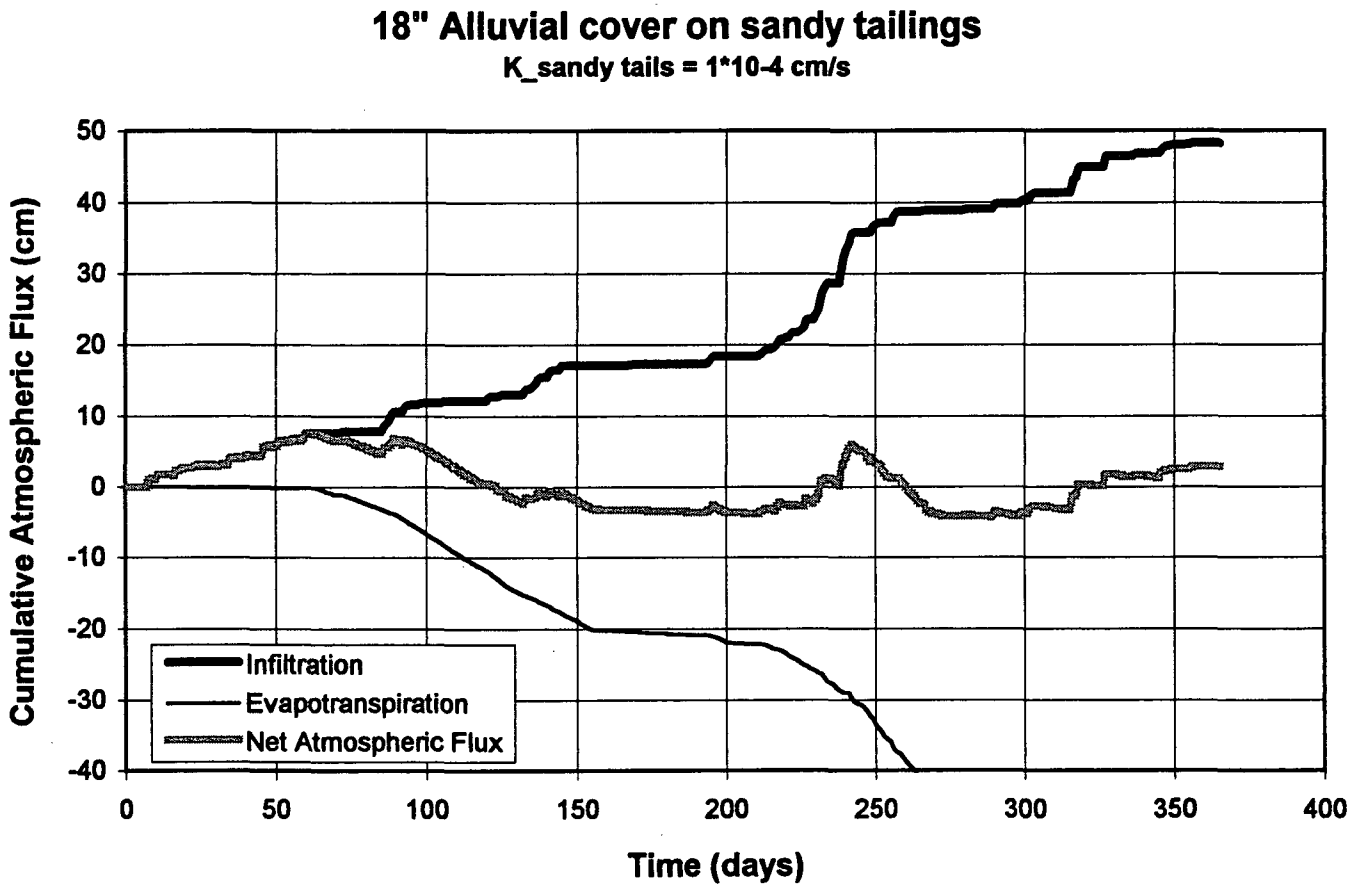


Figure E20.
Simulated Atmospheric Fluxes for Scenario "sens 3b"

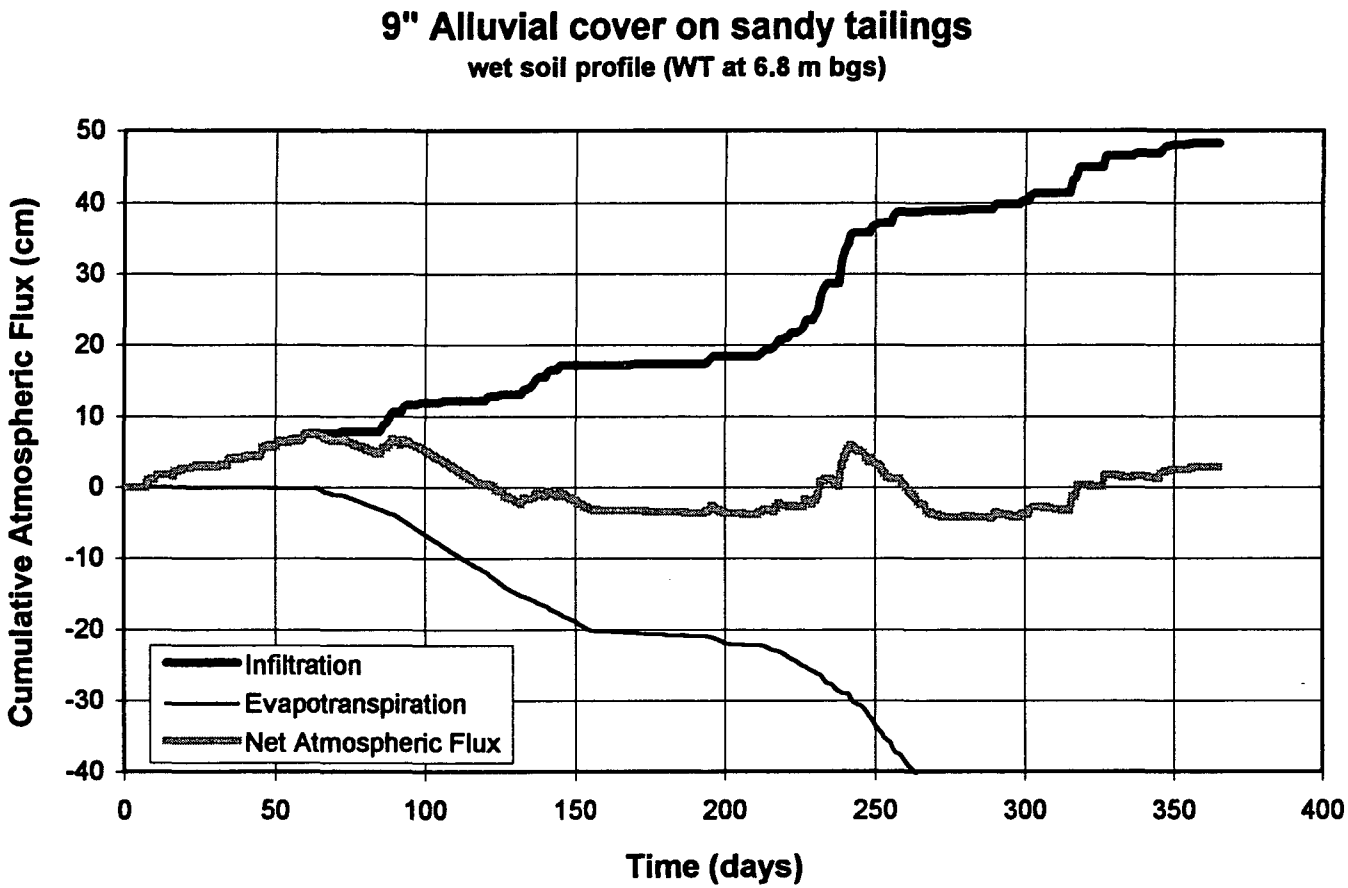


Figure E21a.
Simulated Atmospheric Fluxes for Scenario "sens 4a"

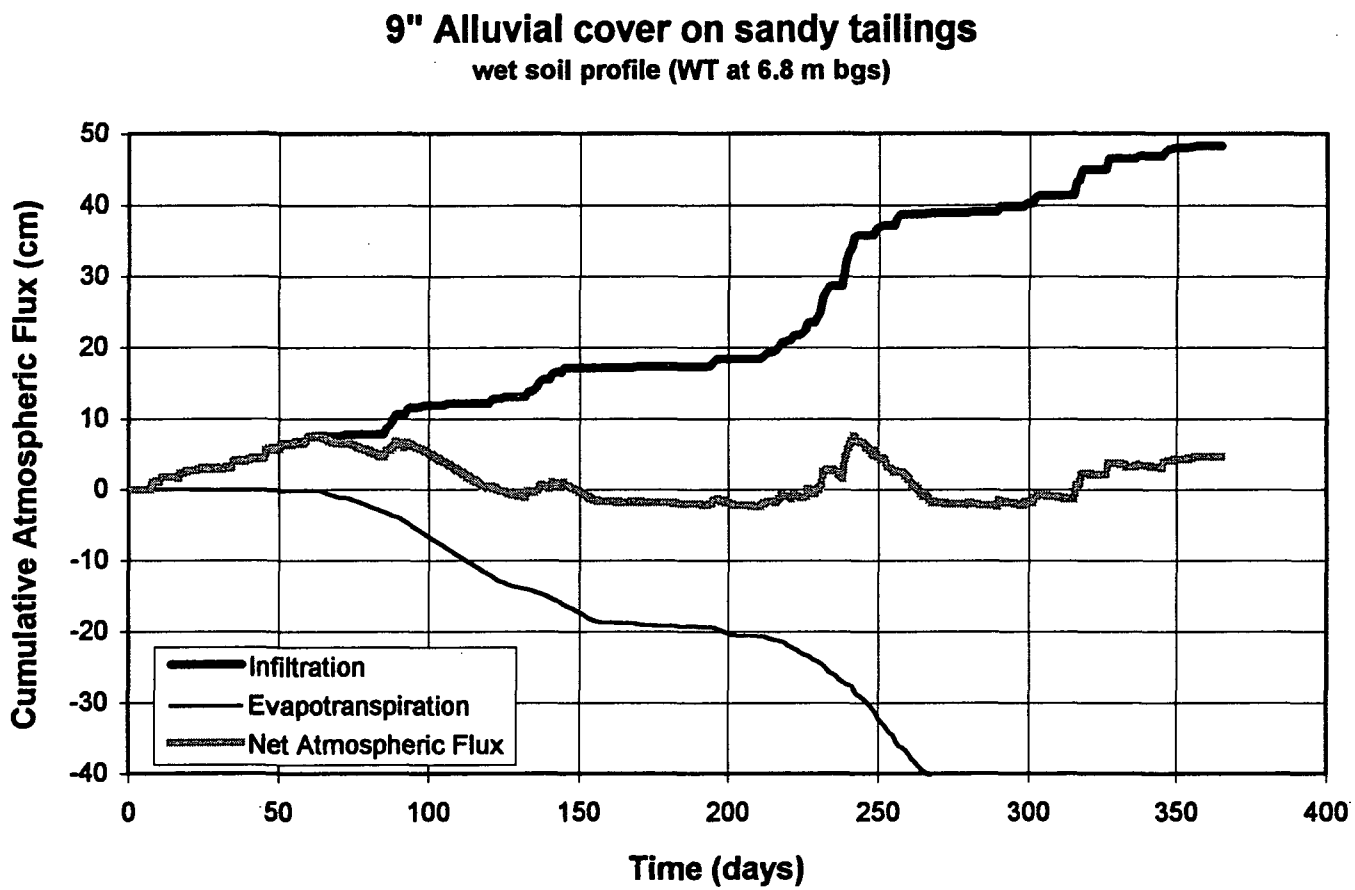


Figure E21a.
Simulated Atmospheric Fluxes for Scenario "sens 4a"

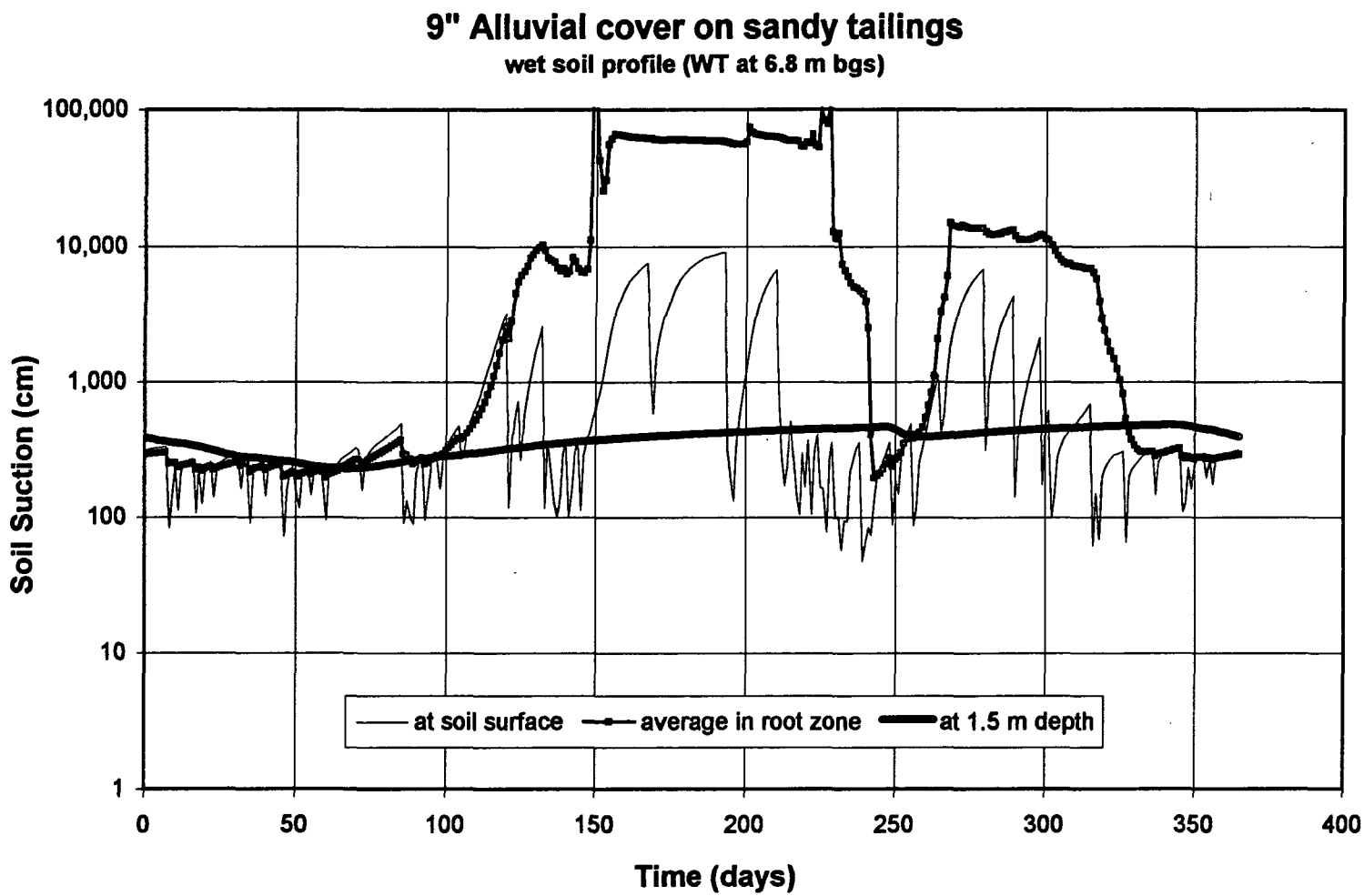


Figure E21b.
Simulated Soil Suction for Scenario "sens 4a"

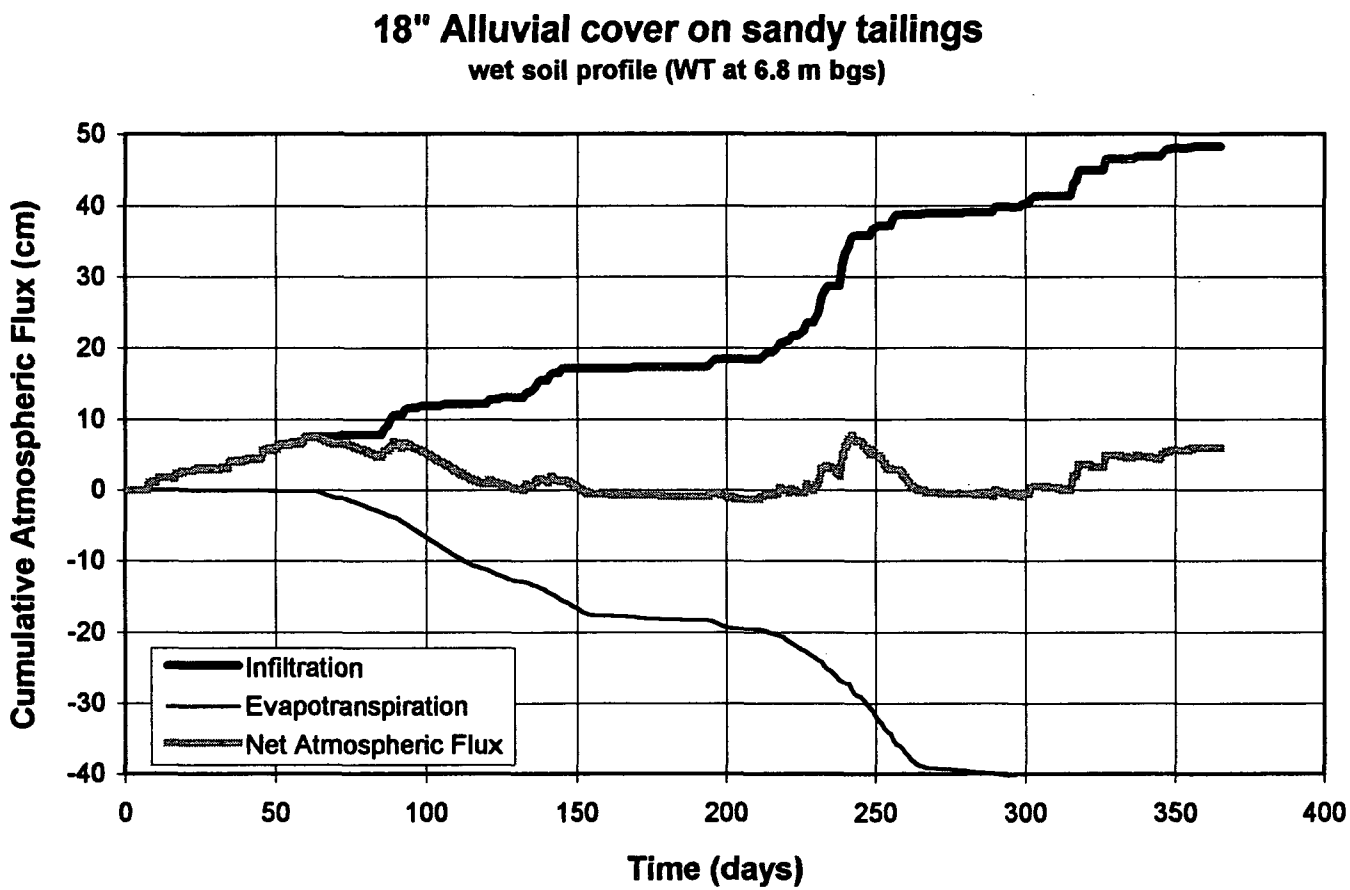


Figure E22a.
Simulated Atmospheric Fluxes for Scenario "sens 4b"

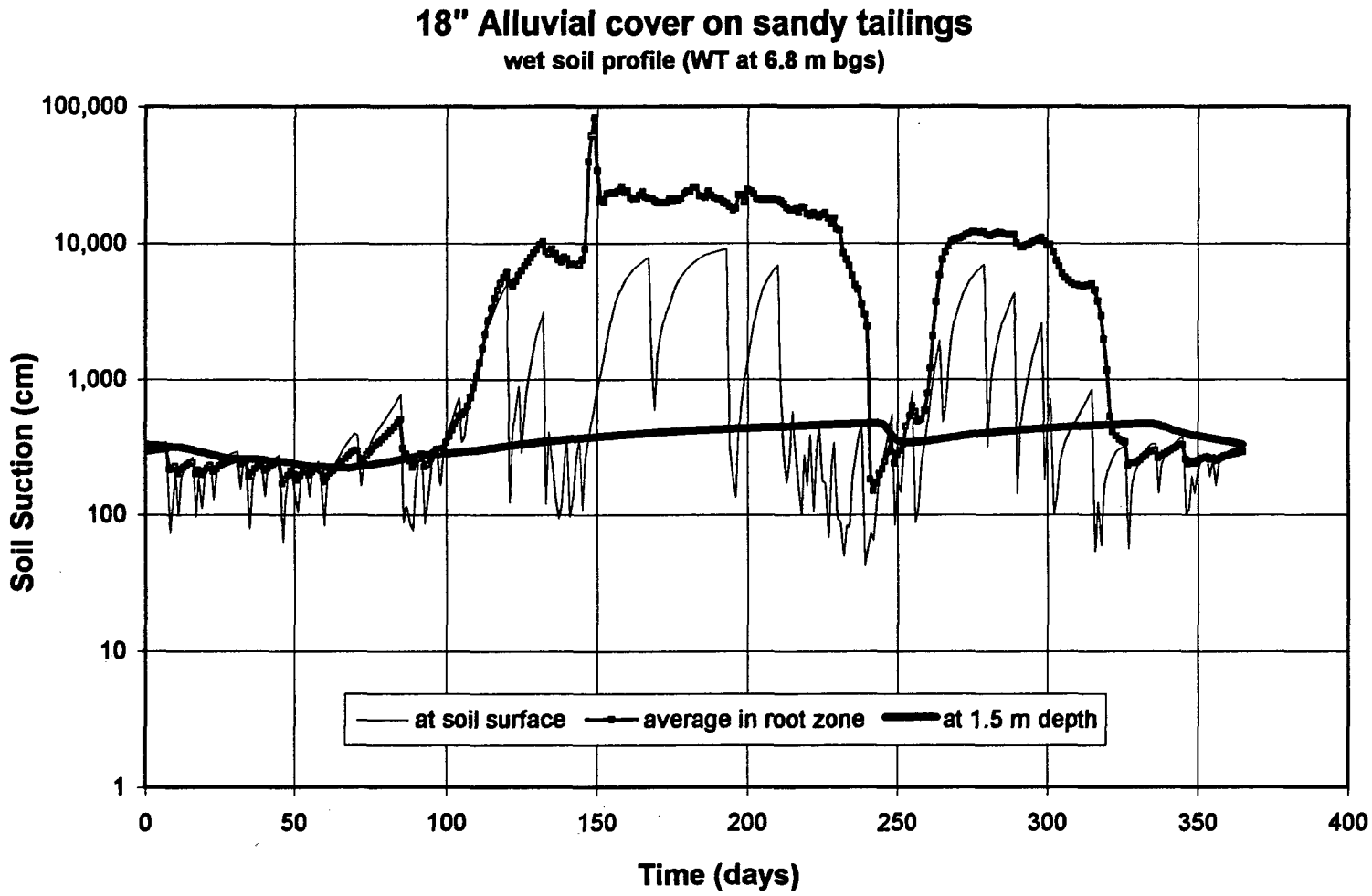


Figure E22b.
Simulated Soil Suction for Scenario "sens 4b"

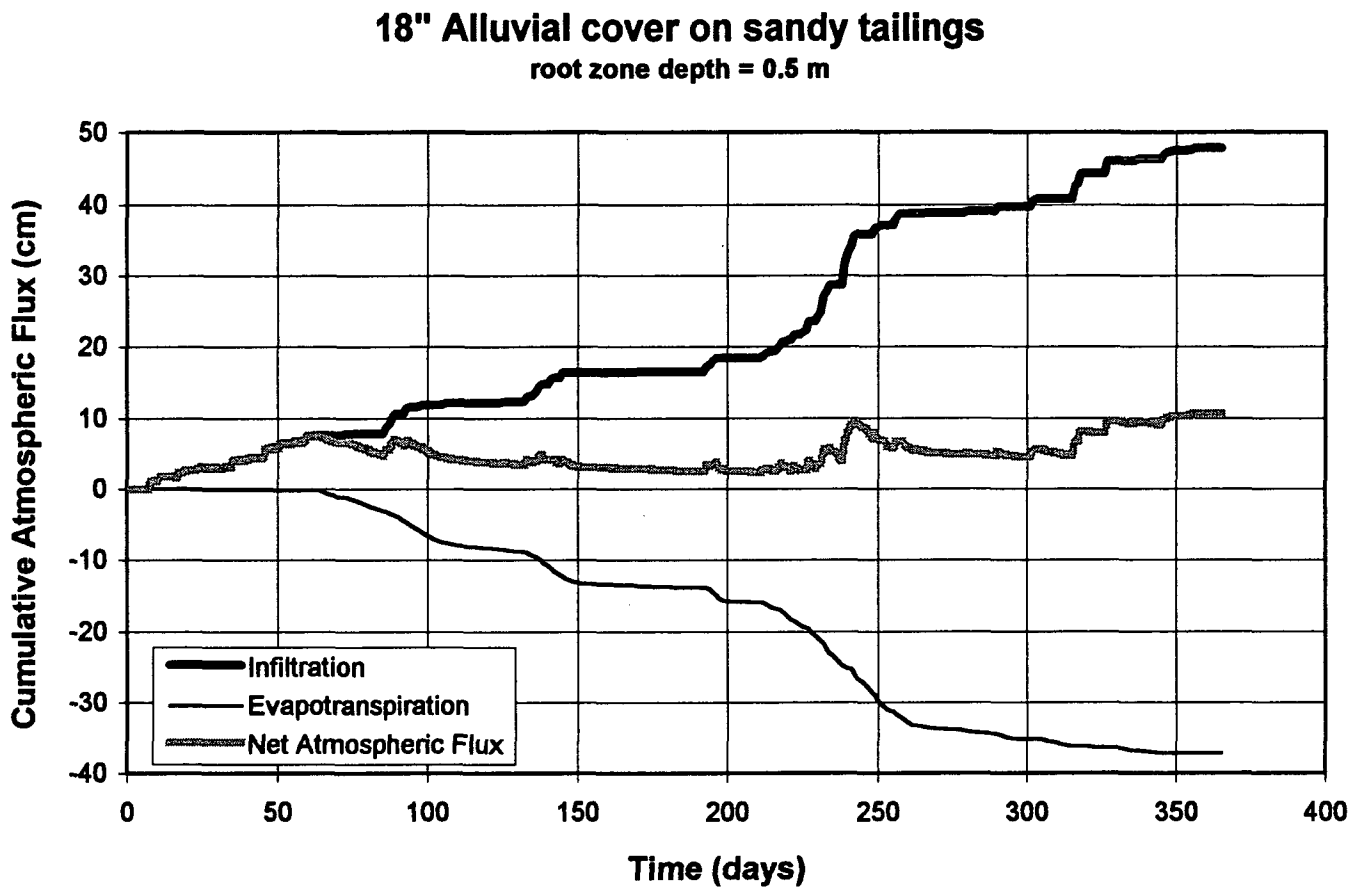


Figure E23a.
Simulated Atmospheric Fluxes for Scenario "sens 5a"

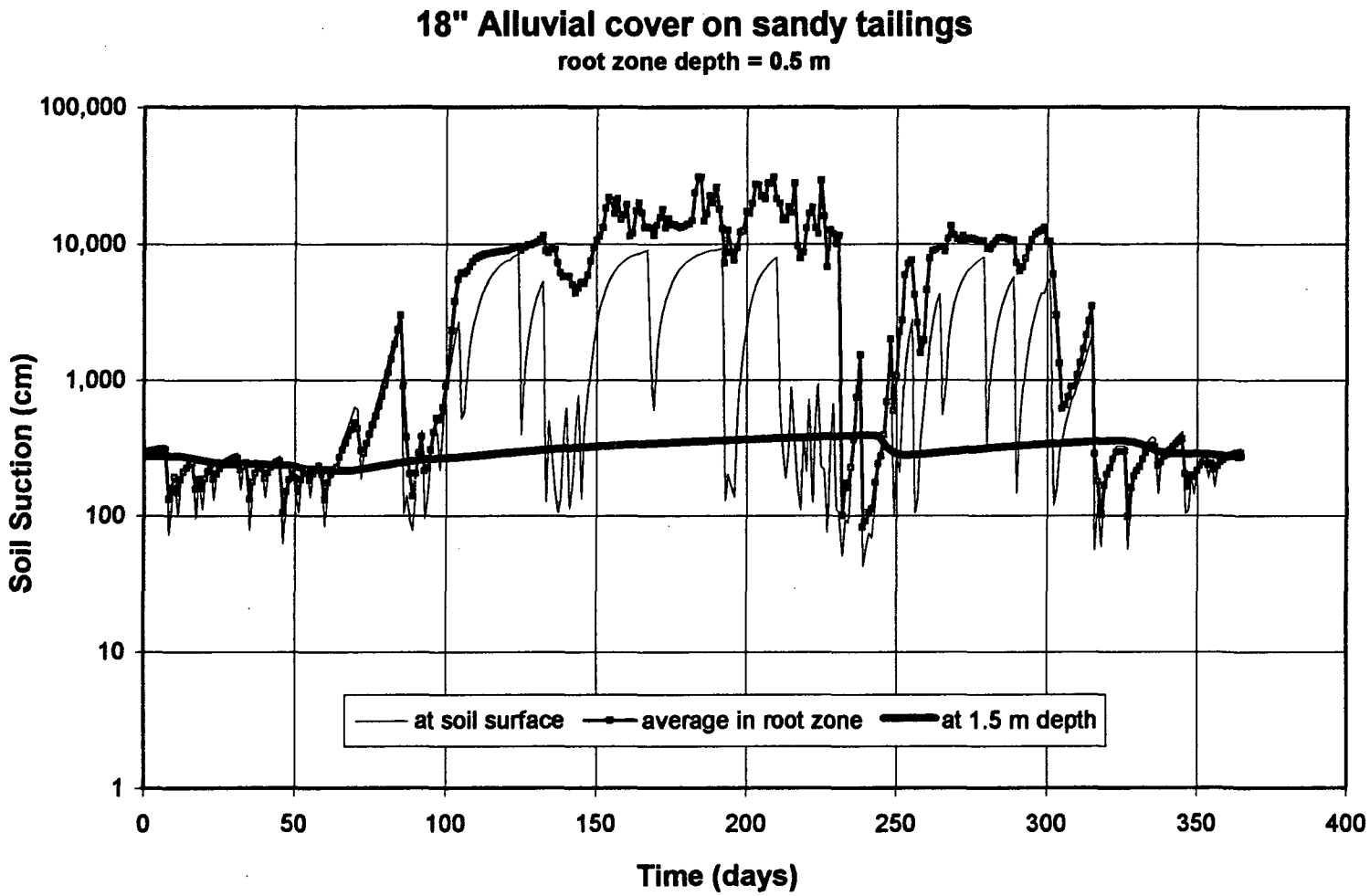


Figure E23b.
Simulated Soil Suction for Scenario "sens 5a"

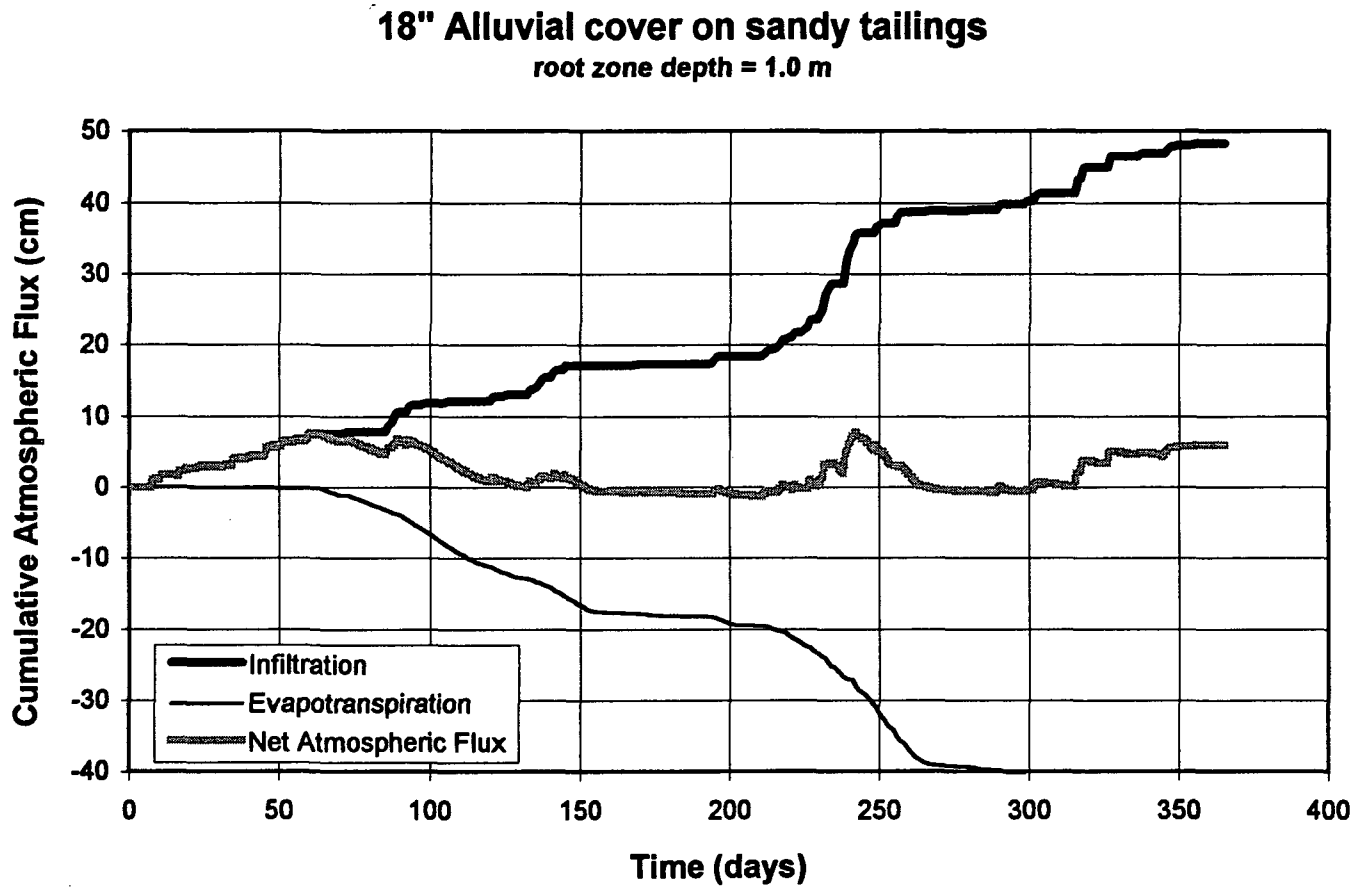


Figure E24a.
Simulated Atmospheric Fluxes for Scenario "sens 5b"

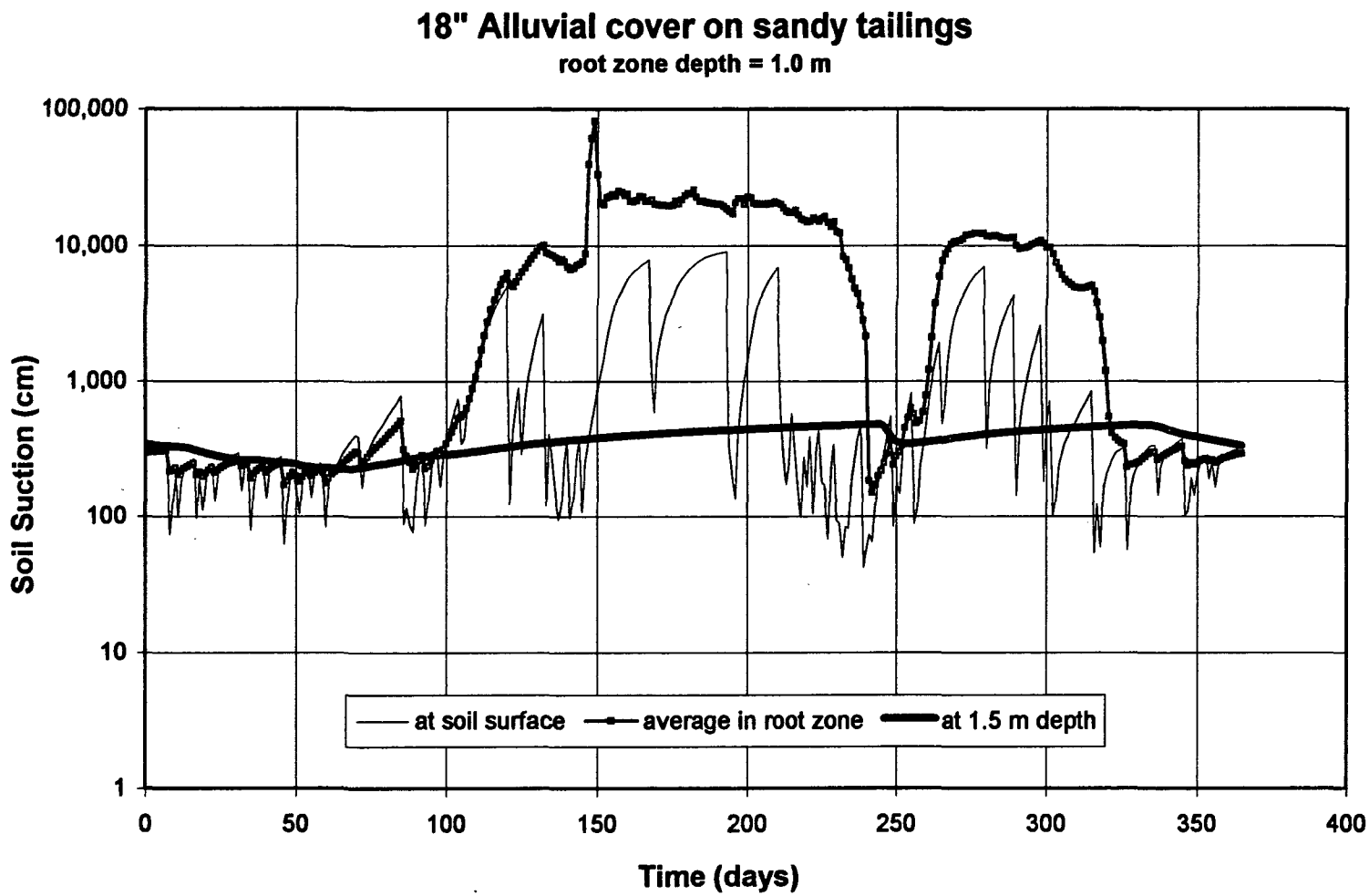


Figure E24b.
Simulated Soil Suction for Scenario "sens 5b"

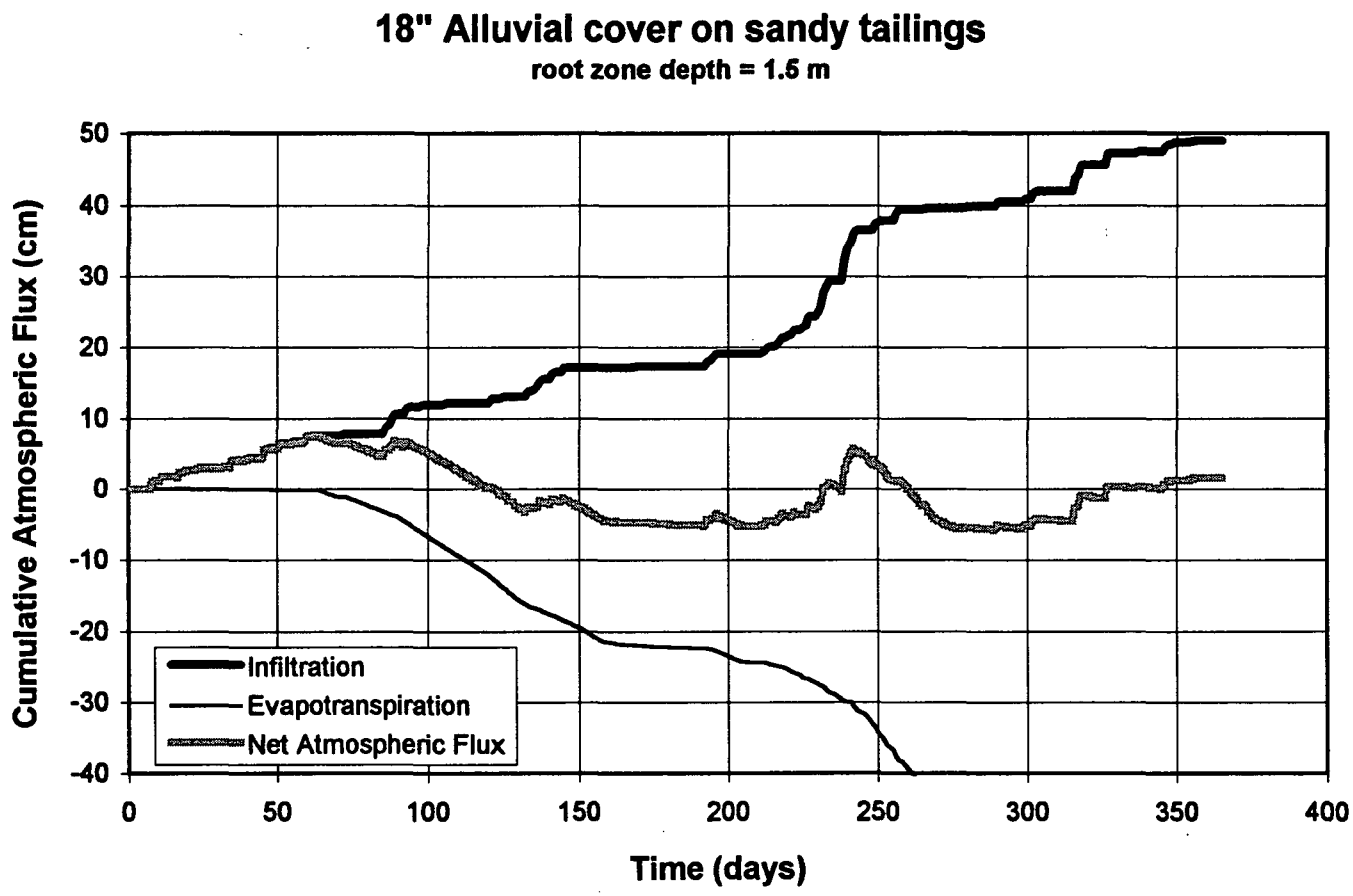


Figure E25a.
Simulated Atmospheric Fluxes for Scenario "sens 5c"

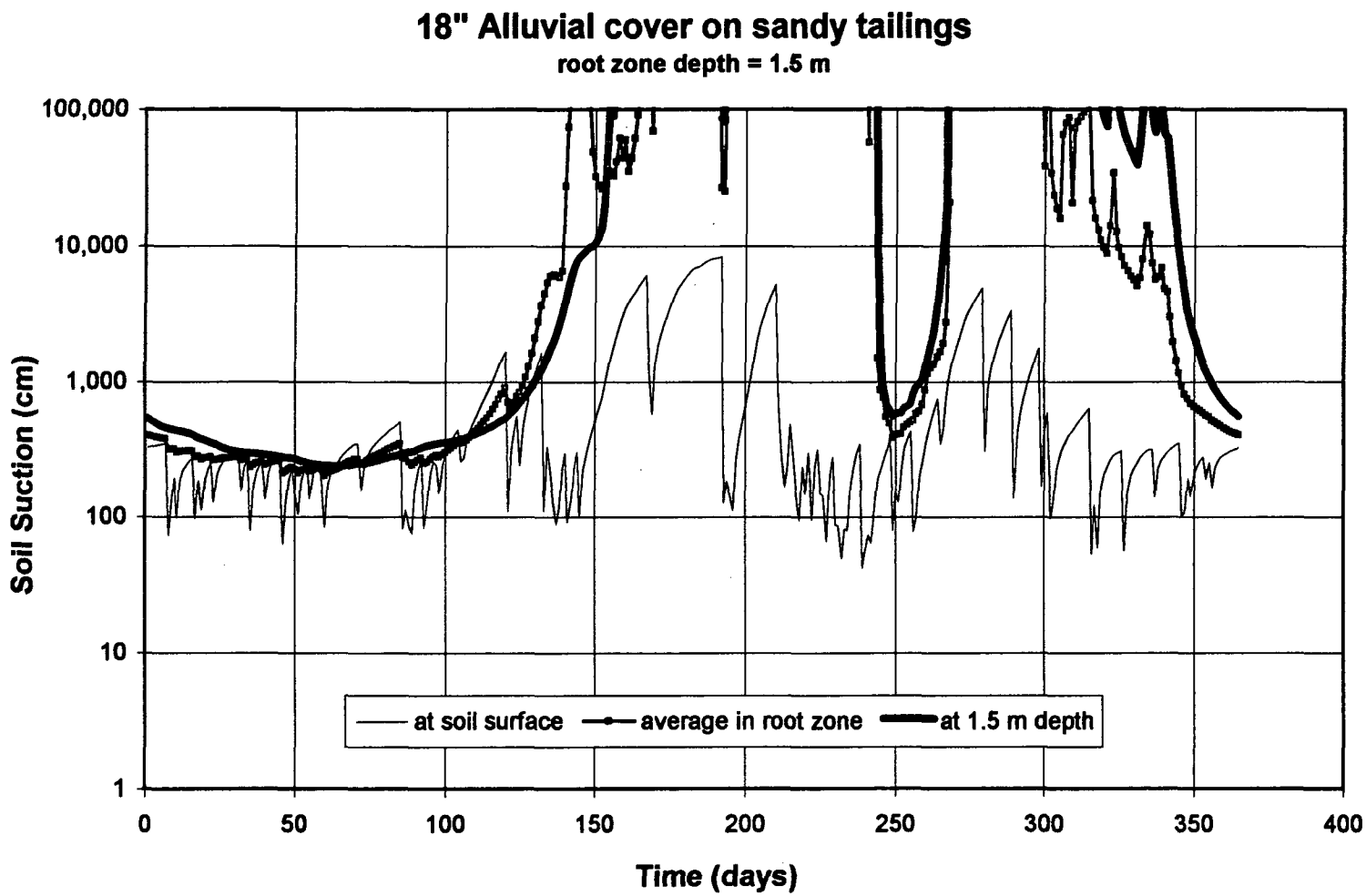


Figure E25b.
Simulated Soil Suction for Scenario "sens 5c"

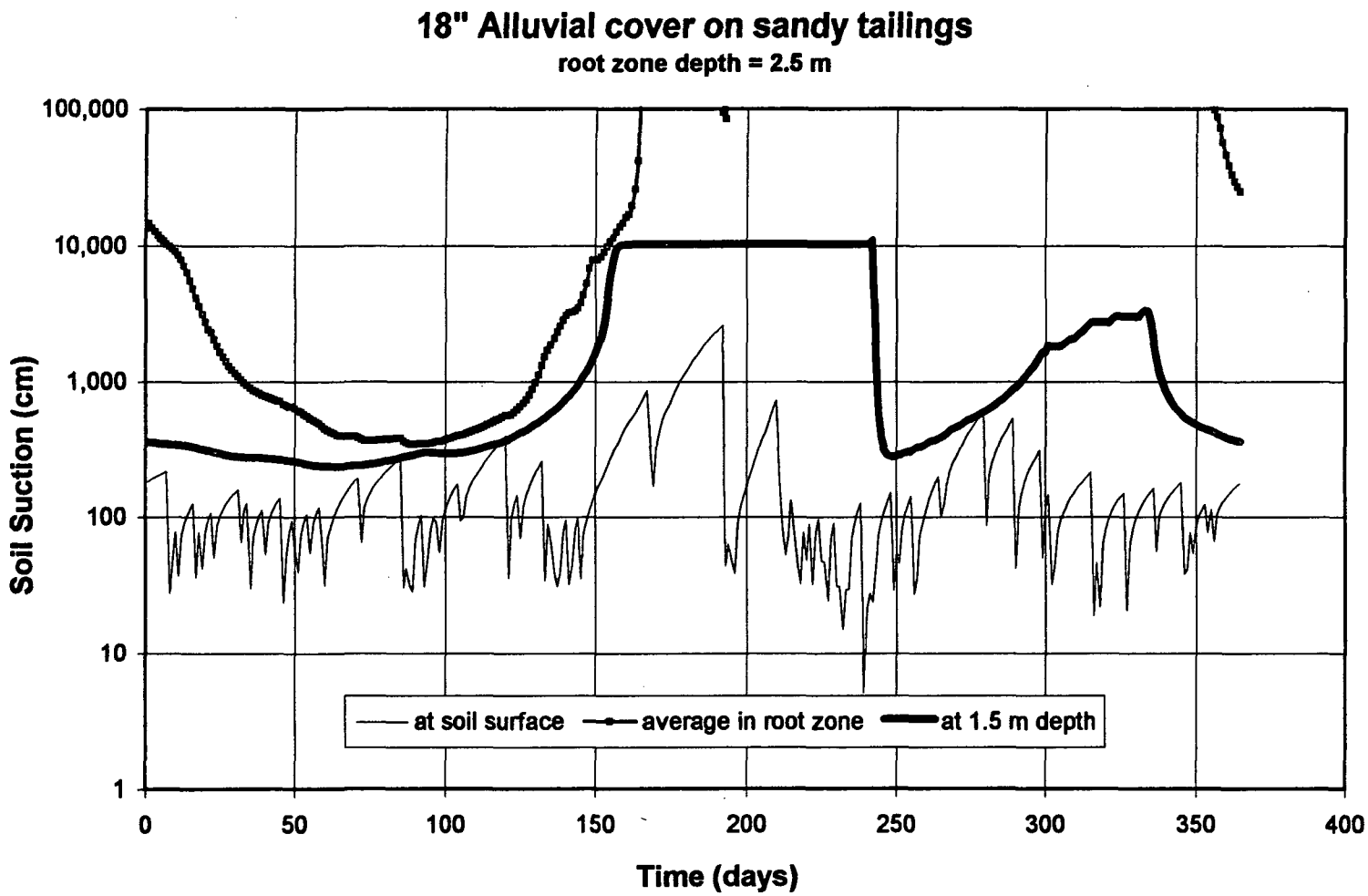


Figure E26b.
Simulated Soil Suction for Scenário "sens 5d"

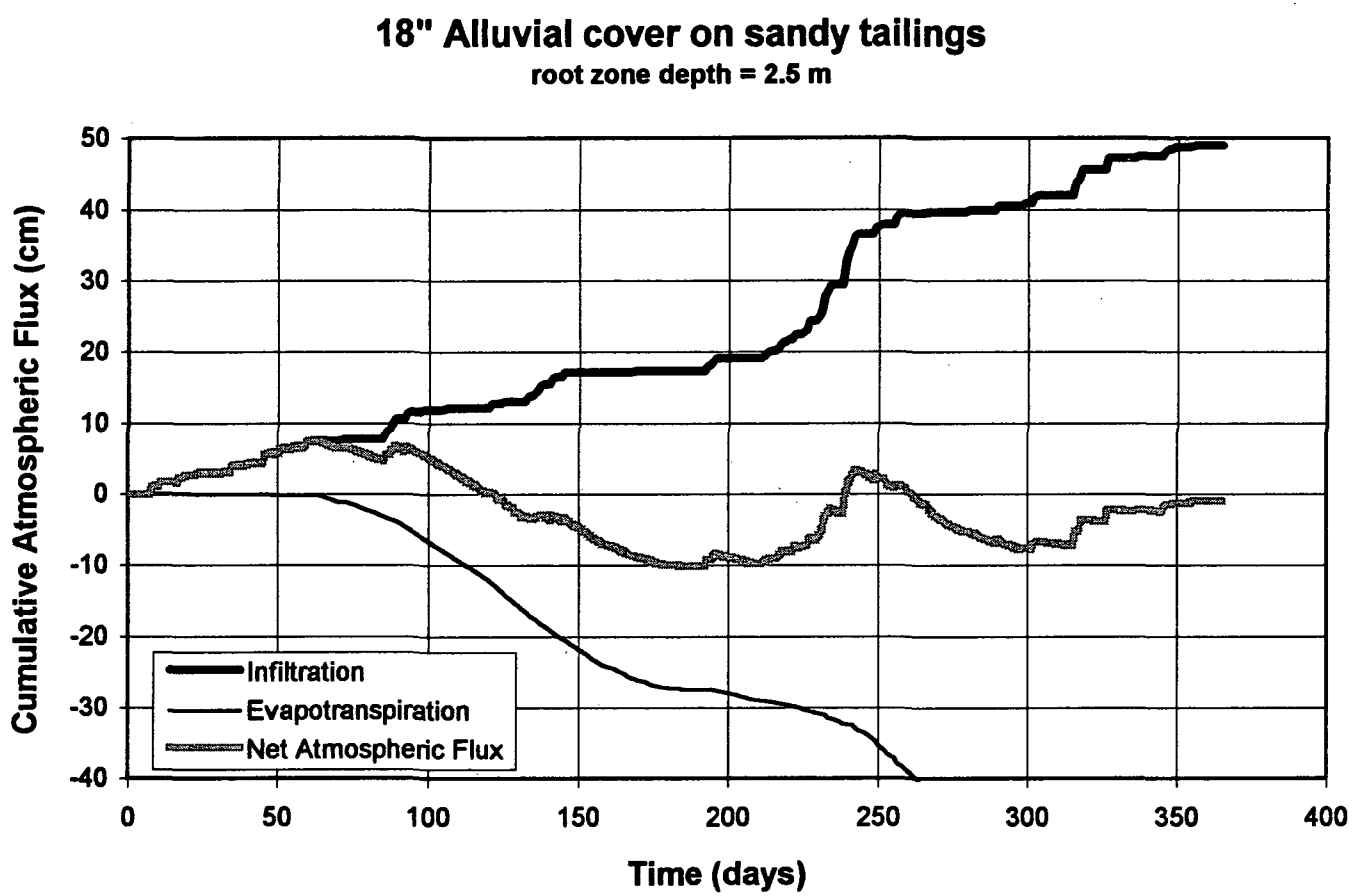


Figure E26a.
Simulated Atmospheric Fluxes for Scenario "sens 5d"

Table E1.
List of Figures Summarizing Cover Performance Analysis

Run	Description	Flux plot	Head plot	Figure No.
quest 1_84b	9" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E1
quest 1_93a	9" alluvial cover on sandy tailings - 1993 w/ short growing season	x		Figure E2
quest 1_93b	9" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E3a & 3b
quest 1_93c	9" alluvial cover on sandy tailings - 1993 w/ long growing season	x		Figure E4
quest 2_84b	9" alluvial cover on fine tailings - 1984 w/ intermediate growing season	x	x	Figure E5a & 5b
quest 2_93a	9" alluvial cover on fine tailings - 1993 w/ short growing season	x		Figure E6
quest 2_93b	9" alluvial cover on fine tailings - 1993 w/ intermediate growing season	x	x	Figure E7a & 7b
quest 2_93c	9" alluvial cover on fine tailings - 1993 w/ long growing season	x		Figure E8
quest 3_84b	18" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E9
quest 3_93b	18" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E10a & 10b
quest 4_84b	36" alluvial cover on sandy tailings - 1984 w/ intermediate growing season	x		Figure E11
quest 4_93b	36" alluvial cover on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E12a & 12b
quest 5_84b	18" alluvium plus 6" silt on sandy tailings - 1984 w/ intermediate growing season	x		Figure E13
quest 5_93b	18" alluvium plus 6" silt on sandy tailings - 1993 w/ intermediate growing season	x	x	Figure E14a & 14b
sens 1a	9" alluvial cover on sandy tailings - Drainable porosity = 30%	x		Figure E15
sens 1b	18" alluvial cover on sandy tailings - Drainable porosity = 30%	x		Figure E16
sens 2a	9" alluvial cover on sandy tailings - K_cover = 3*10-5 cm/s	x		Figure E17
sens 2b	18" alluvial cover on sandy tailings - K_cover = 3*10-5 cm/s	x		Figure E18
sens 3a	9" alluvial cover on sandy tailings - K_sandy tails = 1*10-4 cm/s	x		Figure E19
sens 3b	18" alluvial cover on sandy tailings - K_sandy tails = 1*10-4 cm/s	x		Figure E20
sens 4a	9" alluvial cover on sandy tailings - wet soil profile (WT at 6.8 m bgs)	x	x	Figure E21a & 21b
sens 4b	18" alluvial cover on sandy tailings - wet soil profile (WT at 6.8 m bgs)	x	x	Figure E22a & 22b
sens 5a	18" alluvial cover on sandy tailings - root zone depth = 0.5 m	x	x	Figure E23a & 23b
sens 5b	18" alluvial cover on sandy tailings - root zone depth = 1.0 m	x	x	Figure E24a & 24b
sens 5c	18" alluvial cover on sandy tailings - root zone depth = 1.5 m	x	x	Figure E25a & 25b
sens 5d	18" alluvial cover on sandy tailings - root zone depth = 2.5 m	x	x	Figure E26a & 26b

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Project No. 052002

November 6, 1997

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Received
JAN 18 2000
6WQ-PP

Attention: Geyza Lorinczi, Environmental Manager

Dear Geyza Lorinczi:

Re: Submission of Report on Hydrogeological Modeling and Three-Dimensional Geometric Model of Questa Tailings Facility

Please find enclosed three (3) copies of our reports entitled "Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico" (RGC Report No. 052002/1) and "Three-Dimensional Geometric Model of Molycorp's Questa Tailings Facility" (RGC Report No. 036006). Two (2) additional copies of each report have been sent directly to the Groundwater Quality Bureau at the New Mexico Environment Department (w/ attention to Ms. Marcy Leavitt, Chief).

We trust that the information provided in these reports meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned at your convenience.

Yours sincerely,

ROBERTSON GEOCONSULTANTS INC.

Christoph Wels

Christoph Wels, Ph.D.

Project Manager

cc. Ms. Marcy Leavitt, NMED
Ms. Kerrie Neet, NMED

Report No. 052002/1

Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico

Volume 1: Report

Prepared for

UNOCAL®
MOLYCORP

Questa Division

Prepared by:
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October 1997

Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico

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Section 1

1 Introduction

1.1 Terms of Reference

Molycorp Inc. (Molycorp) is currently preparing a closure plan for their tailings facility at the Questa Mine in New Mexico. To this end, Molycorp has retained Robertson GeoConsultants Inc. (RGC) and Steffen Robertson and Kirsten (U.S.) Inc. (SRK) to complete hydro(geo)logical and geochemical investigations of the tailings facility. This report summarizes the hydro(geo)logical investigation and has been prepared in part to satisfy the requirements of report submission to the New Mexico Environmental Department under Discharge Plan 933 (Final Order, Section 2.K).

A geochemical investigation of the tailings and assessment of long-term potential for acid generation (SRK, 1997) is being completed in conjunction with the hydro(geo)logical investigation reported herein. The purpose of these investigations is to develop the data necessary to predict the short- and long-term tailings seepage quality for alternative closure options of the tailings facility and for the proposed closure plan. In addition, a geometrical model of the tailings facility is being developed to assist in the visualization and understanding of the tailings facility development and deposition history (RGC, 1997). Results of the geochemical investigation and the geometric modeling are presented in separate reports.

The hydro(geo)logical investigations summarized herein include the modeling of regional and local groundwater flow, modeling of tailings seepage after closure, and modeling of infiltration through a soil cover to be placed onto the tailings after closure.

1.2 Background

Molycorp's Questa Division is operating a series of tailings impoundments near the town of Questa, New Mexico in northern Taos County (Figure 1.1). Since 1965, tailings slurry has been piped along the Red River from the mill near the Molycorp molybdenum mine, which is located approximately 8 miles east of the tailings disposal sites. During the temporary shut-down of the Questa mine from 1992 to 1996, all dry beach zones were covered with a layer of alluvial soil. In late 1996 tailings discharge commenced once again. The tailings impoundments currently cover approximately 640 acres.

Molycorp is required to submit a closure plan for its tailings facility by the spring of 1998. This closure plan will have to demonstrate what impact - if any - the tailings impoundments have on the local and regional groundwater quality as well as on the downstream receiving water quality (i.e. Red River) in the long-term. At present, seepage water discharging from the tailings facilities exceeds New Mexico groundwater quality standards for sulfate and molybdenum. Hence, control measures will have to be implemented to protect the groundwater aquifer(s) beneath and downgradient of the facility. Two control strategies are presently being considered: (i) placing a soil cover onto the tailings to reduce infiltration and thus tailings seepage, and (ii) intercepting and pumping tailings seepage water from an interception system of wells and trenches installed below the toe of the dam (i.e. up-gradient of any groundwater users). The latter control strategy is a

requirement for current operation of the tailings facility and has already been implemented down-gradient of the Dam No. 1 tailings facility (in section 36).

The soil cover placed onto the tailings would need to reduce seepage to levels sufficiently low that the water quality of the receiving groundwater at a downstream compliance boundary meets New Mexico groundwater standards. In order to assess the effectiveness of such a cover the following parameters need to be known:

- present and future contaminant levels in tailings pore water;
- net infiltration through a permanent soil cover;
- rate of dewatering of the tailings prior to and after cover placement; and
- groundwater flows in the aquifer(s) receiving tailings seepage.

The geochemical investigation performed by SRK (!997) addresses the first issue. The latter three issues are addressed in the hydrogeological investigation summarized in this report.

The hydrogeological investigation described herein consisted of four parts:

(i) model study on regional groundwater flow;

(ii) model study on local groundwater flow;

(iii) model study on tailings seepage; and

(iv) model study on infiltration through a soil cover.

A regional groundwater flow model has been developed to evaluate the impact of tailings seepage on the regional aquifer system. In addition, this regional model provides a framework for the development of a local flow model (using telescopic grid refinement). The model study on regional groundwater flow is presented in chapter 2.

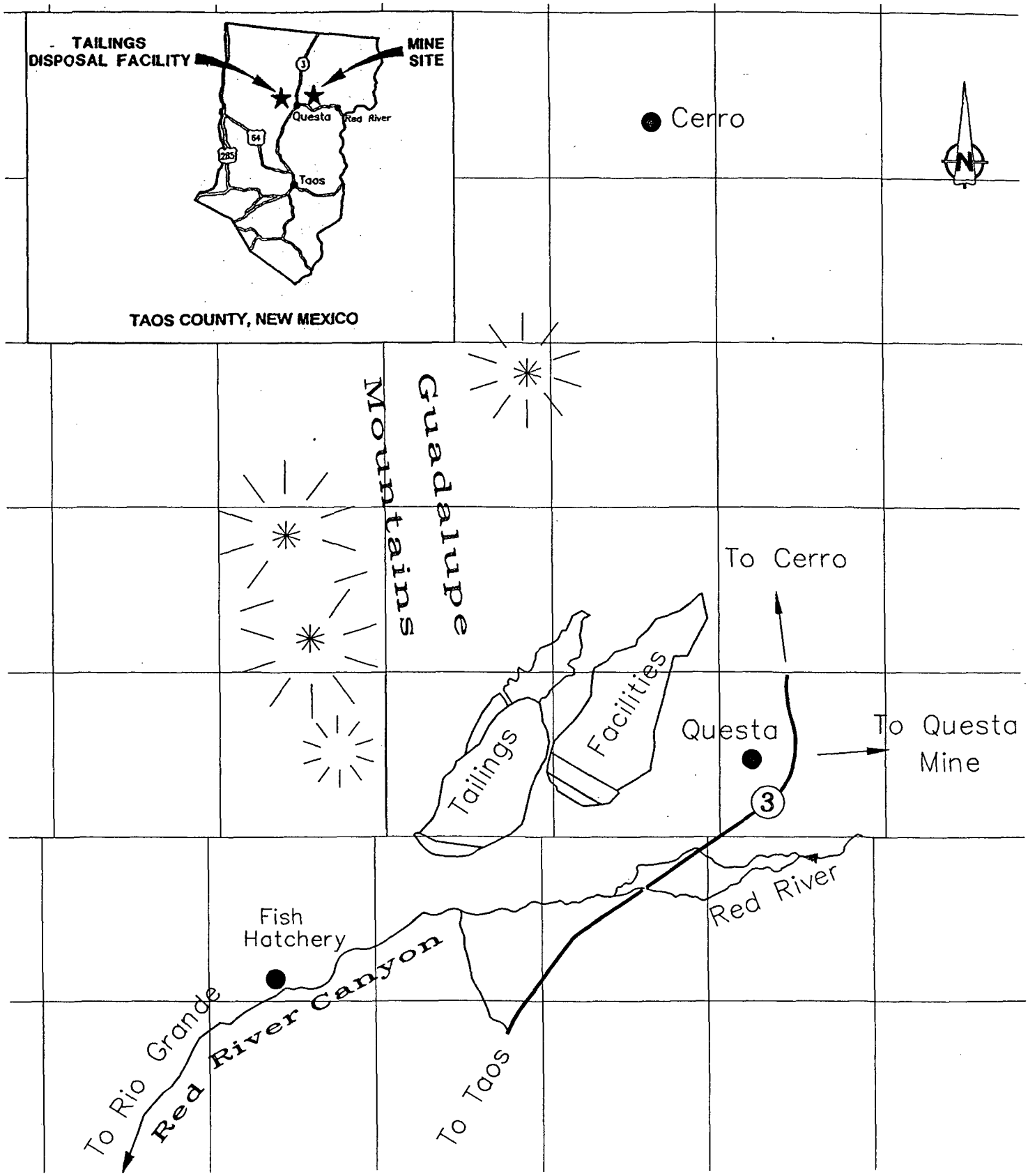
A local groundwater flow model has been developed to evaluate the impact of tailings seepage on the local aquifer system. The model illustrates the flow pattern in vicinity of the tailings facility and provides estimates of groundwater flow receiving seepage from the tailings. The model study on local groundwater flow is presented in chapter 3.

A transient seepage model has been developed to evaluate the rate of dewatering of the tailings over time. The model predicts the drawdown of the water table over time and the time required for final dewatering of the tailings, i.e. when tailings seepage rates equal rates of infiltration through a soil cover. The model study on tailings seepage is presented in chapter 4.

The process of infiltration through a soil cover has been modeled to evaluate the effectiveness of different cover scenarios in reducing net infiltration. The cover model provides estimates of net infiltration through the cover layers and into the deep tailings profile. The model study on cover performance is presented in chapter 5.

The main conclusions of the four model studies are summarized in chapter 6.

Figures



ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

Molycorp - New Mexico

Questa Groundwater and Seepage Study

Questa Tailings Facility
Location Map

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052002	Oct. 1997	1"=6000'		1-1

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Section 2

2 Regional Groundwater Flow Model

A good understanding of the groundwater system in vicinity of the tailings facilities is vital for planning control strategies to protect the groundwater resource (e.g. cover placement to reduce seepage from the tailings and/or extraction wells to avoid migration of contaminants downgradient).

A regional groundwater flow model has been developed to assist in this planning. The regional flow model provides insights into the hydrogeologic properties of the regional aquifers, i.e. direction of groundwater flow in the area, the regional recharge and discharge areas of groundwater, and the volumes of groundwater flowing in the regional aquifer(s). Moreover, the regional flow model provides a basis for developing a local flow model, which is required for evaluating the local groundwater conditions at the tailings site.

This chapter describes the development of the regional groundwater flow model. First, the results of previous studies on the regional hydrogeology are reviewed. Based on this review, a conceptual model is formulated and implemented into a flow model. Next, the regional model is calibrated using field observations of water levels in wells and estimates of groundwater discharge into near-by rivers (river accretion). The robustness of the model is evaluated using a sensitivity analysis. Finally, the implications for groundwater flow in vicinity of the tailings impoundments are discussed.

2.1 Objectives of Regional Groundwater Flow Model

The objectives of the regional groundwater flow model are as follows:

- to develop a water balance for the regional groundwater flow system;
- to estimate permeabilities for the major hydrogeological units in the region; and
- to define boundary conditions for the local groundwater flow model.

2.2 Regional Setting

The study area is located in Taos County, New Mexico in the confluence area of the Rio Grande and the Red River (Figure 2.1). The area is bordered by the Sunshine Valley to the north, Sangre de Cristo Mountains to the west, and the Rio Grande and Red River to the west and south, respectively.

2.2.1 Previous Studies

Winograd (1959) gives a comprehensive account of the general characteristics of groundwater occurrence in the region. However, Winograd's report concentrated on groundwater occurrence

in the Sunshine Valley area, north of Guadalupe Mountain. At the time of Winograd's work, both geologic and hydrogeologic data for the region south of the Sunshine Valley (in particular Guadalupe Mountain area) were sparse. His observations are supplemented primarily by studies commissioned by Molycorp Inc., including:

- South Pass Resources, September 1993: "Hydrogeologic Evaluation of Tailings Ponds";
- Dames and Moore, July, 1987: "Hydrogeologic and Chemical Analysis for the Proposed Guadalupe Mountain Tailings Disposal Site Groundwater Discharge Plan, Taos County, New Mexico";
- Vail Engineering, March 1987: "Geological Evaluation of the Guadalupe Mountain area";
- Vail Engineering, September 1993: "Analysis of Tailings Pond Seepage Flow to Red River";

In the remainder of this section, we summarize the physiography, geology, and hydrogeology of the region, referencing extensively from the reports by Winograd (1959) and Dames and Moore (1987).

2.2.2 Physiography of Study Region

In north-central New Mexico, the southern Rocky Mountains are represented by two highland prongs and a basin between them. The east group is known as the Sangre de Cristo Mountains. The west prong includes the Conejos (San Juan) Mountains, Jemes Mountains and the Sierra Nacimiento. The Rio Grande flows within the intermontane basin, which is commonly known as the Rio Grande trough (Figure 2.1). The course of the Rio Grande within the basin is marked by a scenic canyon cut into the lava-covered plateau.

The three prominent landforms in northern New Mexico are (1) a fault block mountain range, the Sangre de Cristo Mountains; (2) piedmont alluvial plains; and (3) a lava-capped plateau (Figure 2.1). The Sangre de Cristo Mountains form the eastern border of the study region. Structurally, these mountains may be related to the Basin and Range province. The western base of the mountains has been mapped as a fault scarp. The bold western face of the mountains and the presence of fault scarplets and landslide talus at the foot of the range all suggest rapid uplift along a fault zone.

The piedmont alluvial plains are located to the west of the Sangre de Cristo Mountains (Figure 2.1). The piedmont alluvial plains are sloping plains formed at the base of a high mountain range and composed largely of detritus derived from the mountains and deposited in coalescing alluvial fans by many ancient streams. Much channeling of the piedmont alluvial plains has occurred in the past (commonly called "arroyos") and is continuing in the vicinity of Questa. Here, the Red River and its tributary, Cabresto Creek, have cut a prominent valley 100 to 200 feet below the level of the piedmont alluvial plain.

A relatively undisected plateau, largely capped by andesite-basalt lava flows ("flood basalt"), comprises most of Taos County west of the Rio Grande (Figure 2.1). Several extinct volcanoes (e.g. Ute Mountain, Cerro de la Olla, Cerro Chiflo) rise conspicuously above the flat surface of the plateau. These volcanoes were the source of the vast lava flows forming the plateau. The lava

flows of the plateau slope generally eastward and interfinger with the alluvial sediments of the Piedmont alluvial plains to the east of the Rio Grande.

In the study region, the physiography is further complicated by the Guadalupe Mountain (Figure 2.1). The Guadalupe Mountain consists of a pair of volcanic exogenous domes and vent structures that have overlapped and sutured into one another. These volcanoes are older than the volcanoes of the lava-capped plateau and hence represented a barrier to the flow of flood basalt from the west. At the same time they represented a barrier to the movement of relatively young alluvial sediments from the east.

2.2.3 Geology of Study Region

The valley fill materials, which have accumulated to a great thickness in the Rio Grande trough since middle Miocene time are collectively called the Santa Fe Formation (Winograd, 1959). These rocks are not all of one age, for obviously, the valley fill deposited in middle Miocene time is older than the detritus removed from the highlands in Pleistocene time. The Santa Fe Formation also varies in lithology, consisting of alluvial sediments interbedded with volcanic rocks of different age. In this report, the term "Santa Fe sediments" is only used to describe the old alluvial sediments, underlying and interbedding with the andesite basalt flows at greater depths.

In the study region, four geological units have been identified by Vail (1987) (see Figure 2.2):

- recent alluvium (al): surficial alluvial deposits mostly derived from mountains to the east;
- Servilleta flood basalt (svb), olivine bearing; grouped as upper (sbu) and combined middle and lower (sbl) members;
- volcanic flows of Guadalupe Mountain (gv); lobate dacite flows and olivine andesite; and
- old alluvium (al_{SF}): conglomerate, sandstone, and siltstone; mostly derived from mountains to the east.

The young, surficial alluvial sediments are exposed in the eastern parts of the study region (Figure 2.2). Older alluvial sediments are found at greater depths throughout the study region, typically interbedded with the andesite basalt flows of the plateau. These old "Santa Fe sediments" are exposed on the canyon walls of the Rio Grande and the (lower) Red River. The alluvial sediments beneath the valley are estimated to be about 3000' thick (McKinlay, 1956). However, the sediments deposited since the last period of volcanic activity thin out toward the west, and, near the contact with the eastward dipping lava flows, they are only a few feet thick.

The surficial alluvial sediments are composed of materials ranging in size from clay particles to cobbles 8 inches in diameter. Usually the alluvial sediments are unsorted, but locally they are fairly well sorted, and contain lenses of gravel, sand, or clay. Owing to the large range in possible degrees of sorting and coarseness of the alluvial sediments, the permeability of this material varies greatly. The old alluvial sediments located at greater depths are much less permeable than the surficial sediments and have to be considered aquitards at the regional scale (Dames and Moore, 1987).

The Servilleta flood basalts extend from near the ground surface to a depth of a few hundred feet over much of the plateau area west of the Guadalupe Mountain and along the Rio Grande and Red River gorges (Figure 2.2). These andesite-basalt flows were derived largely from molten lavas of low viscosity; hence they were able to spread out over the plateau in tabular sheets, often of large extent. The individual andesite basalt lava flows are generally less than 50 feet thick and are locally interbedded with thin strata of volcanic ash. The sheets were cut by numerous vertical fractures, which formed during cooling of the lava. The rapid chilling of the tops and bottoms of individual flows, and later erosion, resulted in a rugged contact between the lava strata.

The permeability of the Servilleta flood basalts depends largely upon the extent of its fracturing and the bedding contacts of different flows which act as high permeability layers. Vesicles do not seem to be an important medium for groundwater movement through the lava. Although small portions of a lava flow are commonly impermeable, the lava flow as a whole is capable of transmitting large quantities of groundwater (high formational permeability).

The lobate flows of the Guadalupe Mountains (gv) are exposed only in vicinity of the Guadalupe Mountain. However, at greater depths, they reach as far west as the Rio Grande canyon (note outcropping of Guadalupe volcanics near Cerro Chiflo and Big Arsenic Springs, Figure 2.2). The volcanic formations of Guadalupe Mountain rest on the Santa Fe alluvial deposits. The elevation of the top of the Santa Fe sediments beneath Guadalupe Mountain has not been ascertained; however, it probably is a few hundred feet beneath the water table.

The volcanic activity of Guadalupe Mountain has emplaced a variety of volcanic lithologic types including dacites, colluvial and surge breccias, rhyodacite and occasional cinder beds. Probably very few of the rock units are continuous over the study area. Bed orientations and thicknesses are chaotic, and units can not be easily correlated over any great distance (Dames and Moore, 1987). Fracture densities and orientations, which control groundwater flow in this area, appear to vary widely. Indications of high volcanic rock permeability have been observed in the vicinity of the Guadalupe Mountains (e.g. South Pass Resources, 1993; Dames and Moore, 1987).

A series of northwest to southeast trending faults, referred to here as the Red River Fault Zone, bisects the area along the southwestern toe of the Guadalupe Mountain complex (see Figure 2.2). West of the fault zone, the Santa Fe sediments have been uplifted. East of the Red River Fault Zone, the rock units are down-dropped several hundred feet relative to the west of the zone. An exception to this condition can be found in the Big Arsenic Springs area (Figure 2.2), where a lobate dacite flow followed and filled a paleo-valley (possibly an ancestral Red River valley) at a depth that is now a few hundred feet below the top of the Santa Fe sediments (Vail, 1993).

2.2.4 Hydrogeology of Study Region

The groundwater conditions differ significantly between the piedmont alluvial plains to the east and the Guadalupe Mountain area and the lava-capped plateau to the west. Surficial alluvial sediments form the principal aquifer(s) in the eastern parts of the study region. Groundwater occurs under water table and semi-confined conditions (Winograd, 1959). Confining conditions occur locally where the groundwater is forced to flow beneath lenses of low permeability silt and clay. Yet, the confining clay lenses are generally discontinuous and areally limited (hence the

term "semi-confined conditions"). The gradients under which the groundwater moves through the alluvial sediments range from approximately 0.01 to 0.04 feet/foot, or 50 to 200 feet to the mile (Winograd, 1959).

In the vicinity of Cerro, and southward towards Questa, the water table is typically 60 to 160 feet below ground surface, depending on local topography. Most irrigation and water supply wells in this area are completed in the surficial alluvium of recent age (less than 300 feet below ground surface). The specific capacity of these wells is typically less than 20 gpm per foot of drawdown (Winograd, 1959).

In the western parts of the study region, the volcanics form the principal aquifer. In the volcanics, groundwater movement is controlled by fracture permeability, lava flow-boundary permeability and to a lesser extent vesicular permeability (Dames and Moore, 1987). Beneath Guadalupe Mountain and further to the west, groundwater in the volcanic aquifer occurs under water table conditions. However, where the volcanics are overlain by alluvial sediments of appreciable thickness (i.e. east of the Guadalupe Mountain) groundwater is often confined (Winograd, 1959). Owing to the high formation permeability of the volcanics, hydraulic gradients are typically much lower than in the alluvial sediments. Dames and Moore (1987) estimated gradients of approximately 0.0036 feet/foot, or 19 feet to the mile, in the Guadalupe Mountain area.

The water table in the volcanic aquifer(s) is typically several hundred feet below ground surface. The only two water supply wells presently completed in the deep volcanic aquifer(s) are operated by the Bureau Land of Mines in the "Rio Grande Gorge Wild and Scenic River Area". One well is located at the BLM's headquarters and the other one is located at the Chiflo Campground. Both wells produce approximately 30 gpm and operate on a pressure-demand basis (Dames and Moore, 1987). A pump test conducted in a test hole completed in the deep volcanics at the toe of Molycorp's tailings dam No. 4 indicated a specific capacity of approximately 250 gpm per foot of drawdown (South Pass Resources, 1993).

The interaction of shallow groundwater flowing in the sediments of the piedmont alluvial plains and the deep groundwater flowing in the volcanic aquifer(s) is of special importance in this study. It is commonly observed that the hydraulic heads in the alluvial sediments are many tens of feet greater than in the underlying volcanics (e.g. Winograd, 1959; South Pass Resources, 1993). The downward movement of groundwater is retarded by a confining layer of lower permeability material, consisting either of an alluvial silt or clay bed or the upper portion of the lava flow where the fractures have been filled with clay, sand and gravel (Winograd, 1959). This confining layer causes the great head differential between the upper alluvial aquifer and the deeper volcanic aquifer. Groundwater moves through this confining layer recharging the deeper volcanic aquifer below. The absence of springs at the surficial contact of the alluvial sediments and the volcanics, plus the similarity in chemical composition of the water in the volcanics to that in the alluvial sediments, are further evidence that water from the sediments moves into the underlying volcanics (Winograd, 1959).

Perched conditions, i.e. shallow groundwater flow on top of low permeability clay lenses and/or layers resulting in a zone of aeration, occur locally within the alluvial sediments but are not considered important at the regional scale (Winograd, 1959).

Groundwater in the study area generally moves from areas of higher elevation, i.e. recharge areas at the base of the Sangre de Cristo Mountains, to those of lower elevations, i.e. discharge areas along the Rio Grande and the Red River (Winograd, 1959). The groundwater initially moves in a westerly direction through the alluvial sediments, which underlie most of the area receiving recharge, and drains eventually into the underlying, permeable volcanics. The Guadalupe Mountain complex evidently does not represent any barrier to flow and groundwater continues to move in a southwesterly direction beneath this mountain complex (Dames and Moore, 1987).

Groundwater flow down-gradient of the Guadalupe Mountain is controlled primarily by hydraulic properties of volcanics (in particular lobate dacite flows from the Guadalupe Mountain complex) and by the sedimentary Santa Fe Formation (Dames and Moore, 1987). East of the fault zone the water table is in very permeable volcanics and groundwater is discharging at natural discharge points in and adjacent to the Rio Grande and the Red River.

West of the Red River Fault Zone, however, the Santa Fe sediments are uplifted and placed in the flow path of the regional groundwater system. Owing to their low permeability the Santa Fe sediments act as an aquitard restricting groundwater flow from volcanic aquifers east of the fault zone to the Rio Grande and the lower 2 miles of the Red River (Dames and Moore, 1987).

An exception is the dacite filled paleo-channel within the Santa Fe sediments, which emerges at the Big Arsenic Springs complex. The dacite has a relatively high permeability and appears to be an avenue of higher flow through the Santa Fe sediments (Dames and Moore, 1987). This condition explains the presence of the approximately 18 cfs of groundwater discharge in the Big Arsenic Spring complex (see below).

The western flank of the Sangre de Cristo Mountains is thought to be the principal area of groundwater recharge in the study region. The Rio Grande and the Red River gorges are the principal areas of groundwater discharge. Both, groundwater recharge and discharge rates in the study region have been estimated by various authors.

Precipitation in the study area ranges from 14 inches or less below 8,000 feet of elevation to over 30 inches in higher elevations. However, only a small percentage of this precipitation will actually recharge the aquifers. McAda and Waseolek (1987) estimated that the annual recharge from percolation of precipitation in the Espanola Basin (immediately to the south of the study region) is no more than 0.28 inches per year in those areas covered by the Santa Fe Group formation.

Most of the recharge to the groundwater probably occurs from ephemeral and perennial streams running off the Sangre de Cristo Mountains (and related irrigation ditches), which upon leaving their mountain courses and entering the plateau area, lose much of their flow to permeable alluvial sediments. Other sources of recharge are leakage from arroyo flood flows, and infiltration of water pumped for irrigation. Most recharge is to the groundwater body in the alluvial sediments. Recharge to the volcanics occurs predominantly though leakage from the overlying alluvial sediments. Vail estimated that the total recharge to the study region is in the order of 50 cfs (Vail, 1993).

Groundwater discharge in the study region is predominantly through natural springs into and near the Rio Grande and the Red River. The spring flows have been estimated directly and indirectly using accretion measurements (during low flow periods) in these rivers. Dames and Moore (1987)

provide a comprehensive review of springs flows and river accretion measurements. The results of their review are shown in Table 2.1 and can be summarized as follows:

- total accretion to the Rio Grande from the Cerro Chiflo gauging station to the confluence with the Red River is approximately 45 cfs; the groundwater contributions from the east (i.e. the study region) along this river stretch is estimated to be about 31 cfs (or ~65 % of total accretion);
- the Big Arsenic Spring complex is the single largest source of groundwater discharge to the Rio Grande in the study region accounting for 18 cfs alone (Table 2.1);
- total accretion to the Red River from State Highway 3 to the confluence with the Rio Grande is approximately 32 cfs; the groundwater contributions from the north (i.e. the study region) along this river stretch is estimated to be about 21 cfs (or ~65 % of total accretion);
- over 50 percent of the groundwater and spring flow accretion to the Red River occurs upstream of the Fish Hatchery (~18 cfs) with an estimated 12 cfs discharging from the north (i.e. the study region); and
- total discharge of groundwater from the study area to the Rio Grande and Red River combined is estimated to be approximately 50 cfs; for a plane that is perpendicular to the general direction of the regional groundwater flow system, connecting Cerro Chiflo to the head of the Red River Canyon (a length of approximately 5 miles), this estimate yields a flow of approximately 10 cfs per mile of section.

Vail (1993) studied the groundwater accretion to the Red River upstream of the Fish Hatchery in more detail using measurements of stream and spring flow as well as water quality. He distinguished between "cold springs" discharging from alluvial sediments upstream of the Red River Canyon (temperaure ranging from 7° to 10° C) and "warm springs" emanating from the volcanics in the Canyon (temperature ranging from 14° to 16° Celsius). The total flow from the cold springs (commonly referred to as "Questa Springs" or "Big Springs") and related field drainage from the north to the Red River was estimated to be about 5 cfs. The total flow from the warm springs to the Red River above the Fish Hatchery was estimated to be about 13 cfs from north and south combined.

At the regional scale, the groundwater system in the study region appears to be in relative equilibrium (Dames and Moore, 1987). No major changes in spring flows and/or static water levels have been observed in the volcanics and alluvial aquifers as a result of pumping (for irrigation) and/or seasonal recharge. Only very shallow wells show seasonal variations in water levels corresponding to seasonal recharge.

Table 2.1.

Summary of Accretion to Rio Grande and Red River (after Dames and Moore, 1987).

	Total Accretion	Estimated groundwater contribution from study region
Rio Grande		
Cerro Chiflo to Red River Fault Zone	22 cfs	11 cfs from east
Red River Fault Zone to Confluence	23 cfs	18 cfs from Big Arsenic Springs Complex plus 2 cfs from east
Subtotal	**45 cfs**	**31 cfs**
Red River		
Questa to Fish Hatchery	18 cfs	12 cfs from north
Fish Hatchery to Red River Fault Zone	10 cfs	7 cfs from north
Red River Fault Zone to Confluence	5 cfs	2 cfs from north
Subtotal	**32 cfs**	**21 cfs**
TOTAL	**77 cfs**	**52 cfs**

2.3 Conceptualization and Model Construction

2.3.1 Conceptual Model

Based on a comprehensive review of all available information on the geology and hydrogeology of the study region, the following hydrogeological units were defined:

- Surficial alluvial deposits (al);
- Volcanic rocks of Guadalupe Mountain (gv);
- Mixed volcanics in Red River Fault Zone (gv, sbu & sbl);
- Dacite flow in "paleo-channel" (gv); and
- Santa Fe sediments (al_{SF});

Figure 2.3 shows the spatial distribution of these hydrogeological units in the conceptual model. The conceptual model consists of four horizontal layers and five zones. Note the vertical exaggeration (10 x) in this three-dimensional block model. The screened intervals of water wells and spring discharge points all lie within layer 1 (elev. 7200' to 7750') and layer 2 (7000' to 7200'). Layer 3 (6700' to 7000') and layer 4 (6400' to 6700) were included into the model, however, to permit deep recharge from Sangre de Cristo Mountains as well as (potentially) deep circulation of groundwater prior to discharge into the Rio Grande and/or Red River.

The surficial alluvial deposits are assumed to be present in layers 1 and 2 in the eastern part of the model (Zone 1). These deposits are assumed to be much more permeable than the older Santa Fe sediments, accounting for most of the recharge at the upgradient boundary.

The volcanic rocks of the Guadalupe Mountain are assumed to be present in layers 1 and 2 in the central portion of the model (Zone 2). These volcanic rocks of local origin outcrop in the Red River gorge upstream of the Fish Hatchery and also in the Rio Grande gorge near the Cerro Chiflo gauging station. Higher than average spring flows in these areas suggest that this unit is very permeable.

In the "Red River Fault Zone" (Zone 3) the Guadalupe volcanics are interbedded with and displaced against Servilleta flood basalts which were uplifted along several southeast – northwest trending faults (see Figures 2.2 and 2.3). The influence of this zone on regional groundwater was not known a priori and was evaluated during model calibration.

Note that the Red River Fault Zone (and all other units west of the Fault Zone) was not represented in Layer 1 because the groundwater in this region is known to reside entirely within layer 2 (and possibly deeper).

Predominantly old Santa Fe sediments are encountered to the west of the Red River Fault Zone (Zone 4). No major spring flows have been recorded in this region suggesting that this unit has a relatively low permeability.

The Arsenic Springs in the Rio Grande gorge several miles upstream of the confluence with the Red River represent a major discharge point for the regional groundwater system. The spring flow is emerging from what is believed to be a paleochannel, now filled with lobate Dacite flows from the Guadalupe mountains (Zone 5). The extent and exact location of this apparently very permeable paleochannel is unknown. It is assumed here that this very permeable Dacite flow extends through the Red River Fault Zone and connects with the permeable Guadalupe volcanics (Zone 2) (Figure 2.3).

The Santa Fe sediments are assumed to be present throughout layers 3 and 4. These sediments are old and highly consolidated and/or cemented allowing relatively little groundwater flow in them.

At a regional scale, groundwater is moving in a predominantly southwesterly direction, i.e. from the Sangre de Cristo Mountains towards the Rio Grande and the Red River. Although the Guadalupe Mountains represent a local topographic divide, they are not considered to significantly alter the direction of the deep, regional groundwater flow.

Groundwater is assumed to enter through the western (upgradient) face of the model domain (predominantly through layers 1 and 2) representing recharge from the Sangre de Cristo

Mountains. Recharge from local precipitation is assumed negligible and is not included in the regional flow model. The current recharge from the tailings impoundments into the regional groundwater flow system has been estimated to be in the order of 1 cfs (Geocon, 1983). Hence, a recharge value of 1 cfs, equally distributed across the surface area of the tailings impoundment is used for calibration of the regional groundwater flow model.

The Red River to the south and Rio Grande to the west are the only discharge areas of groundwater. The river beds of these two rivers are entirely within layers 1 and 2 and there are no discharge points in layers 3 and 4. In those areas, where the rivers flow through permeable, surficial alluvium or permeable volcanics (gv), groundwater levels are assumed to be controlled by the river; i.e. groundwater levels are assumed equal to river elevation. In those areas where the riverbed is in less permeable units the groundwater levels are assumed to be structurally controlled. For example, at the Big Arsenic Springs complex, groundwater emerges some 400' above the bottom of the Rio Grande Canyon at the bedding plane of permeable volcanics and underlying, low permeability Santa Fe sediments. In such areas, groundwater levels near the rivers are assumed to be controlled by observed elevations of major groundwater springs (in particular Big Arsenic Springs).

Groundwater flow is assumed to be at steady state, i.e. seasonal variations of heads and/or flows are assumed negligible.

2.3.2 Numerical Model

Regional groundwater flow was simulated using the popular finite difference groundwater flow code MODFLOW, developed by the USGS (McDonald and Harbaugh, 1988) in conjunction with the GMS pre-post processor (ECGL, 1997), which is commercially available and licensed to Robertson GeoConsultants Inc..

Figure 2.4 shows the finite difference grid and boundary conditions for model layers 1 and 2. The model domain is discretized into 42 rows by 55 columns with equal grid spacing of 1000 ft. The same grid spacing was used in all four model layers resulting in a total of 9240 cells. Note that the active model grid in layer 1 extends only to the Red River Fault Zone. The active model grid was not extended further to the west since the water table in this area is known to be several tens of feet below the bottom of model layer 1.

A constant head boundary is used at the eastern boundary in all four layers. Constant head values range from 7750 ft in the north-eastern corner to 7360 ft in the south-eastern corner, i.e. at the confluence of Cabresto Creek and Red River. The constant head values at this upgradient boundary were assumed to be equal in all four model layers.

The northern boundary of the model domain, running approximately from the town of Cerro to the Cerro Chiflo gauging station in the Rio Grande gorge, was modeled in all four model layers as a no-flow boundary, representing a regional flow line.

The boundary conditions for the southern and western boundaries of the model domain differed between the four model layers. In layer 1, a constant head boundary condition was used for that stretch of the Red River, which lies within this model layer. The constant head values ranged from 7360 ft to 7200 ft representing the river elevation in this stretch of the Red River. A no-flow

boundary was used for the remaining section of the southern boundary and the western boundary.

In model layer 2, constant head boundary conditions were used for the lower section of the southern boundary (representing the lower Red River from the upstream end of the Canyon to the confluence) and the entire western boundary (representing the Rio Grande Canyon). The constant head values of the southern boundary (Red River Canyon) ranged from 7200 ft at the entrance of the Canyon to 7000 ft at the confluence with the Rio Grande. The constant head values of the western boundary ranged from 7140 ft at Cerro Chiflo to 7030 ft at Arsenic Springs and on to 7000 ft at the confluence. Note that the assumed water table in the lower section of the Rio Grande and Red River Canyons is assumed to be structurally controlled, i.e. lies several hundred feet above the riverbed elevation (Vail, 1987).

In model layers 3 and 4, the southern and western boundaries of the model domain were assumed to be no-flow boundaries, representing convergent flow from both sides of the rivers. In other words groundwater can not pass beneath the rivers and deep flow is required to move upward and discharge in the rivers.

All groundwater flow simulations were run assuming steady-state flow in the regional model.

2.3.3 Model Assumptions

The main assumptions in our approach to modeling the regional groundwater flow system are as follows:

- at the scale of the analysis, the geologic units can be grouped into five hydrogeologic units: (1) surficial alluvial sediments, (2) volcanics of Guadalupe Mountain, (3) mixed volcanics of Red River Fault Zone; (4) Dacite flow in paleochannel, and (5) Santa Fe sediments;
- groundwater flow in all hydrogeologic units follows Darcy's Law; flow through fractured rock (e.g. volcanics) can be modeled using the "equivalent porous medium" approach, i.e. average, "effective" permeabilities can be assigned to each unit;
- recharge to the model domain can be simulated as inflow from the eastern boundary of the model domain using constant head boundary conditions; recharge from precipitation can be ignored;
- the Red River and the Rio Grande Canyon represent natural discharge points of groundwater in the study region; river elevation or spring elevation control the groundwater levels in vicinity of the discharge points; groundwater does not pass beneath the rivers as a result of converging flow; and
- the three-dimensional groundwater flow system is at steady-state.

2.4 Model Calibration

The regional groundwater flow model was calibrated against observed head values and measured springs flows and/or estimates of accretion to individual reaches of the Rio Grande and Red River, respectively. Figure 2.5 shows the location of the groundwater wells and the extent of the river reaches used for model calibration. The actual calibration targets for observed head (static water level in well) and estimated groundwater discharge (river accretion) are listed in Table 2.2 and 2.3, respectively. A uniform confidence interval of ± 25 feet was assigned to each of the available monitoring wells.

Note that only one river reach ("Upper Red River") lies in model layer 1. All other river reaches lie in model layer 2. The accretion values used for calibration of the regional flow model (Table 2.3) are essentially identical with estimates provided by Dames and Moore (compare Table 2.1) with one exception. We have used slightly higher values for groundwater discharge from the study region to the Red River (i.e. in the reach of the Red River Canyon above the Fish Hatchery), based on discussions with staff from the Hatchery who have been collecting spring flows in this area for several decades.

The regional groundwater flow model was calibrated using the trial-and-error approach. The following parameters were varied during calibration:

- permeability of all hydrogeological units; and
- constant head values at upgradient boundary;

The constant head values at the downgradient boundaries (i.e. elevation of springs and/or river bed) were assumed to be known. The spatial orientation of the various hydrogeological units was also not changed. Initial calibration runs using varying degrees of vertical anisotropy indicated that this parameter is not an important controlling factor at the regional scale. Hence, isotropic conditions were assumed for the regional model (Note, however, that vertical anisotropy is an important factor at the local scale, see chapter 3).

The calibration started with head values at the upstream boundary using a map of depth to groundwater published in Winograd (1959). In addition, initial estimates of permeability were used which were considered typical for the various hydrogeological units.

The model was subsequently refined by adjusting the heads at the upstream boundary and in particular by varying the permeability values of the various units. The permeability values were adjusted in increments of half an order of magnitude at first. It was found, however, that the spring flows were quite sensitive to the permeability of the more permeable units (volcanics and in particular the dacite flow in the paleo-channel). Hence, these permeability values were varied at even finer increments.

Table 2.2

Calibration Targets used for Regional Flow Model

Well ID	Location	Collar Elevation (ft asl)	Material	Screening Interval (ft asl)	Depth to Water Minimum (ft b.c.)	Depth to Water Average (ft b.c.)	Depth to Water Maximum (ft b.c.)	Calibration Target (ft asl)	Confidence Interval (ft)
R-6[1]	29.13.7.333	~7610*	Alluvium	7475 (+)	N/A	62	N/A	7550	+/- 25
Sanchez[1]	29.13.18.414	~7760*	Alluvium	7485' (+)	N/A	205	N/A	7555	+/- 25
Young[2]	29.13.19.322	~7650*	Alluvium	unknown	128.7	146	164.5	7500	+/- 25
Questa[3]	near High School	~7640	Alluvium	7290' (+)	N/A	~220	N/A	7420	+/- 25
MW-10[4]	Embargo Rd	7353	Alluvium	7228'-7258'	28.8	30	30.9	7322	+/- 25
MW-1[4]	arroyo south of Dam 1	7275	Volcanics	7170' (+)	47.9	51	54.2	7226	+/- 25
MW-11[4]	arroyo south of Dam 4	7347	Volcanics	7095'-7135'	193.2	194	194.4	7153	+/- 25
G-1[5]	Guadalupe Mtn.	7940	Volcanics	6929'-7160'	785.5	787	788.4	7153	+/- 25
G-3[5]	Guadalupe Mtn.	7627	Volcanics	7131'-7187'	N/A	475	N/A	7152	+/- 25
CE-1[5]	near Cerro Chiflo	7856	Volcanics	7121' (+)	697	699	701	7157	+/- 25
BLM-Chiflo[5]	Cerro Chiflo Campsite	7493	Volcanics	7083'-7102'	342	343	344	7150	+/- 25
BLM-HQ[5]	BLM Headquarters	7570	Volcanics	7034'-7057'	485	486	487	7084	+/- 25

Notes:

[2] from State Engineers Office, 1997

[3] from Questa Municipal Office, 1997

[4] unpublished Molycorp files (1996-1997)

[5] from Dames and Moore, July 1987

* estimated from 1:24000 topo maps

+ bottom of hole (screen interval unknown)

Table 2.3.

Calibration Targets For Groundwater Discharge (all in cfs).

Reach	Estimated Discharge (in cfs)	Confidence Interval (in cfs)	Simulated Discharge w/ calibrated regional flow model (in cfs)
Upper Rio Grande	11	±2	13.1
Lower Rio Grande	2	±2	0.3
Arsenic Springs	18	±2	18.9
Subtotal for Rio Grande	**31**		**32.3**
Upper Red River	4	±2	1.8
Red River above Fish Hatchery	10	±2	11.7
Red River Fault Zone	7	±2	7.9
Lower Red River	2	±2	0.0
Subtotal for Red River	**23**		**21.3**
TOTAL	**54**		**53.7**

The calibrated permeability values for the five hydrogeological units are as follows:

- surficial alluvial deposits - $3 \cdot 10^{-3}$ cm/s ($1 \cdot 10^{-4}$ ft/s);
- Guadalupe volcanics - $1.5 \cdot 10^{-1}$ cm/s ($4.9 \cdot 10^{-3}$ ft/s);
- volcanics of Red River Fault Zone - $5 \cdot 10^{-2}$ cm/s ($1.6 \cdot 10^{-3}$ ft/s);
- dacite flow in paleochannel - $3 \cdot 10^{-1}$ cm/s ($1 \cdot 10^{-2}$ ft/s); and
- Santa Fe sediments - $3 \cdot 10^{-4}$ cm/s ($1 \cdot 10^{-5}$ ft/s).

The calibrated "effective" (or formation) permeabilities are within the range of published values for the various units (Freeze and Cherry, 1979). Note the very high permeability of the Guadalupe volcanics and the dacite flow in the paleo-channel. The permeability of these volcanics is about two orders of magnitude greater than that of the surficial alluvial deposits.

The hydraulic head contours of the calibrated flow model are shown in Figure 2.6. The error bars shown next to the calibration targets represent the assumed confidence interval of ±25 feet. The match of the simulated and observed hydraulic heads is considered acceptable, in particular throughout the volcanic aquifer. Note that the regional flow model correctly predicts that the water table in the volcanics falls below model layer 1 before reaching the Guadalupe Mountain

(note the absence of head contours in the volcanic in most of the volcanics (zone 2) in model layer 1).

The only significant discrepancy between observed and simulated heads was observed in the tailings area (in particular for MW-10), where the model predicted much lower heads than are actually observed. As will be shown in the local groundwater flow model (chapter 3), this is a result of strong vertical anisotropy of the alluvial sediments (at least in this area).

The volumetric flow vectors shown in Figure 2.7 give a graphical representation of the direction and quantities of groundwater flow in the study region. The simulated groundwater flows to the various river reaches are shown in Table 2.3. The calibrated regional flow model simulates accretion to those reaches with major groundwater discharge (i.e. Upper Rio Grande, Arsenic Springs, Red River above F.H. etc.) very well.

Some discrepancy between simulated and estimated accretion was observed for the lower Rio Grande, the lower Red River and the Upper Red River (Table 2.3). The estimated accretion to the lower Rio Grande and the lower Red River is not very well known, and it can not be ruled out that there is significantly less accretion than previously estimated. In the case of the upper Red River, however, the accretion is relatively well known and the model probably does underpredict flow to the Red River. This discrepancy is attributed to the fact that vertical anisotropy is important in this area of the study region (see chapter 3). Nevertheless, these discrepancies apply only to the local allocation of the discharge whereas good matches were observed for the subtotals of the Rio Grande and the Red River, respectively (Table 2.3).

2.5 Sensitivity Analysis

The sensitivity of the calibrated flow model to various model input parameters (in particular permeability of the various units) was evaluated in a sensitivity analysis. Table 2.4 summarizes the scenarios simulated. Note that the simulation run "Region 1a" represents the calibrated regional flow model. Note also, that the permeabilities of the various units were varied systematically from those of the calibrated model (i.e. permeability decreased by a factor of 5 or increased by a factor of 2).

The hydraulic head contours of the various scenarios are shown in Figures A.1 to A.7 (Appendix A). A comparison of simulated to observed heads for the calibration points is provided in Table A1. The simulated flows of the various scenarios for the calibration reaches are shown in Table 2.5. The results of the sensitivity analysis can be summarized as follows:

- recharge from the tailings does not significantly influence the hydraulic head distribution in the aquifers nor discharges of the regional groundwater to the rivers (Figure A.1);
- total flows in the regional groundwater system are very sensitive to the permeability of the surficial alluvial deposits; a higher permeability results in significantly higher flows into the alluvial aquifer and hence at the groundwater discharge points (and vice versa) (Figure A.2 and Table 2.5);

Table 2.4.

Simulation Runs used in Sensitivity Analysis.

Simulation	Description
"Region 1"	vary recharge from tailings a) total recharge from tailings = 1 cfs b) no recharge from tailings
"Region 2"	vary permeability of surficial alluvial sediments a) $K_{al} = 6 \cdot 10^{-3}$ cm/s ($2 \cdot 10^{-4}$ ft/s) b) $K_{al} = 6 \cdot 10^{-2}$ cm/s ($2 \cdot 10^{-5}$ ft/s)
"Region 3"	vary permeability of Guadalupe volcanics a) $K_{gv} = 3 \cdot 10^{-1}$ cm/s (1 10^{-2} ft/s) b) $K_{gv} = 3 \cdot 10^{-2}$ cm/s ($1 \cdot 10^{-3}$ ft/s)
"Region 4"	vary permeability of Red River Fault Zone a) $K_{RRFZ} = 1 \cdot 10^{-1}$ cm/s (3.3 10^{-3} ft/s) b) $K_{RRFZ} = 1 \cdot 10^{-2}$ cm/s ($3.3 \cdot 10^{-4}$ ft/s)
"Region 5"	vary permeability of Paleochannel a) $K_{Paleo} = 6 \cdot 10^{-1}$ cm/s (2 10^{-2} ft/s) b) $K_{Paleo} = 6 \cdot 10^{-2}$ cm/s ($2 \cdot 10^{-3}$ ft/s)
"Region 6"	vary permeability of Santa Fe sediments a) $K_{Santa\ Fe} = 6 \cdot 10^{-4}$ cm/s (2 10^{-5} ft/s) c) $K_{Santa\ Fe} = 6 \cdot 10^{-5}$ cm/s ($2 \cdot 10^{-6}$ ft/s)
"Region 7"	vary constant head at upgradient boundary b) constant heads increased by 50 ft d) constant heads reduced by 50 ft

Table 2.5.
Results of Sensitivity Analysis.
Simulated Flows for different Reaches of Red River and Rio Grande.

	Recharge region 1		Alluvium region 2		Volcanics region 3		R Fault Zon region 4		Arsenic Spr. region 5		Santa Fe region 6		Upgr. B. region 7	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Upper Red River	1.8	1.6	4.6	0.1	1.4	3.6	1.7	1.8	1.7	1.9	1.8	1.8	2.8	0.7
Red River a. F.H.	11.7	11.3	27.0	-1.6	13.8	8.4	8.2	15.9	7.5	17.1	14.0	9.8	14.4	9.2
Red River fault zone	7.9	7.8	9.5	6.5	8.3	6.2	14.2	1.9	6.4	9.6	8.3	7.5	8.2	7.6
Lower Red River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	21.4	20.7	41.1	5.0	23.5	18.2	24.0	19.5	15.6	28.6	24.0	19.1	25.4	17.5
Upper Rio Grande	13.1	12.9	32.1	-3.6	11.4	10.9	10.2	15.5	8.3	19.2	15.7	10.9	16.8	9.6
Arsenic Springs	18.9	18.9	22.2	16.0	19.7	16.0	18.8	18.2	29.3	5.2	19.6	18.3	19.6	18.3
Lower Rio Grande	0.3	0.3	0.4	0.2	0.3	0.2	0.3	0.3	0.2	0.4	0.6	0.1	0.3	0.3
Subtotal	32.3	32.0	54.7	12.6	31.4	27.1	29.3	34.0	37.8	24.9	35.9	29.2	36.7	28.2
TOTAL	53.7	52.7	95.8	17.6	54.8	45.3	53.3	53.6	53.4	53.4	59.9	48.3	62.1	45.7

Notes:
(1) simulation "region 1a" represents the calibrated regional flow mo

- the water table configuration in the volcanic aquifer (and to a lesser extent in the alluvial aquifer) is very sensitive to the difference in permeability between the volcanic aquifer and the alluvial aquifer; the higher the permeability of the Guadalupe volcanics relative to the alluvial sediments the lower will be the water table and the regional hydraulic gradients in the volcanics (and vice versa) (Figure A.3);

- the relative discharge flows of regional groundwater at the various reaches of the Red River and Rio Grande are sensitive to the permeability of the Red River Fault Zone and the paleo-channel: (1) a lowering of the permeability of the Red River fault Zone would result in higher spring flows in the Red River above the Fish Hatchery and in the uppermost reaches of the Rio Grande (and vice versa) and (2) an increase in permeability of the dacite flow in the paleochannel would divert even more groundwater flow away from the discharge points along the Red River above Fish Hatchery and along the upper Rio Grande and towards the Arsenic Springs (Table 2.5 and Figures A.4 and A.5);

- the permeability of the Santa Fe sediments does not influence the regional flow system significantly (no deep circulation); however it controls how much groundwater is flowing through these deep sediments and ultimately discharge into the Red River and Rio Grande;

- the hydraulic head at the upgradient boundary influences the hydraulic gradients in the alluvial aquifer near this boundary; a higher constant head results in increased groundwater flow into the regional groundwater system (and vice versa) (Table 2.5 and Figures A.7); and

- the direction of regional groundwater flow is not sensitive to the parameters studied here, i.e. the groundwater flow is predominantly in a westerly direction in the alluvial deposits and in a southwesterly direction in the volcanics.

The sensitivity analysis has shown that the groundwater flows and accretion values are quite sensitive to the permeabilities of the various hydrogeological units. Assuming our estimates of accretion to the various reaches of the Red River and Rio Grande (used for model calibration) are accurate, the calibrated permeabilities of the various units can be considered fairly accurate as well (i.e. probably to less than half an order of magnitude). Note that the simultaneous calibration of the regional groundwater flow model (against observed heads as well as estimated accretion to various reaches of the river) has significantly improved the accuracy of the calibrated flow model.

2.6 Discussion and Implications

The calibrated flow model illustrates several important characteristics of the regional groundwater flow system:

- the volcanics are much more permeable than the (recent) alluvial sediments, resulting in much lower hydraulic gradients in the volcanic aquifer compared to in the alluvial aquifer (Figure 2.6);

- highest hydraulic gradients are observed in the alluvial aquifer east of Cerro near the base of the Sangre de Cristo Mountains (0.06 ft/ft); lowest gradients are observed in the volcanic aquifer beneath the Guadalupe Mountain (0.003 ft/ft) (Figure 2.6);
- groundwater flow is predominantly in a westerly direction in the alluvial aquifer and assumes a southwesterly direction upon entering the volcanic aquifer (Figure 2.7);
- the dacite filled paleo-channel acts as an avenue of high groundwater flow in the plateau area channeling much of the regional groundwater flow towards the Arsenic Springs (Figure 2.7);
- the Santa Fe sediments to the west of the Fault Zone represent a major impediment to regional groundwater flow allowing very little accretion to the lower Rio Grande and the lower Red River (Figure 2.7); and
- total steady-state flux of groundwater in the study region is in the order of 50 cfs (Table 2.3); a large percentage of this flow (~90%) occurs above an elevation of 7000 ft (i.e. deep circulation through the Santa Fe sediments does not appear to be significant for the purpose of this study).

All of these characteristics are consistent with field observations suggesting that the calibrated regional flow model is a good representation of actual hydrogeologic conditions at the scale of interest. With respect to seepage from the tailings impoundment into the regional groundwater system the following conclusions can be drawn.

- seepage from the tailings facility in section 36 (behind Dam No. 1 and 1c) drains predominantly into the alluvial aquifer; the underflow of groundwater beneath section 36 is estimated to be approximately 1.5 and 4 cfs in layers 1 and 2, respectively;
- seepage from the tailings facility in section 35 (behind Dam No. 4 and 5) drains into the deeper, volcanic aquifer; the underflow of groundwater beneath section 36 is estimated to be approximately 7.5 cfs (layer 2);
- seepage from the tailings entering the regional groundwater system all discharges into the Red River upstream of the Fish Hatchery or close to it (Figure 2.7); and
- seepage from the tailings impoundments has no significant effect on the regional groundwater flow system (such as water table mounding).

Some of these conclusions will be further refined in the study of local groundwater conditions in the vicinity of the tailings impoundments (see chapter 3 on local groundwater flow model).

One important objective of the development of a regional flow model was to establish defensible boundaries for the local flow model. In the absence of any natural boundaries (e.g. topographic divides or rivers) to the north and west of the tailings impoundments the following approach was taken to establish this boundary. The direction of groundwater flow was traced by releasing a particle a significant distance upgradient of the impoundments and simulating its movement with

the groundwater (using particle tracking code MODPATH, Pollock, 1994). The trajectory of this particle is equivalent to a "flow-line". This flow line represents a no-flow boundary for the local groundwater flow.

Figure 2.8 shows the boundaries that have been selected for the local groundwater model using the calibrated regional flow model. The northern and western boundary of the local model follows a flow line starting at the 7480 contour line (near calibration well "Young" on State Highway 3) and running parallel to the impoundments until it reaches the Red River Fault Zone. This boundary reaches the Red River just downstream of the Fish Hatchery. The entire northern and western boundary is assumed to be a no-flow boundary.

On the eastern side, the local model boundary follows the 7480 ft contour line representing a constant head boundary. In the southeast and south, the model boundary follows Cabresto Creek and the Red River, respectively. Similar to the regional flow model, these rivers represent natural boundaries where groundwater converges and discharges. These boundaries would be modeled either as constant head boundaries (as done in the regional model) or as no-flow boundaries with discharge into the river a function of the permeability of the riverbed.

These boundaries isolate a section of the regional flow system for more detailed analysis at the local scale. At the same time this isolated section has been chosen sufficiently large, so that any possible changes in model parameters at the local scale do not influence the assumed boundary conditions significantly.

Figures

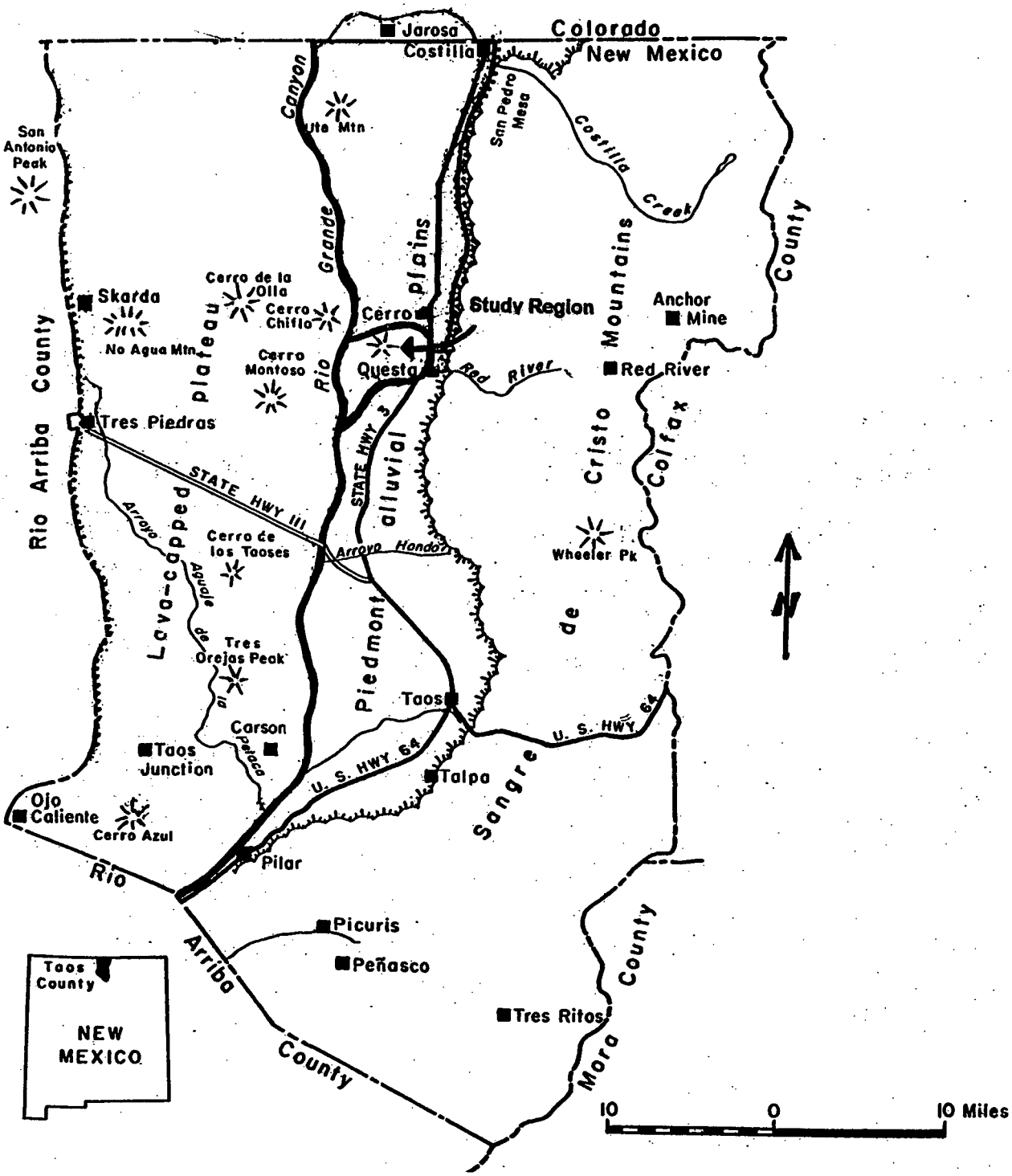
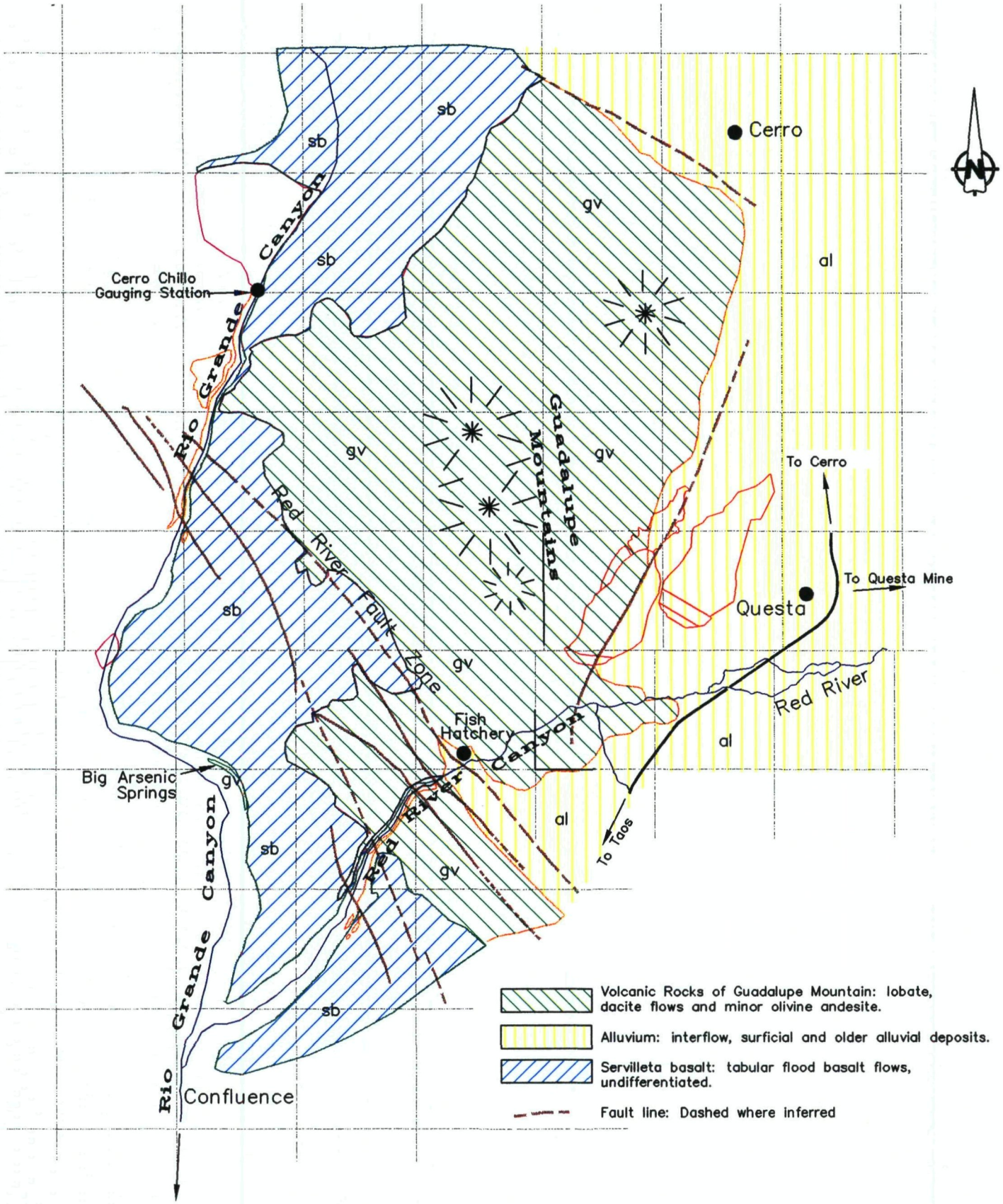


Figure 2.1.
Location of Study Area (adapted from Winograd, 1959)



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Molycorp - New Mexico

Questa Groundwater and Seepage Study

Regional Geology

(after Vail, 1987)

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
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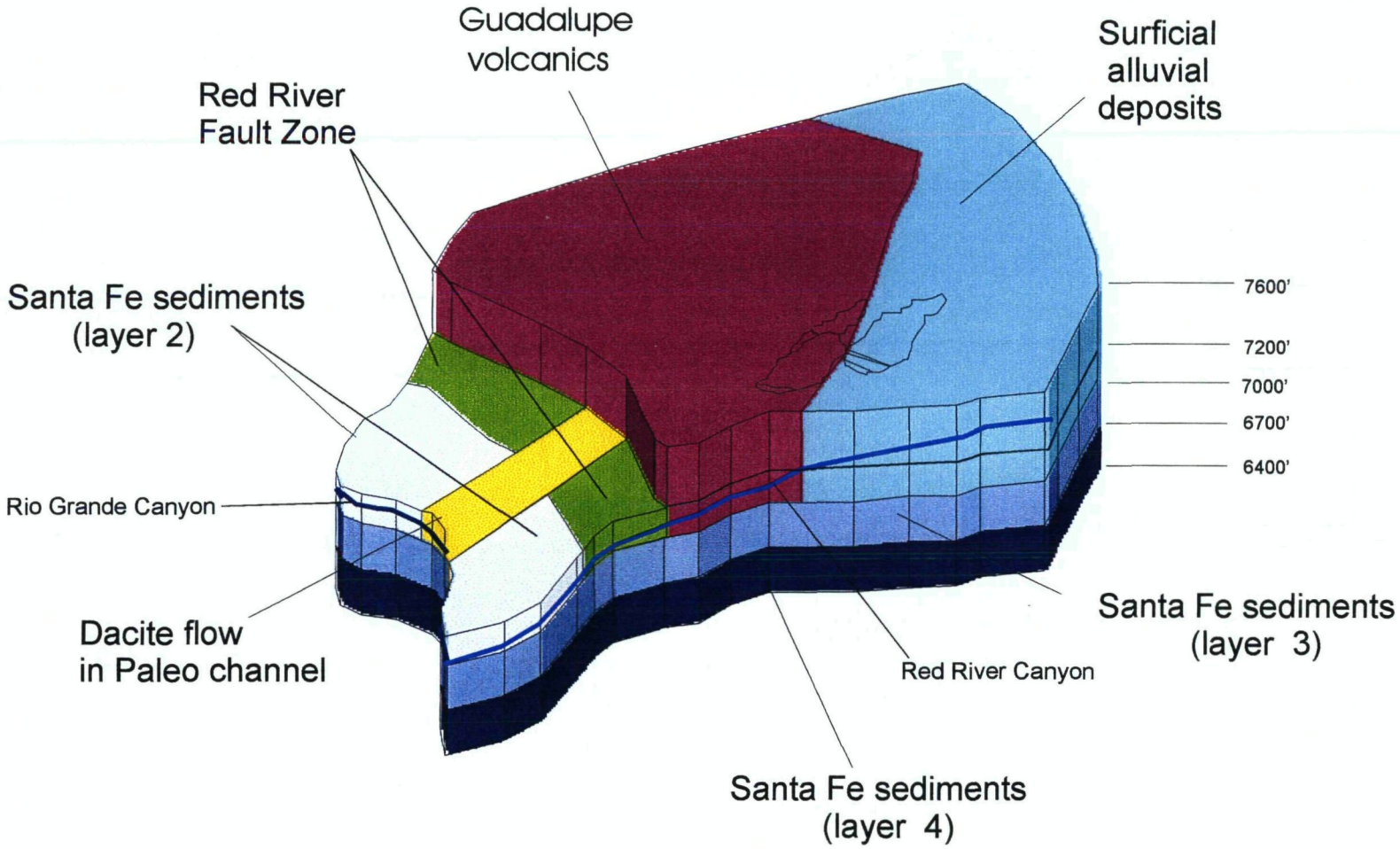

Vertical Scale= 10x Horizontal

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Questa Groundwater and Seepage Study

Conceptual Model of Regional Groundwater System

PROJECT NO.	DATE	APPROVED	FIGURE
052002	Oct. 1997		2.3

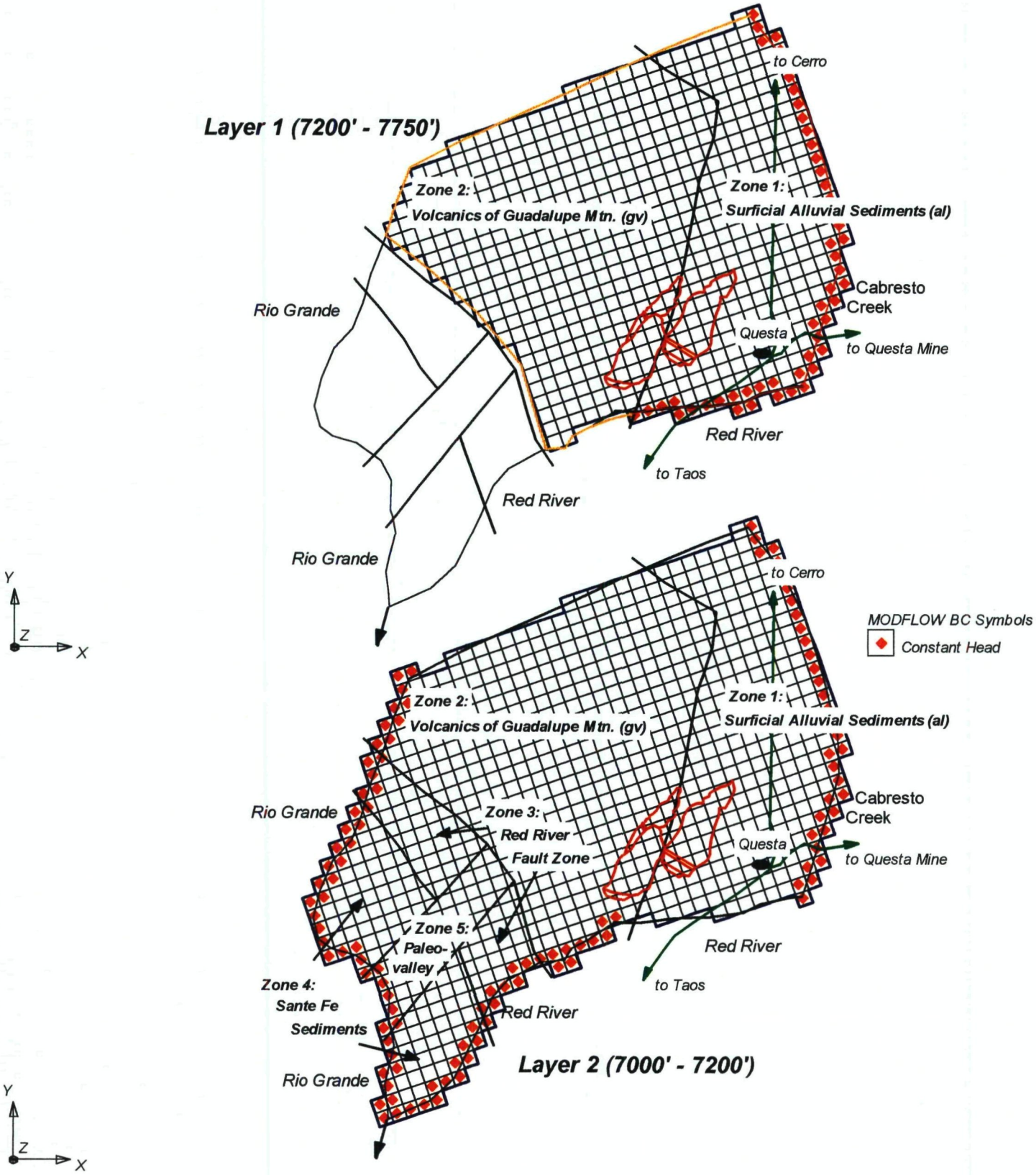


Figure 2.4.
Setup of regional groundwater flow model.

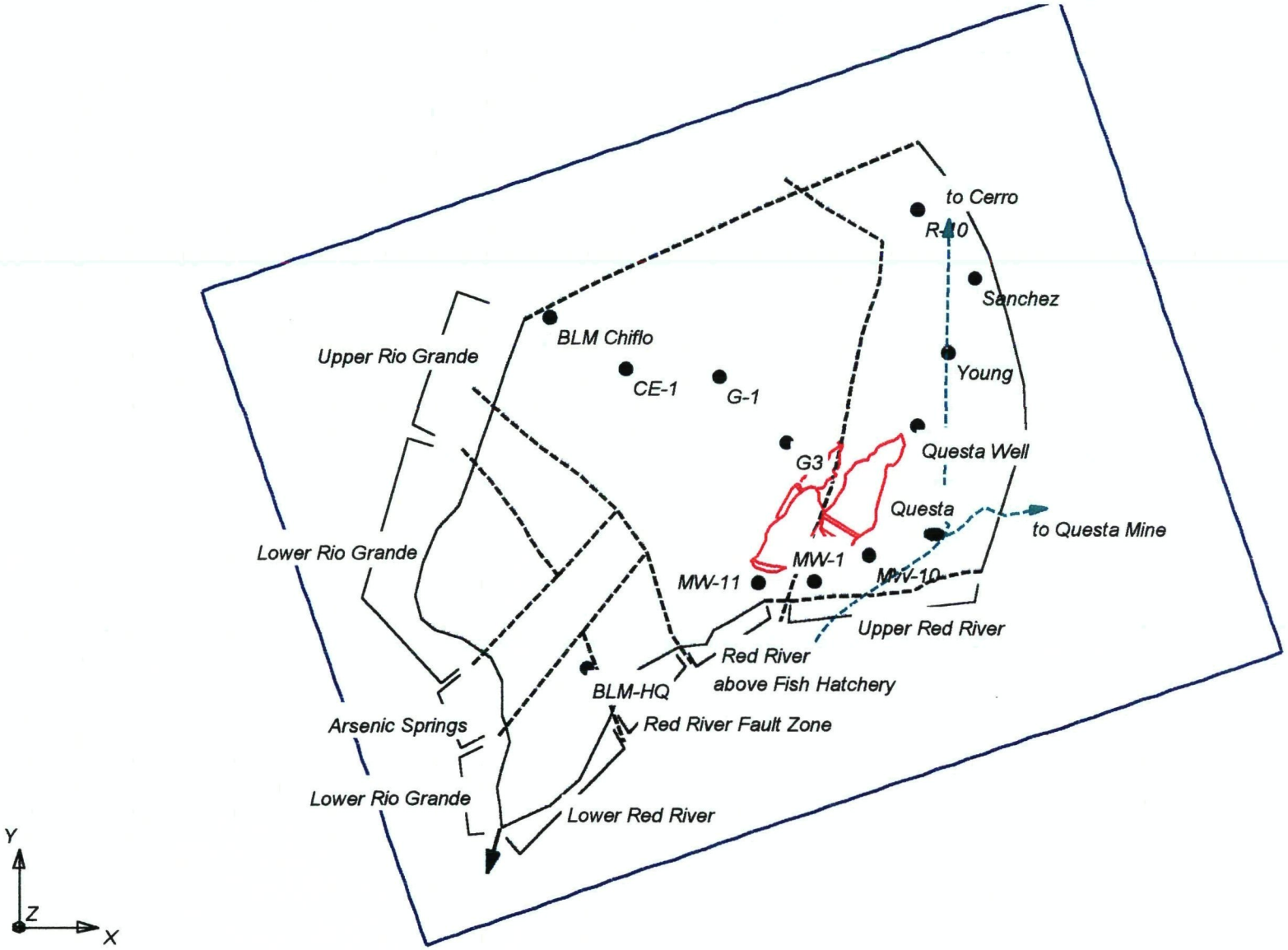


Figure 2.5.
Location of wells and river reaches used for calibration of regional groundwater flow model.

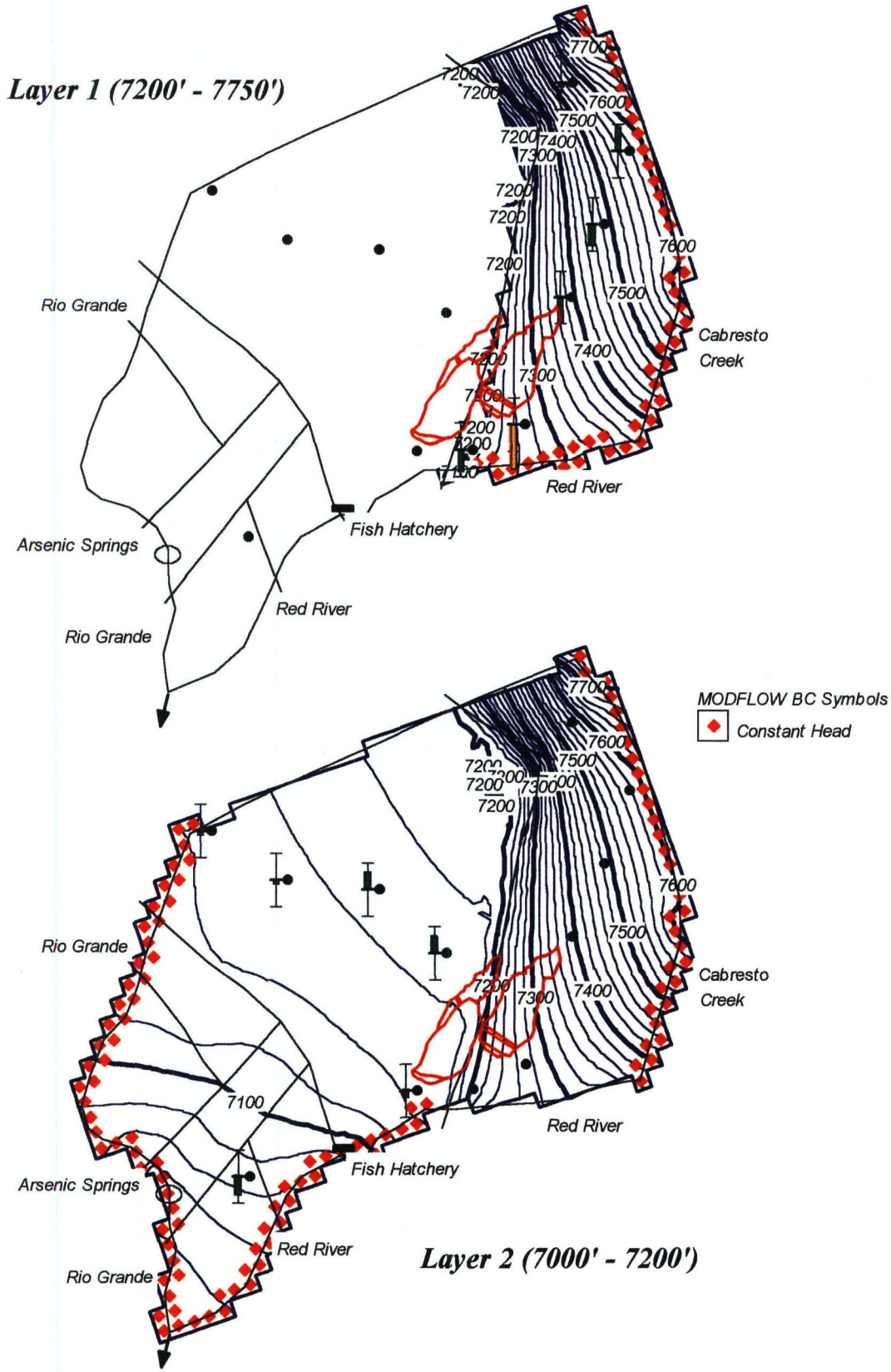


Figure 2.6.
Simulated heads for calibrated regional flow model.

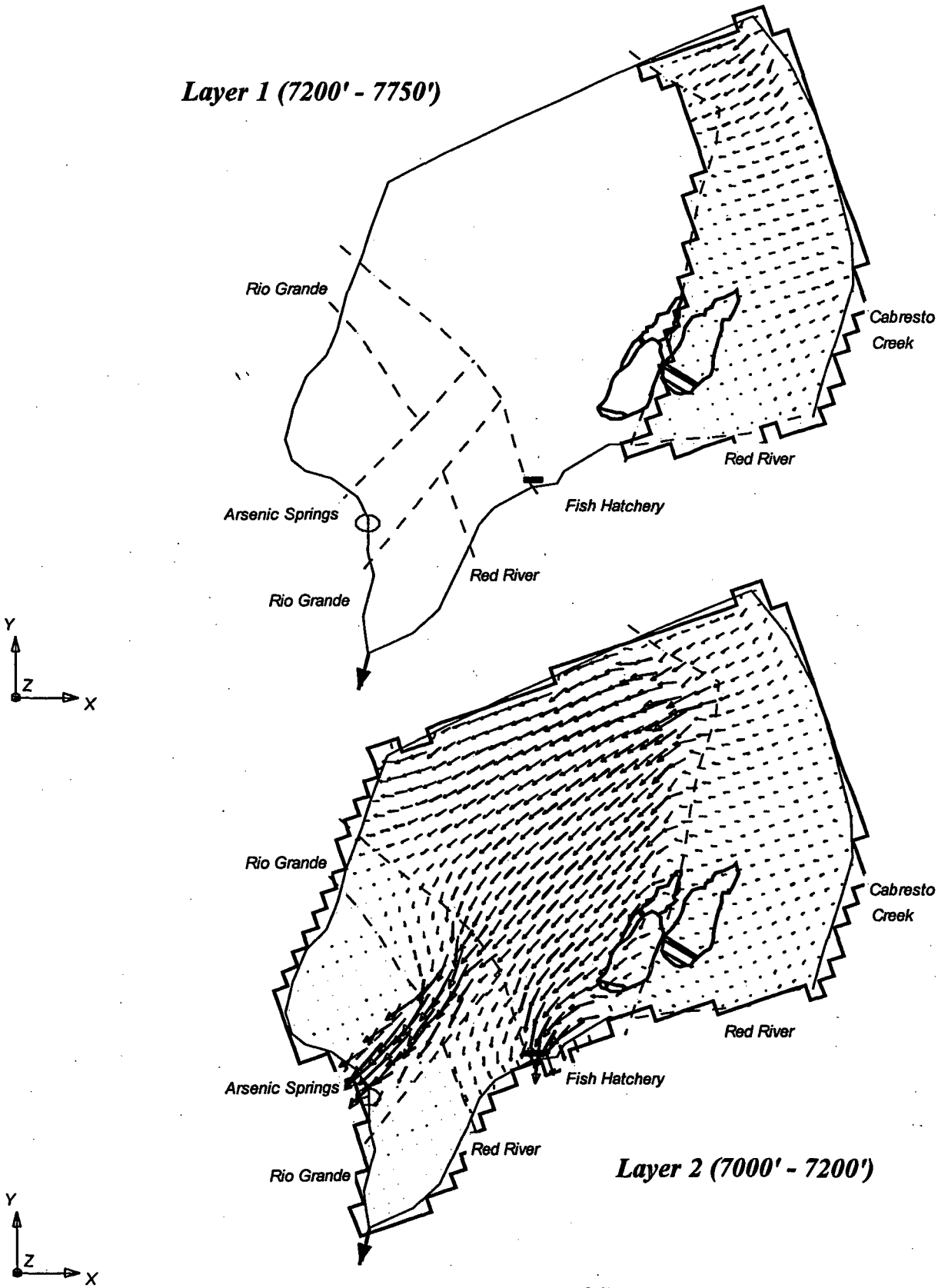
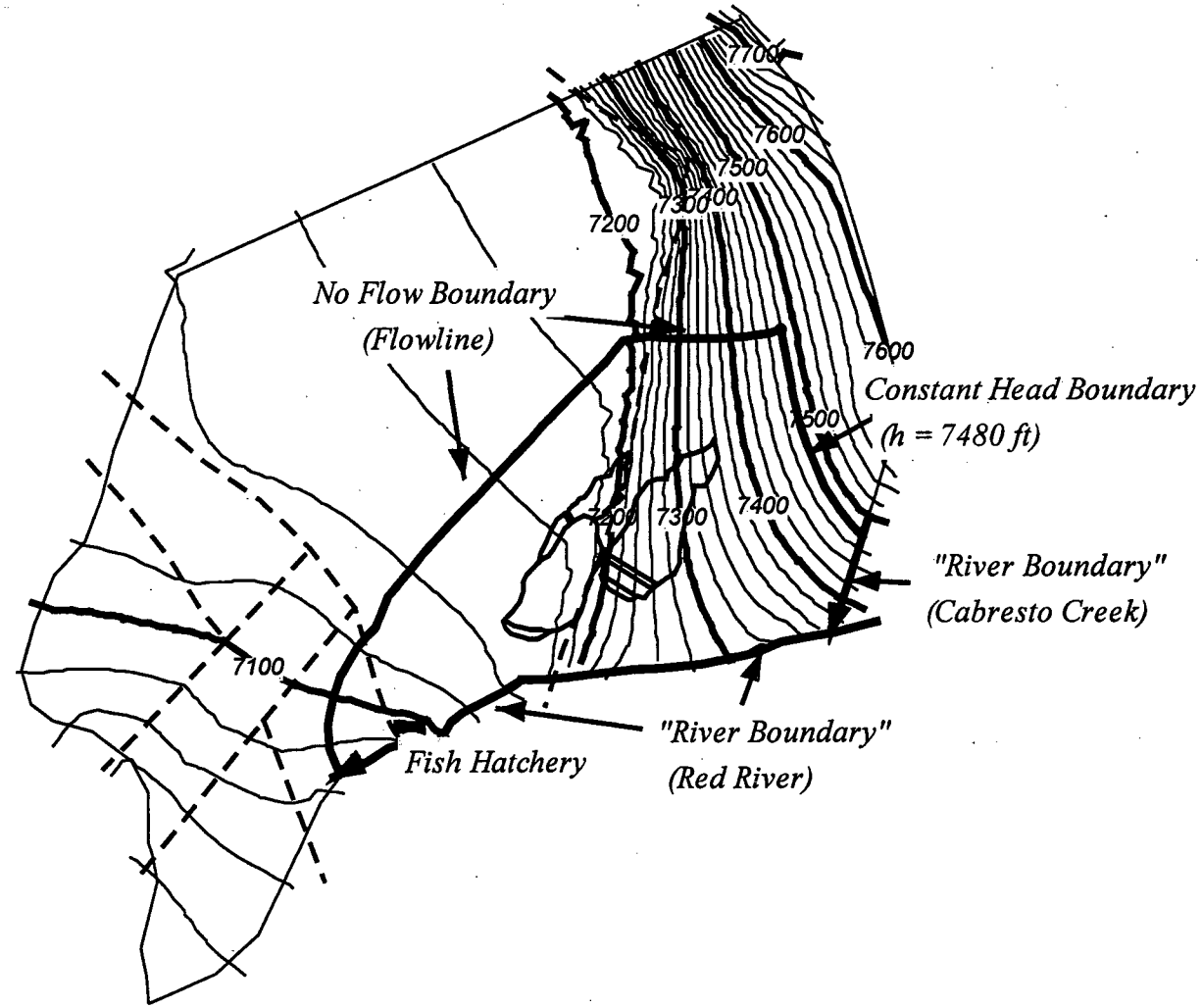


Figure 2.7.
Simulated volumetric flow vectors for calibrated regional flow model.



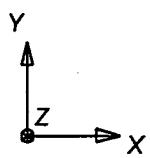


Figure 2.8.
Boundary conditions for local flow model deduced from regional flow model.

Section 3

3 Local Groundwater Flow Model

For a detailed planning of control measures to minimize seepage from the tailings facility upon closure (e.g. cover placement, extraction wells etc.) the local groundwater conditions need to be understood. The regional groundwater flow model, developed in the previous chapter, has shown that the tailings facility is located at the transition zone between the alluvial aquifer and the volcanic aquifer. The scale of the regional flow model, however, is not suitable to evaluate these complex hydrogeological conditions in vicinity of the tailings facility.

A local groundwater flow model has been developed to allow such an evaluation of local groundwater conditions. The local flow model provides insights into the hydrogeologic characteristics of the local aquifers, i.e. direction of groundwater flow in the area, the local recharge and discharge points of groundwater, and the volumes of groundwater flowing in the local aquifers.

This chapter describes the development of the local groundwater flow model. First, the results of previous studies on the local hydrogeology are reviewed. Based on this review (and results of the regional flow model) a conceptual model is formulated and implemented into a local flow model. Next, the local flow model is calibrated using observed water levels in the tailings area and estimates of groundwater flows at local discharge points (springs and rivers). A sensitivity analysis follows, illustrating the influence of critical hydrogeologic parameters on the flow solution. Finally, the implications for controlling seepage flow from the tailings into the local aquifers are discussed.

3.1 Objectives of Local Groundwater Flow Model

The objectives of the local groundwater flow model are as follows:

- to develop a water balance for the local groundwater flow system;
- estimate hydraulic conductivities for the local hydrogeological units;
- estimate groundwater flows of local aquifers receiving seepage from the tailings; and
- to evaluate the direction of groundwater flow beneath and downgradient of the tailings impoundments.

3.2 Local Hydrogeology

Molycorp Inc. has commissioned several field investigations since 1989 to evaluate the impact of tailings seepage on the water quality of the local aquifers. It was recognized that tailings seepage with elevated levels of TDS, sulphate and molybdenum was moving down-gradient and impacting on (shallow) private wells located immediately down-gradient of Dam No. 1. In 1993, five monitoring wells were installed down-gradient of the tailings impoundments by South Pass Resources Inc. (SPRI). The results of this field investigation are summarized in SPRI (1993). In

1994, four extraction wells and an additional monitoring well were installed down-gradient of the impoundments (SPRI, 1995). In the fall of 1997, an additional set of monitoring wells and extraction wells was completed under the supervision of Souder, Miller and Associates, Santa Fe, New Mexico. Most of the latest field results were not available for consideration in this report. During each field investigation, selected wells were pump tested to obtain estimates of aquifer transmissivity.

Figure 3.1 shows the local topography and the location of the various monitoring and extraction wells in the vicinity of the tailings impoundments. Figure 3.2 presents borehole logs of the various monitoring and extraction wells in the area (adapted from Vail, 1997). Table 3.1 summarizes the results of pump or bail tests conducted on selected wells to obtain estimates of aquifer transmissivity.

The reader is referred to the cited literature for detailed interpretation of the field investigations. Here we provide only a short synopsis of these findings. As a first approximation, the local groundwater system can be divided into an upper (shallow) aquifer system (above an elevation of ~7220 ft) and a lower (deep) aquifer system (below an elevation of ~7220 ft). The two aquifer systems may be characterized as follows:

- the shallow aquifer system consists of a complex mixture of recent alluvial sediments, ranging from coarse, permeable sand and gravel units to very low permeable clay layers (compare Figure 3.2 and Table 3.1); these alluvial and alluvial/lacustrine sediments appear to be lensoid in character with limited lateral extent resulting in very high spatial heterogeneity at the local scale;
- groundwater in the shallow aquifer system preferentially moves in permeable sand and gravel units of limited extent; it is difficult to isolate distinct aquifer units at this scale (note that SPRI has postulated the presence of an upper and lower aquifer separated by a middle aquitard; however, the lateral extent of these units is difficult to trace in the existing borehole logs); shallow groundwater may be unconfined or confined depending on the extent of locally confining silt and clay lenses; shallow groundwater also appears to be perched locally as a result of low permeability clay lenses and/or layers;
- groundwater flow in the shallow aquifer system is predominantly in a south-southwesterly direction discharging in various springs at or near the Red River (e.g. Big Springs including Questa Springs); some shallow groundwater percolates downward and into the deeper aquifer system (leakage);
- the deep aquifer system consists of volcanic rocks interbedded with permeable alluvial sediments (Figure 3.2); the volcanics have a very high secondary permeability (e.g. MW-11, Table 3.1);
- groundwater in the deep aquifer preferentially moves through permeable sand and gravel layers of the deep alluvium and fractures and bedding planes in the volcanics; to the east of Dam No 1 arroyo the deep aquifer system is confined; to the west the deep aquifer system is unconfined with a water table near or below the level of the Red River (Figure 3.2);

Table 3.1.
Results of Pump Tests near Tailings Facility.

Borehole	Aquifer Material	Method	Transmissivity g/d/ft	Transmissivity m^2/s	Saturated Thickness (ft)	Permeability $g/d/ft^2$	Permeability cm/s	Reference
MW-7a	sandy gravel	Cooper - recovery	2,500	3.6E-04	10	250	1.2E-02	
MW-10	gravelly sandy clay w/ thin layers of sandy gravel	Cooper - drawdown(1)	9	1.3E-06	50	0.18	8.5E-06	SPRI, 1993
		Cooper - recovery(1)	2	2.9E-07	50	0.04	1.9E-06	
		Specific Capacity Test (1)	51	7.3E-06	50	1.012	4.8E-05	
MW-11	volcanics	Cooper - drawdown	1,932,000	2.8E-01	56	34,500	1.6E+00	SPRI, 1993
		Cooper - recovery	784,000	1.1E-01	56	14,000	6.6E-01	
		Specific Capacity Test	383,700	5.5E-02	56	6,852	3.2E-01	
EW-2	sandy gravel	Cooper - drawdown	2,600	3.7E-04	30	87	4.1E-03	SPRI, 1994
		Cooper - recovery	27,000	3.9E-03	30	900	4.2E-02	
EW-3	gravelly clay and clayey gravel	Cooper - drawdown	4,400	6.3E-04	15	293	1.4E-02	SPRI, 1994
		Cooper - recovery	2,200	3.2E-04	15	147	6.9E-03	

Notes:
(1) maximum drawdown was not reached

- groundwater flow in both aquifer systems is at steady-state, i.e. the seasonal variations in observed water levels are relatively minor (see Table 3.3 below).

Note that the observed heads in the shallow aquifer system are many tens of feet higher than in the deep aquifer system (compare e.g. water levels in EW-4 and MW-2 to those in EW-2 and MW-12, Figure 3.2). The difference in permeability of shallow alluvial sediments and the units in the deep aquifer alone can not explain these very high vertical gradients. In addition, a significant barrier to downward flow must be present between these two systems in order to maintain such a high head differential. The importance of such a flow barrier to local groundwater flow is examined in more detail in the sensitivity analysis of the local groundwater flow model.

Note also that the local stratigraphy is complicated by a set of two (possibly more) faults. Vail (1987) mapped a northeast trending high angle fault along the east flank of the Gadalupe Mountain). This fault appears to follow the west side of a linear, northeast trending wash (arroyo), now largely covered by the tailings behind Dam No. 4 (Figure 3.1). East of this fault line, the Guadalupe volcanics are exposed at the surface (c. Figure 2.2).

A second high angle fault line runs along the center of the northeast trending arroyo, now largely covered by the tailings behind Dam No. 1 (Figure 3.1). The borehole logs suggest that the volcanic unit has been displaced downward to the east of this fault line (SPRI, 1993; Figure 3.2). Both of these fault lines act as sharp boundaries between different stratigraphic units. The influence of these boundaries on local groundwater flow is also examined in more detail in the sensitivity analysis of the local groundwater flow model.

Note that the borehole data and field exposures are concentrated in a narrow band to the south of Dams No. 1 and No. 4 (Figure 3.1). It is believed, however, that the structure and lithologic units, particularly the basalt unit, extend northward beneath the tailings pond facility and southward at least to the Red River (SPRI, 1993).

3.3 Conceptualization and Model Construction

3.3.1 Conceptual Model

Figure 3.3 shows the boundaries that have been selected for the local groundwater model using the calibrated regional flow model. The northern and western boundary of the local model follows a flow line starting at the 7480 contour line (near calibration well "Young" on State Highway 3) and running parallel to the impoundments until it reaches the Red River Fault Zone. This boundary reaches the Red River just downstream of the Fish Hatchery. The entire northern and western boundary is assumed to be a no-flow boundary.

On the eastern side, the local model boundary follows the 7480 ft head contour line representing a constant head boundary. In the southeast and south, the model boundary follows Cabresto Creek and the Red River, respectively. Similar to the regional flow model, these rivers are assumed to represent natural boundaries where groundwater converges and discharges (i.e. groundwater divides).

The conceptual model used to develop the regional groundwater flow model (section 2.3) had to be refined to account for additional factors controlling groundwater movement at the local scale. These refinements include:

- greater vertical discretization in the shallow aquifer system (above 7200 ft elevation) to better represent vertical flow in the alluvial sediments;
- use of additional model zones (i.e. regions within the model domain assumed to represent a given hydrogeologic unit) in vicinity of the tailings impoundments to represent fault contacts between volcanics and alluvial sediments;
- a differentiation of surficial alluvial sediments (al) into coarse, mixed, and fine alluvium to represent the large range in local permeabilities of this geological unit; and
- use of vertical anisotropy to represent the effects of horizontal layering and confining clay layers.

A total of seven hydrogeological units were defined using the results of the regional flow model (section 2.4) and the borehole logs of wells completed in vicinity of the tailings impoundments (Figure 3.2):

- surficial alluvial deposits (al), subdivided into
  - coarse alluvial deposits;
  - mixed alluvial deposits;
  - fine alluvial deposits;
  - lower confining clay layer;
- volcanic rocks of Guadalupe Mountain (gv);
- mixed volcanics in Red River Fault Zone (gv, sbu & sbl); and
- Santa Fe sediments (al_{SF});

The local flow domain was subdivided into five horizontal layers and five zones. Top and bottom elevations of the model layers are summarized in Table 3.2. The vertical position of the model layers 1-4 relative to observed stratigraphy south of the tailings facility is shown in Figure 3.2. Figure 3.3 shows the boundaries of the five zones. These boundaries are assumed to extend vertically through model layers 1 – 4. Santa Fe sediments are assumed to be present throughout model layer 5, i.e. in all five zones (equivalent to model layer 3 in regional model).

Note that the boundary between zones 2 and 3 represents a high angle fault line running in a northeasterly direction. The boundary between zones 3 and 4 represents the mapped (surficial) contact line between volcanics and alluvial sediments which, for the most part, runs in close proximity of another northeast trending, high angle fault (Vail, 1987).

Alluvial sediments are assumed present in zones 1, 2 and 3. The type of alluvial sediments (coarse, mixed or fine) for a given zone and model layer was determined during model calibration. A clay layer was assumed to be present at the base of the shallow aquifer system (at bottom of model layer 3) representing a significant vertical barrier to flow from the shallow aquifer system to the deeper aquifer system. This clay layer was not modeled explicitly as a model layer but represented by way of reducing the vertical permeability of a given unit between model layers 3 and 4 (see section 3.3.2). The horizontal extent of this clay layer was determined during model calibration.

Guadalupe volcanics and mixed volcanics of the Red River Fault Zone are assumed present in zones 4 and 5, respectively. The boundary between those two units was taken from the regional flow model (see chapter 2).

Table 3.2.

Summary of Model Layers used in Local Flow Model.

	Top elevation (ft a.s.l.)	Bottom elevation (ft a.s.l.)	Thickness (in feet)
Layer 1	7480	7320	160
Layer 2	7320	7270	50
Layer 3	7270	7220	50
Layer 4	7220	7000	220
Layer 5	7000	6700	300

Local recharge from precipitation is assumed negligible and is not included in the local flow model. The current recharge from the tailings impoundments into the groundwater flow system has been estimated to be on the order of 1 cfs (Geocon, 1983). Hence, a recharge value of 1 cfs, equally distributed across the surface area of the tailings impoundments was used for calibration of the local groundwater flow model.

Based on the results of the regional model and field observations, shallow groundwater flowing in the alluvial sediments is assumed to discharge into the Red River upstream of the Red River Canyon (i.e. in layers 1 to 3). Deep groundwater flowing in deep alluvial sediments and/or the volcanics is assumed to discharge into the Red River downstream of the entrance of the Red River Canyon (i.e. in layer 4). Locally, the river may also recharge the aquifer (e.g. in the uppermost reaches of the Red River Canyon in zone 4, where the river level is significantly higher than the water table of the deep volcanic aquifer (compare Figure 3.2). The discharge into (and recharge from) a given river reach is assumed to be controlled by aquifer permeability and, to a

lesser degree, by the effective permeability ("conductance") of the sediments in or near the riverbed.

Groundwater flow is assumed to be at steady-state, i.e. seasonal variations of heads and/or flows are assumed negligible as supported by field observations.

3.3.2 Numerical Model

Local groundwater flow was simulated using the finite difference code MODFLOW, developed by the USGS (McDonald and Harbaugh, 1988) in conjunction with the GMS pre-post processor (ECGL, 1997), which is commercially available and licensed to Robertson GeoConsultants Inc..

Figure 3.4 shows the finite difference grid and boundary conditions. The finite difference grid consists of 67 rows x 78 columns in 5 layers with a total of 26130 cells. It has a variable grid spacing with fine discretization near the lines of fault contact between volcanics and sediments. The grid cell size ranges from 100 ft x 100 ft in the center of the model domain to approximately 1000 ft by 1000 ft at the model boundaries (Figure 3.4). The same grid spacing was used in all five model layers.

The thicknesses of the five model layers are summarized in Table 3.2. Note that these model layers do not necessarily represent individual aquifers but rather individual layers of a contiguous groundwater body. In the zones 1 to 3, a clay layer is assumed to be (optionally) present representing a barrier to vertical flow from the shallow aquifer system (model layers 1 to 3) into the deep aquifer system (layers 4 and 5). This clay layer is modeled implicitly by adjusting the vertical leakance term (VCONT) of model layer 3 in these zones accordingly (see p. 5-16 in McDonald and Harbaugh, 1988).

A constant head boundary (7480 ft) is used at the eastern boundary in all five layers. All other boundaries are assumed to be no-flow boundaries representing either a flow line boundary (to the north and west) or a river boundary (to the south). Cabresto Creek and the Red River are modeled as "river nodes", i.e. groundwater is discharging into the river when the hydraulic head in the aquifer is greater than the river elevation (McDonald and Harbaugh, 1988). Conversely, the river is recharging the aquifer when the hydraulic head in the aquifer is lower than the river elevation. The rate of groundwater discharge (or recharge) is controlled by the effective permeability of the river bed and aquifer material immediately surrounding the riverbed (termed "riverbed conductance", McDonald and Harbaugh, 1988). The use of river nodes was preferred over the use of constant head nodes in simulating the rivers at the local scale because the modeler has more control over the rates of groundwater discharge to and recharge from the rivers (by way of calibrating the river bed conductance). The different reaches of Cabresto Creek and Red River residing within the various model layers are shown in Figure 3.4. Note that there are no river nodes in model layer 5; all groundwater flowing in this layer must first move upward into layer 4 prior to discharging into the Red River.

All groundwater flow simulations were run assuming steady-state flow, i.e. the boundary conditions are assumed to be constant over time.

3.3.3 Model Assumptions

The main assumptions in our approach to modeling the local groundwater flow system are as follows:

- at the scale of the analysis, the geologic units can be grouped into four major hydrogeologic units: (1) surficial alluvial sediments, (2) volcanics of Guadalupe Mountain, (3) mixed volcanics of Red River Fault Zone; and (4) Santa Fe sediments; the surficial alluvial sediments (unit 1) can be further classified into coarse, mixed and fine alluvial sediments;
- groundwater flow in all hydrogeologic units follows Darcy's Law; perched zones in the alluvial sediments can be neglected; flow through fractured rock (e.g. volcanics) can be modeled using the "equivalent porous medium" approach, i.e. average, "effective" permeabilities can be assigned to each unit; horizontal anisotropy can be ignored;
- the regional flow model provides meaningful boundaries for the local flow model; in particular groundwater just north of the impoundments moves in a westerly direction and then assumes a southwesterly direction representing a flow line (no flow) boundary for local groundwater flow;
- natural recharge to the local flow system can be simulated as inflow from the eastern boundary of the model domain using constant head boundary conditions (as provided by the regional flow model); recharge from precipitation can be ignored;
- the Red River (and to a lesser extent Cabresto Creek) represents a natural discharge line for groundwater at the local scale; river bed conductance controls discharge of groundwater into (or recharge from) the river; groundwater does not flow beneath the rivers as a result of converging flow; and
- the three-dimensional groundwater flow system is at steady-state.

3.4 Model Calibration

The local groundwater flow model was calibrated against observed head values and measured springs flows and/or estimates of accretion in two reaches of the Red River. Table 3.3 summarizes the information on the local wells used for model calibration. The location of most of these wells is shown in Figure 3.1.

The calibration targets for spring flow/river accretion are as follows (see also section 2.4):

- 4 cfs accretion to Red River upstream of Red River Canyon from "cold springs" (including discharge at Questa Springs and field drainage); and
- 14 cfs accretion to Red River along Red River Canyon (within model domain) from "warm springs".

The local groundwater flow model was calibrated using the trial-and-error approach. The following parameters were varied during calibration:

Table 3.3
Groundwater Wells used for Calibration of Local Flow Model.

Well ID	Location	Collar Elevation (ft asl)	Material	Screen Interval (ft asl)	Depth to Water Minimum (ft b.c.)	Depth to Water Average (ft b.c.)	Depth to Water Maximum (ft b.c.)	Calibratio Target (ft asl)	Confidence Interval (ft)
Young[2]	29.13.19.322	~7650*	Alluvium	unknown	128.7	146	164.5	7500	+/- 25
Questa[3]	near High School	~7640	Alluvium	7290' (+)	N/A	~220	N/A	7420	+/- 25
EW-5a[4]	at toe of Dam 1	7315	Alluvium	7255'-7285'	N/A	16	N/A	7299	+/- 25
MW-7a[4]	arroyo south of Dam 1	7320	Alluvium	7232'-7242'	58.5	60	62.4	7260	+/- 25
MW-2[4]	arroyo south of Dam 1	7281	Alluvium	7200' (+)	36.8	38	38.7	7243	+/- 25
EW-3[4]	arroyo south of Dam 1	7317	Alluvium	7242'-7252'	57.1	59	61.3	7258	+/- 25
EW-4[4]	arroyo south of Dam 1	7277	Alluvium	7224'-7232'	18.3	20	21.8	7257	+/- 25
MW-1[4]	arroyo south of Dam 1	7275	Volcanics	7170' (+)	47.9	51	54.2	7224	+/- 25
MW-12[4]	arroyo south of Dam 1	7275	All./Volc.	7050'-7065'	123.3	127	129.7	7148	+/- 25
MW-10[4]	Embargo Rd	7353	Alluvium	7228'-7258'	28.8	30	30.9	7323	+/- 25
MW-14[4]	Embargo Rd	~7330	Alluvium	7228'-7258'	N/A	47	N/A	~7283	+/- 25
MW-11[4]	arroyo south of Dam 4	7347	Volcanics	7095'-7135'	193.2	194	194.4	7153	+/- 25
G-3[5]	Guadalupe Mtn.	7627	Volcanics	7131'-7187'	N/A	475	N/A	7152	+/- 25

Notes:
[2] from State Engineers Office, 1997
[3] from Questa Municipal Office, 1997
[4] unpublished Molycorp files (1996-1997)
[5] from Dames and Moore, July 1987
* estimated from 1:24000 topo maps
+ bottom of hole (screen interval unknown)

- hydraulic conductivity of alluvial sediments;
- vertical anisotropy of all hydrogeologic units;
- extent and thickness of basal clay layer (between layers 3 and 4); and
- river bed conductance.

Note that the hydraulic conductivities of all hydrogeological units except the alluvial sediments are assumed to be known (from the regional flow model). The hydraulic conductivity of the alluvial sediments in zones 1–3 was varied using order-of-magnitude estimates of hydraulic conductivity ranging from $3 \cdot 10^{-2}$ cm/s ("coarse alluvium") and $3 \cdot 10^{-3}$ cm/s ("mixed alluvium") to $3 \cdot 10^{-4}$ cm/s ("fine alluvium").

The calibration process proceeded as follows. First, all alluvial sediments were assumed to be "mixed alluvium" (i.e. equivalent to that in the regional flow model) and riverbed conductances were adjusted to approximate observed heads and spring flows as much as possible. Next, the hydraulic conductivity of the alluvial sediments was varied. Finally, vertical anisotropy and the hydraulic conductivity and the extent of the basal clay layer were calibrated.

Model calibration indicated that in the shallow alluvial aquifer system the permeability of the alluvial sediments is the dominant control on groundwater flow and spring discharge. In the deep aquifer system the permeability of the volcanics controls overall flows in the aquifer. The riverbed conductance is important for the local allocation of discharge into (and recharge from) the Red River.

The calibrated values of key parameters of the local flow model are summarized in Table 3.4. Model calibration suggested that a major impediment to vertical flow from the shallow aquifer system down into the deeper aquifer system must be present in zones 1 and 2, i.e. east of the fault line in Dam No. 1 arroyo (Table 3.4). Vertical anisotropy due to horizontal layering of sediment units alone (typically in the order of K_h/K_z~10 to 100) could not explain the large head differences observed between layers 3 and 4. Note also, that the alluvial sediments in zone 2 of model layer 3 (7220' – 7270') had to be quite permeable to allow for the significant spring flows observed in this reach of the Red River (i.e. Big Springs including Questa Springs).

The hydraulic head contours of the calibrated flow model are shown in Figure 3.5. The overall match of the simulated and observed hydraulic heads is considered acceptable. Note that at some calibration points the model matches the observed heads very well, whereas at others (often in close vicinity) the fit is much poorer. This scatter in observed head data suggests that the local hydrogeology is more complex than has been simulated here. A more detailed flow model was not considered necessary, however, considering the study objectives. In our opinion, the calibrated local flow model is adequate for estimating the direction and volumes of groundwater flows beneath the tailings impoundments.

The volumetric flow vectors of the calibrated flow model are shown in Figure 3.6. These flow vectors give a graphical representation of the direction and quantities of groundwater flow in the tailings area. East of the fault line in the Dam No. 1 arroyo (which separates zones 2 and 3),

Table 3.4
Calibrated Hydogeological Parameters of Local Flow Model.

<table>
<tr><th></th><th>Zone 5</th><th>Zone 4</th><th>Zone 3</th><th>Zone 2</th><th>Zone 1</th></tr>
<tr><td>Layer 1</td><td rowspan="4">Red River Fault Zone
(K_h=2.5*10^{-2} cm/s);
CRIV=1*10^{-3} cm/s</td><td rowspan="4">Guadalupe Volcanics
(K_h=1.5*10^{-1} cm/s);
CRIV$_{>7050'}$=1*10^{-4} cm/s;
CRIV$_{<7050'}$=1*10^{-2} cm/s</td><td colspan="3">Fine Alluvium (K_h=3*10^{-4} cm/s); CRIV=1*10^{-2} cm/s</td></tr>
<tr><td>Layer 2</td><td>Fine Alluvium
(K_h=3*10^{-4} cm/s)</td><td>Mixed Alluvium
(K_h=3*10^{-3} cm/s);
CRIV=1*10^{-2} cm/s</td><td>Fine Alluvium
(K_h=3*10^{-4} cm/s)</td></tr>
<tr><td>Layer 3</td><td rowspan="2">Fine Alluvium
(K_h=3*10^{-4} cm/s):
CRIV=1*10^{-2} cm/s</td><td>Coarse Alluvium
K_h=3*10^{-2} cm/s;</td><td>Fine Alluvium
(K_h=3*10^{-4} cm/s)</td></tr>
<tr><td></td><td colspan="2">Basal Clay Layer K_z=1*10^{-7} cm/s (w=30 ft)</td></tr>
<tr><td>Layer 4</td><td colspan="3">Mixed Alluvium (K_h=3*10^{-3} cm/s);</td></tr>
<tr><td>Layer 5</td><td colspan="5">Santa Fe sediments (K_h=1*10^{-4} cm/s)</td></tr>
</table>

Notes:
(1) CRIV = riverbed conductance
(2) vertical hydraulic conductivity is smaller than horizontal conductivity by a factor of 100 in all zones and layers

shallow groundwater flows in a southwesterly direction towards the Red River. Note that this flow pattern is consistent with the movement of tailings seepage water (as evidenced by elevated sulfate and molybdenum concentrations) in a southwesterly direction, which was observed prior to interception of tailings seepage water by the extraction wells and trenches at the toe of Dam No. 1. Most of the discharge of shallow groundwater to the Red River is concentrated at an elevation of 7240' to 7270', i.e. in vicinity of the Big Springs (including Questa Springs) (Figure 3.6). The calibrated flow model indicates that about 3.4 cfs of shallow groundwater discharges in this area.

West of the fault line (i.e. in zone 3) the shallow groundwater moves almost vertically (downward) due to very steep gradients and recharges the deeper aquifer system (Figure 3.6). The calibrated flow model indicates that the total recharge from the shallow aquifer system (layers 1 to 3) to the deeper aquifer system (layers 4 and 5) is about 2.8 cfs. Most of this recharge occurs in zone 3, where it is assumed that no basal clay layer is present.

The deep groundwater of the volcanic aquifer flows in a nearly westerly direction in the alluvial sediments and assumes a southwesterly direction upon entering the volcanic aquifer (Figure 3.6). beneath the tailings and emerges in the Red River Canyon below a river elevation of approximately 7050 ft. In the upper reaches of the Canyon, the river level is higher than the water table in the volcanics and there is some recharge from the Red River to the deep volcanic aquifer. The simulated (net) accretion to the Red River from the deep groundwater system is about 14.4 cfs.

3.5 Sensitivity Analysis

The influence of various model input parameters (in particular extent of basal clay layer and degree of vertical anisotropy) on local groundwater flow was evaluated in a sensitivity analysis.

Table 3.5 summarizes the scenarios simulated. Note that scenario "Local 5a" represents the calibrated local flow model.

The hydraulic head contours of the various scenarios are shown in Figures B1 to B14 (Appendix B). The simulated groundwater inflows and outflows for the various scenarios are shown in Table 3.6. The results of the sensitivity analysis can be summarized as follows:

- the shallow groundwater system is very sensitive to the presence (or absence) of a basal clay layer (or similar barrier to flow); in particular, discharge of shallow groundwater at the "cold springs" (Big Springs including Questa Springs) is controlled by the horizontal extent and permeability of this flow barrier (see Table 3.6);
- a hydraulic conductivity of K_{clay}= $1 \cdot 10^{-7}$ cm/s for the basal clay layer (assumed 30' thick) provides sufficient resistance to vertical leakage to allow for the observed discharge of shallow groundwater (see "local 1a" to "local 1c");
- extending the basal clay layer into zone 3 (i.e. west of the fault line in Dam No 1 arroyo) increases simulated flows to the "cold springs" by about 0.4 to 0.8 cfs (compare scenarios local 1 and local 2);

Table 3.5.

Scenarios studied in Sensitivity Analysis for Local Flow Model.

Scenario	Description
"Local 0"	equivalent of regional flow model, i.e. mixed alluvium in zones 1 to 3; no vertical anisotropy; no basal clay layer;
"Local 1a"	distribution of alluvial sediments as for calibrated model (Table 3.4); vertical anisotropy of all units = 100; basal clay layer in zones 1 & 2 w/ K_{clay}= $1 \cdot 10^{-9}$ cm/s; no recharge from tailings;
"Local 1b"	as above w/ K_{clay}= $1 \cdot 10^{-7}$ cm/s;
"Local 1c"	as above w/ K_{clay}= $1 \cdot 10^{-5}$ cm/s;
"Local 1d"	as for "Local 1b" except basal clay layer absent (vert. anisotropy = 100);
"Local 1e"	as above w/ vertical anisotropy of all units = 10;
"Local 2a"	as for "Local 1b" except basal clay layer extended into zone 3; K_{clay}= $1 \cdot 10^{-7}$ cm/s
"Local 2b"	as above w/ K_{clay}= $1 \cdot 10^{-9}$ cm/s
"Local 3a"	as for "Local 1b" except "mixed alluvium" present in zone 3 (layer 3)
"Local 4a"	as for "Local 1b" except "coarse alluvium" in zone 2 (layer 3) w/ $K_{coarse\ al}$ = $8 \cdot 10^{-2}$ cm/s;
"Local 4b"	as for "Local 1b" except "coarse alluvium" in zone 2 (layer 3) w/ $K_{coarse\ al}$ = $8 \cdot 10^{-3}$ cm/s;
"Local 5a"	as for "Local 1b" except w/ tailings recharge = 1 cfs;
"Local 5b"	as for "Local 1b" except w/ tailings recharge = 2 cfs
"Local 5c"	as for "Local 1b" except w/ tailings recharge = 3 cfs

Table 3.6
Summary of Sensitivity Analysis
Net Water Balances

	INFLOW (cfs)				OUTFLOW (cfs)			
Simulation	Recharge	Shallow Groundwater (layers 1-3)	Deep Groundwater (layers 4-5)	Total	Cabresto Ck. & Upper R.R. (layers 1+2)	Cold Springs (layer 3)	Warm Springs (layer 4)	Total
Local 0	0.00	8.49	8.53	17.02	-1.39	0.14	-15.79	-17.03
Local 1a	0.00	5.55	11.12	16.67	-0.16	-3.25	-13.27	-16.68
Local 1b	**0.00**	**6.44**	**10.67**	**17.11**	**-0.13**	**-3.18**	**-13.80**	**-17.11**
Local 1c	0.00	8.86	9.06	17.92	-0.15	-2.08	-15.69	-17.93
Local 1d	0.00	10.85	8.00	18.84	-0.17	-1.28	-17.39	-18.85
Local 1e	0.00	12.63	7.97	20.60	-0.38	-0.62	-19.60	-20.60
Local 2a	0.00	5.33	11.06	16.39	-0.12	-3.60	-12.67	-16.39
Local 2b	0.00	4.28	11.71	16.00	-0.18	-4.08	-11.73	-16.00
Local 3a	0.00	9.08	9.83	18.92	-0.11	-2.35	-16.47	-18.92
Local 4a	0.00	12.75	10.55	23.30	-0.13	-9.12	-14.04	-23.30
Local 4b	0.00	3.23	10.85	14.09	-0.10	-0.68	-13.32	-14.09
Local 5a	0.99	6.24	10.59	17.82	-0.12	-3.35	-14.35	-17.82
Local 5b	1.98	6.03	10.53	18.55	-0.13	-3.50	-14.92	-18.55
Local 5c	2.98	5.83	10.47	19.27	-0.14	-3.66	-15.48	-19.28

Notes:
(1) negative values represent flow out of the model domain
(2) simulation "Local 1b" represents the calibrated local flow model

- the shallow groundwater system is also sensitive to vertical anisotropy of the alluvial sediments themselves; a higher vertical anisotropy results in higher spring flows at the "cold springs" and vice versa (compare "local 1d" to "local 1e" in Table 3.6); however, vertical anisotropy ratios of the alluvial sediments alone (K_h/K_z = 10 to 100 due to horizontal stratification) still allow significant leakage into the deeper aquifer system thus under-predicting flows in the "cold springs";
- the volumetric flows in the shallow aquifer system (inflows and outflows) are quite sensitive to the permeability of the "coarse alluvium" (assumed present only in zone 2 of model layer 3) (see scenarios "local 4a" and "local 4b"); and
- recharge from the tailings has no significant effect on the local groundwater system (other than a proportionate increase in groundwater flows) (see scenarios "local 5a" and "local 5c").

The sensitivity analysis has shown that a basal clay layer (or similar impediment to vertical flow) must be present to reproduce the observed heads and flows in the shallow aquifer system. Such a barrier to vertical flow must be present east of the fault line running along Dam No. 1 arroyo. This finding is consistent with local borehole logs which indicate the presence of a thick clay layer in this area (see e.g. EW-2 and MW-2 in Figure 3.2). The extent of this flow barrier to the west of the fault line is less certain. The clay layer was assumed to be absent west of this fault line based on well log information which does not indicate significant clay layers to the west of the fault line (Figure 3.2). In addition, the water table west of the fault line drops off quickly suggesting that no significant barrier to flow is present in this area.

3.6 Discussion and Implications

The calibrated flow model illustrates several important characteristics of the local groundwater flow system:

- the local groundwater system can be divided into a shallow aquifer system in the alluvial sediments (above 7220 ft elevation) and a deep aquifer system in the volcanics and (deeper) alluvial sediments (below 7220 ft elevation);
- shallow groundwater flows in a southwesterly direction and discharges to the Red River in vicinity of the Big Springs (including Questa Springs) (Figure 3.6); total flows in these "cold springs" are in the order of 3-4 cfs;
- deep groundwater travels in a westerly direction beneath the tailings impoundments and assumes a south-westerly direction upon entering the volcanic aquifer; groundwater from this deep system discharges in the Red River Canyon above and to a lesser extent below the Fish Hatchery (Figure 3.6); total flows in these "warm springs" are in the order of 14 cfs;

- the very permeable volcanics act as a drain for local groundwater causing leakage from the shallow groundwater system into the deeper aquifer system; the rate of leakage is controlled by a clay layer (or similar barrier to flow) separating the shallow from the deep aquifer system; sensitivity analyses suggest that the hydraulic conductivity of such a clay layer is on the order of $K_{clay} = 1 \cdot 10^{-7}$ cm/s or lower;

- the spatial configuration of geologic units on either side of a high-angle, north-east trending fault line following the Dam No. 1 arroyo appears to exert a significant influence on local (shallow) groundwater flow by way of placing ; east of the fault line, shallow groundwater is essentially isolated from the deeper aquifer system and discharges towards the Red River (Figure 3.6); west of the fault line, the shallow groundwater moves (downward) into the volcanic aquifer causing a sharp drop in the shallow water table (Figure 3.5);

- significant spring flows (~3-4 cfs) observed at the Big Springs complex (including Questa Springs) indicate that the alluvial sediments in this region must be quite permeable; the calibrated flow model suggests that these coarse alluvial sediments have a (horizontal) hydraulic conductivity of $K_{coarse\ al} = 3 \cdot 10^{-2}$ cm/s and extend further to the northeast (Figure 3.6).

It is emphasized here that the local flow model was not intended to reproduce all details of the complex hydrogeology near the tailings facility. Instead, the local flow model should illustrate the controls on local groundwater flows and allow estimates of volumetric flows beneath the tailings to be made. We believe that the calibrated flow model accounts for most, if not all, important controlling factors on local groundwater flow.

The calibrated model suggests that recharge from the shallow groundwater system to the deeper aquifer system is significantly reduced due to the presence of a "basal clay layer" east of the fault line in Dam No. 1 arroyo. This hypothesis is consistent with local borehole logs, which indicate the presence of a thick clay layer in several boreholes east of the fault line (e.g. EW-2; MW-2; MW-12). It is possible that these clay layers produce perched conditions so that the shallow aquifer is effectively "hydraulically disconnected" from the deep aquifer system. Perched conditions per se can not be modeled with the saturated flow code MODFLOW used in this analysis. However, the effect of a low permeability clay layer (assumed here) is very similar to that of a zone of aeration due to perched groundwater flow.

Note also, that the water temperature in the Big Springs complex is several degrees colder than in those springs emanating from the volcanics along the Red River Canyon (Vail, 1993). This observation further supports the hypothesis that the shallow and deep aquifer systems are distinct units with little mixing of these two types of groundwater (at least east of the fault line in Dam No. 1 arroyo).

With respect to simulated seepage from the tailings impoundment into the local groundwater system the following conclusions can be drawn:

- about 2/3 of the simulated seepage from the tailings facility in section 36 (behind Dam No. 1 and 1c) drains into the shallow aquifer system; the underflow of shallow groundwater beneath section 36 is estimated to be approximately 2.1 cfs;
- about 1/3 of the simulated seepage from the tailings facility in section 36 (behind Dam No. 1 and 1c) drains into the deep aquifer system; the underflow of deep groundwater beneath section 36 is estimated to be approximately 4 cfs;
- all simulated seepage from the tailings facility in section 35 (behind Dam No. 4 and 5) drains into the deeper, volcanic aquifer; the underflow of deep groundwater beneath section 35 is estimated to be approximately 5.4 cfs; and
- simulated seepage from the tailings impoundments has very little influence on the flow pattern of the groundwater flowing beneath the tailings facility.

A critical issue for tailings decommissioning is the potential of contaminant migration from the tailings facility into the underlying aquifers. At present, two control strategies are under consideration: (1) placing a soil cover onto the decommissioned tailings to reduce seepage, and (2) intercepting and pumping of tailings seepage water using extraction wells and trenches at the toe of the dam (i.e. up-gradient of any groundwater users). The latter control strategy is a requirement for current operation of the tailings facility and as implemented at Dam No. 1.

To use only a soil cover, the soil cover would need to reduce seepage to such levels that the water quality of the receiving groundwater at a downstream compliance boundary meets New Mexico groundwater standards. The factors controlling water quality in the receiving groundwater after closure are:

- rate of tailings seepage after closure;
- long-term water quality of tailings seepage;
- volumes of groundwater available for mixing; and
- degree of solute dispersion in groundwater.

Cover modeling indicates that the rate of infiltration through a 9 inch thick alluvial cover would be in the order of 0.75 inches resulting in a total (steady-state) flow of 0.055 cfs over the entire tailings facility (chapter 5). Assuming for the moment complete mixing of this seepage in the receiving groundwater the tailings seepage from tailings in section 36 (behind Dam No. 1) would be diluted by a factor of ~115 in the shallow aquifer system and ~430 in the deep aquifer system. Tailings seepage from tailings in section 35 would be diluted by a factor of ~200 in the (deep) volcanic aquifer system. Assuming present-day tailings pore water chemistry these dilution factors would be sufficient to reduce sulfate and molybdenum levels in the local groundwater to well below state standards.

However, complete mixing is not a conservative assumption. The degree of mixing is a function of the transport distance and dispersion characteristics of the aquifer. In addition, the dilution

calculations assume that contaminant levels in the tailings seepage do not change over time. Results of the kinetic geochemical testing of the tailings indicate that the quality of seepage through the tailings will improve as contaminant concentrations reduce over time (SRK, 1997). Furthermore, there may be chemical controls on water quality (e.g. sorption, dissolution/precipitation reactions etc.) which could influence the groundwater quality.

Current proposals for mine closure provide for cover placement to reduce the seepage flux combined with maintenance of the interception well system, until the intercepted groundwater quality improves sufficiently to allow interception to be discontinued. Seepage rates will be estimated once final dam configurations and cover systems have been selected as part of the closure plan.

It is recommended that the effects of dispersion and geochemical reactions (adsorption and/or precipitation/dissolution) on contaminant transport and downstream water quality be evaluated as part of the closure plan report. The long-term water quality of the tailings seepage entering the groundwater system would be estimated based on kinetic test performed on tailings samples (SRK, 1997). The effects of dispersion and chemical reactions along the flow path (e.g. adsorption) could be evaluated using analytical solutions of the advection-dispersion equation with provisions for geochemical reactions (e.g. retardation factors).

Figures

Section 4

4 Tailings Seepage Analysis

In the previous two chapters we have focused on the groundwater flows beneath the tailings facilities. Here we turn our attention to the flow of water through the tailings themselves (referred to as "tailings seepage"). As discussed in chapter 3, Molycorp is planning to place a permanent soil cover onto the tailings upon closure of its tailings facilities. One of the key functions of such a soil cover would be to reduce infiltration into and thus seepage out of the tailings. The reduction in net infiltration due to cover placement could be almost immediate (depending on cover type). The desired reduction in tailings seepage, however, may take many years to many tens of years as a result of slow dewatering of the tailings. This delay is very important for closure planning because interim solutions for controlling tailings seepage (e.g. interception of shallow seepage using trenches and extraction wells) may be required.

The transient process of tailings dewatering, with and without cover placement, has been simulated using a finite-element model for unsaturated/saturated flow. Note that in the tailings facility very permeable sandy tailings are located next to and are interlayered with low-permeability slimes. It was beyond the scope of this study to develop a "site model" that represents these local heterogeneities in detail. Instead, a parameter study is performed here, using representative tailings properties (permeability, soil water characteristic curve etc..) and simplifying assumptions with respect to spatial orientation of different tailings types. This parametric study, nevertheless, illustrates the effects of cover placement on dewatering of the tailings and provides order-of-magnitude estimates of seepage losses as a function of time.

4.1 Objectives of Tailings Seepage Analysis

The objectives of the tailings seepage analysis are as follows:

- to evaluate seepage patterns for Section 35 and 36 Tailings Areas;
- to estimate seepage losses from the two tailings areas as a function of time; and
- to estimate time to "steady-state", i.e. when seepage losses at the base of the tailings equal net infiltration.

4.2 Previous Studies

In 1982, Geocon studied the moisture conditions in the Section 36 Tailings Area. The piezometric heads in piezometers located predominantly in the southern segment of Section 36 Tailings Area (between Dam No. 1 and Dam No. 1C) were monitored from 1980 to 1091. There was no discharge of tailings slurry into the impoundment at this time allowing estimates of the decline of the phreatic surface (water table) to be made. In addition, tailings samples were taken at various locations and at varying depths to determine the in-situ moisture contents of the tailings. It was concluded that the decline of the phreatic surface in the Dam No. 1C area during the period of observation was approximately 5 to 5.5 ft per year (Geocon, 1982). The soil moisture measurements suggested that the lowering of the phreatic surface would probably

involve a reduction of the average moisture content from about 30 to 15 percent, i.e. an approximate yield of 0.24 cubic foot of water per foot drop in the phreatic surface.

In 1983, Geocon studied the seepage losses from the southern portion of section 36 tailings area in more detail. First, all piezometer monitoring data collected from 1981 to 1983 were reviewed to estimate the rate of lowering of the phreatic surface within the tailings. Due to construction in 1982-83 and shut-down of the mill since August 1981, there had been practically no discharge of tailings slurry into this area until the start-up of the mill in October 1983. Hence, the decline in the phreatic surface during this period could be interpreted as the rate of seepage through the tailings (Geocon, 1983). Second, Geocon (1983) carried out a parametric modeling study by using finite element seepage analyses covering a wide range of assumed horizontal and vertical permeability values. The results of their tailings seepage study with respect to section 36 tailings may be summarized as follows:

- the section 36 tailings area is characterized by a relatively pervious perimeter comprised of a ridge of alluvial sand and gravel along the west side and unlined impoundment dams of zoned earth fill construction along the south and east sides; the valley floor consists predominantly of sands and gravel, containing layers or lenses of silty clay.

- the general seepage pattern in the tailings is predominantly vertical flow modified near the perimeter by horizontal flow components towards the pervious retention dams or natural ridge; the influence of Dam No. 1 (on the south side) is particularly pronounced due to its height and the historical manner of tailings operation;

- estimated rates of decline of piezometric elevation in the piezometers (in the south near Dam No. 1C) in 1981 ranged from 3.7 to 12.1 feet per year with an average decline of 7.5 feet per year; for the period 1981-1983 the average rate of decline in piezometric elevation was only 3.1 feet per year (in part due to surcharge during fill placement in 1982);

- the average rate of decline of the phreatic surface (water table) in the Dam No. 1C area was 5.4 feet per year for the 1981 observation period; the rate of decline of the phreatic surface in the Dam No. 1 area may have been as high as 8.4 feet per year;

- the parametric modeling study suggested that the tailings in the southern portion of Section 36 between Dam No. 1 and Dam No. 1C have an average (en-masse) permeability of $2 \cdot 10^{-5}$ cm/s with a vertical anisotropy of Kh/Kz=10; i.e. the horizontal permeability is approximately $6.3 \cdot 10^{-5}$ cm/s and the vertical permeability is approximately $6.3 \cdot 10^{-6}$ cm/s;

- the computed inflow rate from the phreatic surface near Dam No. 1C was $4.4 \cdot 10^{-3}$ $ft^3/day/ft^2$; the computed outflow rate through the base of the tailings was $3.0 \cdot 10^{-3}$ $ft^3/day/ft^2$ which is equivalent to $1.5 \cdot 10^{-3}$ cfs per acre;

In the fall of 1995, several deep boreholes were drilled through the tailings of section 35 and 36 to obtain samples for geochemical testing (SRK, 1997a). These boreholes indicated that there is significant interlayering of coarse and fine tailings in both impoundments. The drilling also indicated that the tailings in section 35 (at least where sampled) were unsaturated throughout (i.e.

no phreatic surface). In section 36, the phreatic surface was at an elevation of approximately 7460 ft, i.e. approximately 100 feet below the tailings surface, in the southern portion of the impoundment.

Molycorp is currently installing additional piezometers in the tailings areas of section 35 and 36 to determine the current position of the phreatic surface in both impoundments. Unfortunately, the results of this latest investigation were not yet available for consideration in the present report.

4.3 Modeling Approach

The previous investigations by Geocon provide good estimates of the decline in the phreatic surface as well as seepage losses from the southern portion of the section 36 tailings area. However, these estimates represent only a snapshot of a transient process that stretches over many years to many ten of years. The lowering of the phreatic surface (and thus seepage losses) can be expected to decline over time as the (vertical) head gradients diminish over time as well.

Furthermore, the seepage studies performed by Geocon focused on piezometric data from the southern portion of section 36 where the tailings are known to be relatively permeable and where seepage is strongly influenced by the unlined earth fill Dam No. 1. It is unclear to what extent these results are applicable to other areas of the tailings impoundments where tailings may be significantly less permeable and/or are not influenced by horizontal seepage to a permeable berm or dam. To this end, we simulate transient seepage for a range of representative tailings types, with and without the influence of a permeable dam structure.

4.3.1 Section 35 Tailings Area

The tailings in section 35 are located on top of very permeable volcanics covered only by a thin layer of alluvial sediments. The water table in the underlying volcanic aquifer is several hundred feet below the base of the tailings (see chapters 2 and 3). Under these conditions it can be assumed that the tailings at the base of the tailings are free-draining, i.e. there is no resistance to flow out of the tailings.

It is further assumed that tailings seepage in section 35 is essentially vertical with negligible horizontal flow components. This is a conservative assumption in so far that the resulting time to steady-state is greater than if horizontal flow (through permeable berms or dams) would take place. Note, that the upstream face of Dam No. 4 has been lined with asphalt liners resulting in very low seepage rates through this dam (no seepage has been observed in recent years below the toe of this dam) which is consistent with the assumption of vertical seepage flow.

Transient flow within the tailings of section 35 is modeled in a vertical column of unit cross-sectional area and a representative height of 150 feet (Figure 3.1). Initially, the tailings are assumed to be completely saturated with the water table at the tailings surface. The tailings are then allowed to drain freely at the base resulting in a gradual dewatering of the tailings column. Note that the seepage through the tailings is assumed to be entirely controlled by the characteristics of the tailings; the underlying aquifer material is not included explicitly in the conceptual model.

Transient seepage in section 35 was simulated for the case of uniformly coarse and uniformly fine tailings, respectively. The soil water characteristic curves and permeabilities for those two tailings types have been determined in the laboratory (see Appendix C for details). The permeability (as a function of soil moisture content) for each tailings type was varied to evaluate the sensitivity of modeling results to this critical parameter.

The placement of a soil cover onto the tailings reduces the net infiltration (recharge) into the tailings profile. A detailed modeling of the seasonal processes of infiltration into and evapotranspiration out of the cover suggests that the annual net infiltration through a 9 inch thick alluvial soil cover would be about 1.1 and 0.4 inches per year for coarse tailings and fine tailings, respectively (see chapter 5). In this seepage analysis, these representative infiltration rates were applied to the top of the tailings as a steady-state surface flux. The effects of seasonal trends in the infiltration rate (producing wetting fronts within the tailings profile) were assumed negligible.

4.3.2 Section 36 Tailings Area

Seepage flow in the tailings area of section 36 is significantly influenced by Dam No 1. This large earth-fill dam is not lined (unlike Dam No 4) and therefore acts as a drain producing significant horizontal flow within the tailings. Another important difference between seepage flow in section 36 and section 35 is the potential influence of the underlying aquifer system. For section 35 it was assumed that the tailings are free-draining owing to the very deep water table in the permeable volcanic aquifer. At section 36, however, tailings seepage is discharging into a shallow aquifer system with a water table only a few tens of feet below the base of the tailings (see chapter 3).

To account for these two-dimensional effects, transient flow through the tailings in section 36 is modeled using a cross-sectional (2D) model which include both Dam No. 1 and the underlying (shallow) aquifer system (Figure 3.2). The three aquifer (model) layers used in this cross-sectional model are equivalent to model layers 1 to 3 in the calibrated local flow model (chapter 3). The hydraulic conductivities and steady-state flows in the three layers, and the water table elevation of this shallow aquifer system were taken directly from the calibrated local flow model.

It is known from drilling and reconstruction of tailings deposition, that the tailings in the southern region of the impoundment are in general coarser than those deposited in the northern region. To account for this spatial distribution the tailings were sub-divided into two zones (Figure 3.2). The hydraulic conductivity of the tailings "en-masse" in the southern region is relatively well-known based on the work done by Geocon (!982; 1983). Their estimates of horizontal and vertical hydraulic conductivity of the tailings in this region were used for this analysis. For the northern region, laboratory estimates of hydraulic conductivity of fine tailings were used.

Initially, the tailings are assumed to be completely saturated. The position of the water table and groundwater flows in the underlying aquifer were assumed to be known using the results of the calibrated local groundwater flow model (chapter 3). Next, the flux at the tailings surface is reduced to that of net infiltration through a 9 inch thick alluvial soil cover (see chapter 5). The program then simulates the transient process of dewatering of the tailings. Note that no a priori assumptions are made here with respect to drainage at the base of the tailings. The model determines if, and to what extent, the permeable dam and the underlying groundwater aquifer influence drainage of the tailings.

4.4 Numerical Methods

The finite-element code SEEP/W was used to simulate seepage flow through the tailings. SEEP/W is commercially available through GEOSLOPE in Calgary, Alberta, and simulates two-dimensional saturated and/or unsaturated flow using Darcy's Law (Geoslope, 1994). The model allows the definition of subregions within the model domain for which the material functions (soil water characteristic curve and hydraulic conductivity characteristic curves) are specified (Geoslope, 1994)

As outlined in section 4.3, a 1D column model was used for simulating seepage flow in tailings of section 35 and a 2D cross-sectional model was used for section 36. The two different models are presented separately below.

4.4.1 Vertical Column Model (Section 35 Tailings Area)

Figure 4.1 shows the setup of the vertical column model used for simulating seepage flow through tailings in section 35. The vertical column is 150 feet tall and has a width of 2 feet. A variable grid spacing was used for the finite element grid with finer discretization near the top and bottom of the column resulting in a total of 428 elements.

The following boundary conditions were used. At the surface, a constant flux boundary was used. The magnitude of the surface flux varied between different simulations depending on the tailings type and the presence or absence of a soil cover (see below). At the base of the column a constant head boundary was used. The constant head was set equal to the elevation at the base of the tailings representing free-draining conditions (pressure head = 0).

The dewatering of the tailings was simulated for a column of uniformly coarse and uniformly fine tailings, respectively. The hydrologic properties of those two tailings types were determined in the laboratory (see Appendix C for details). The soil moisture characteristic curves, i.e. volumetric moisture content as a function of soil suction (negative heads), of two representative tailings samples were used as input to the column model (97-T-7 for sandy tailings and T-2 for fine tailings, see Figure 4.3). The hydraulic conductivity of these two tailings types as a function of soil suction (negative head) was estimated using the (measured) saturated permeability and the van Genuchten model (van Genuchten, 1980). The resulting hydraulic conductivity functions are shown in Figure 4.4. The hydraulic conductivity function is by far the most critical parameter in determining the rate of dewatering of the tailings. This parameter was varied using different estimates of the saturated hydraulic conductivity to evaluate the possible range of dewatering rates of tailings (Figure 4.4). Note that the use of different saturated hydraulic conductivity values for a given tailings type shifts the entire hydraulic conductivity function in the y-direction, but does not change its shape (which is controlled by the soil moisture characteristic curve) (Figure 4.4).

A total of seven simulations were run representing a range of tailings and cover conditions (Table 4.1). For the coarse tailings, the (saturated) permeability was varied by one order of magnitude (K_s ranging from $1 \cdot 10^{-3}$ cm/s to $1 \cdot 10^{-4}$ cm/s). For the fine tailings, the (saturated) permeability was varied by two orders of magnitude (K_s ranging from $5 \cdot 10^{-6}$ cm/s to $5 \cdot 10^{-7}$ cm/s). For each tailings type, a representative cover flux was used as determined during cover modeling (0.4 inches per year ($9.1 \cdot 10^{-5}$ ft/day) over the fine tailings and 1.1 inches per year ($2.5 \cdot 10^{-4}$ ft/day) for the coarse tailings; see chapter 5). For comparison, those simulations for the coarse tailings were also run

for a surface flux of 6 inches per year ($1.4 \cdot 10^{-3}$ ft/day). This surface flux is a rough approximation of the infiltration one might expect on the coarse tailings beaches without any cover on the tailings.

Table 4.1.

Scenarios evaluated using Tailings Column Model.

Simulation	Tailings Type	Saturated Hydraulic Conductivity (K_z)	Surface Flux
Run 1a	coarse tailings	$K_s = 1 \cdot 10^{-3}$ cm/s or 2.8 ft/day	1.1 inches per year (soil cover)
Run 1b	coarse tailings	$K_s = 1 \cdot 10^{-4}$ cm/s or 0.28 ft/day	as above
Run 2a	coarse tailings	$K_s = 1 \cdot 10^{-3}$ cm/s or 2.8 ft/day	6 inches per year (no soil cover)
Run 2b	coarse tailings	$K_s = 1 \cdot 10^{-4}$ cm/s or 0.28 ft/day	as above
Run 3a	fine tailings	$K_s = 5 \cdot 10^{-6}$ cm/s or $1.4 \cdot 10^{-2}$ ft/day	0.4 inches per year (soil cover)
Run 3b	fine tailings	$K_s = 5 \cdot 10^{-7}$ cm/s or $1.4 \cdot 10^{-3}$ ft/day	as above

The initial conditions for the transient simulation of tailings were those of a fully saturated column with gravity drainage. These initial conditions were generated by applying a constant flux equivalent to the (vertical) saturated hydraulic conductivity at the top of the column (tailings surface) using a constant head equal to the 0 at the base. The steady-state solution of this boundary value problem represents a saturated, free-draining column with gravity-driven flow, i.e. the (vertical) total head gradient is equal to 1 throughout the column. Furthermore, the total head at a given point is equal to its elevation, i.e. the pressure head is equal to 0 throughout the column. These free-draining conditions were assumed as the initial condition for the transient simulation to model the dewatering of the tailings in section 35.

4.4.2 2D cross-sectional Model (Section 36 Tailings Area)

Figure 4.5 shows the set-up of the two-dimensional cross-sectional model used for simulating seepage flow through the tailings in section 36. The model domain represents an idealized cross-section extending from the northern end of the impoundment along the center of the in-filled

arroyo to Dam No 1 and on to the Red River (near Questa Springs). The tailings impoundment itself is subdivided into three regions; (i) Dam No. 1 consisting of permeable earth fill material; (ii) coarser tailings in the southern portion of the impoundment; and (iii) finer tailings in the northern portion of the impoundment. Note that the tailings thickness ranges from about 200 feet near Dam No. 1 to about 100 feet at the northern end of the model domain owing to the slope of the underlying ground surface. The thin deposits of tailings pinching out to the north were not included here for simplicity.

The underlying (shallow) aquifer system is subdivided into three layers: (i) an upper layer with fine alluvium (above 7325 feet a.s.l.); (ii) a middle layer with mixed alluvium (7325 – 7270 feet a.s.l.); and (iii) a lower layer of coarse alluvium (7270 – 7220 feet a.s.l.). Note that the aquifer layers used here are equivalent to those of the calibrated local flow model (chapter 3). The lower model layer pinches out near the Red River in vicinity of the Questa Springs. The riverbed elevation of the Red River (7220 feet a.s.l.) is used as the datum (z=0 feet) for the cross-sectional model.

The soil moisture characteristic curves for the two tailings types used here are equivalent to those used in the vertical column model (Figure 4.3). For the various alluvial units (earth fill, as well as fine, mixed and coarse alluvium) the measured soil moisture characteristic curve of a representative alluvial soil sample (sample T-21) was used (Figure 4.3, see also Appendix C). The saturated hydraulic conductivities of the various hydrogeological units are summarized in Table 4.2. The hydraulic conductivity values for the aquifer units (fine, mixed and coarse alluvium) were taken from the calibrated local flow model (see chapter 3). Geocon's estimates of hydraulic conductivity of the tailings "en masse" in vicinity of Dam 1 and Dam 1c were used for the coarser tailings in the southern portion of the impoundment. The hydraulic conductivity values for the fine tailings in the northern portion were taken from laboratory measurements of fine tailings (Appendix C). The hydraulic conductivity of the earth fill material in Dam No. 1 was assumed to be equivalent to the (horizontal) permeability of the mixed alluvium.

For all units, the hydraulic conductivity characteristic curve (as a function of soil suction) was estimated using the saturated hydraulic conductivity estimates and the van Genuchten model (van Genuchten, 1980).

Table 4.2

Hydraulic Conductivity Estimates used for 2D Cross-Sectional Seepage Model.

Unit	Saturated Hydraulic Conductivity K_s		Reference
	Horizontal Conductivity K_h (cm/s)	Vertical Conductivity K_z (cm/s)	
Coarser Tailings (southern portion of impoundment)	$6.3 \cdot 10^{-5}$ cm/s or 0.18 ft/day	$6.3 \cdot 10^{-6}$ cm/s or 0.018 ft/day	Geocon, 1983
Finer Tailings (northern portion of impoundment)	$5 \cdot 10^{-7}$ cm/s or $1.4 \cdot 10^{-3}$ ft/day	$5 \cdot 10^{-7}$ cm/s or $1.4 \cdot 10^{-3}$ ft/day	Appendix C
Fine Alluvium	$3 \cdot 10^{-4}$ cm/s or 0.85 ft/day	$3 \cdot 10^{-6}$ cm/s or $8.5 \cdot 10^{-3}$ ft/day	Local Flow Model (chapter 3)
Mixed Alluvium	$3 \cdot 10^{-3}$ cm/s or 8.5 ft/day	$3 \cdot 10^{-5}$ cm/s or 0.085 ft/day	Local Flow Model (chapter 3)
Coarse Alluvium	$3 \cdot 10^{-2}$ cm/s or 85 ft/day	$3 \cdot 10^{-4}$ cm/s or 0.85 ft/day	Local Flow Model (chapter 3)
Earth Fill Material	$3 \cdot 10^{-3}$ cm/s or 8.5 ft/day	$3 \cdot 10^{-3}$ cm/s or 8.5 ft/day	assumed

The following boundary conditions were used in the cross-sectional model (Figure 4.5). A constant flux boundary was used along the right hand side (northern boundary) representing steady-state underflow of groundwater. Note that this flux boundary extends only to the height of the water table determined from the calibrated local flow model (Figure 4.5). The total groundwater flux at the right-hand side boundary was about 71 ft^3/day (per foot of cross-section) with the majority of flow occurring in the lower aquifer layer 3 (64 ft^3/day (per foot of cross-section) (compare chapter 3). The bottom of the model domain is a no-flow boundary representing the basal clay layer beneath model layer 3 in the local flow model. The Red River on the left-hand side boundary is modeled as a constant head boundary with a head equal to the river elevation. The area from the Red River to the toe of the dam is assumed to be a seepage face (Figure 4.5). Here, so-called "review nodes" are used which allow seepage out of the model domain if the water table is higher than the elevation of the node (Geoslope, 1994). The face of Dam No. 1 is modeled as a no-flow boundary. At the tailings surface, a constant flux boundary was used. The magnitude of the surface flux varied depending on the tailings type and presence or absence of a cover (see below).

The cross-sectional model was initially run at steady-state to evaluate the influence of the shallow groundwater table in the underlying aquifer system on steady-state conditions within the tailings. The surface flux through the tailings was varied until the entire tailings mass was saturated but no ponding occurred.

The total head distribution of this steady-state solution was then used as the initial condition for the transient simulation of dewatering of the tailings. For the transient simulation, a cover was assumed to be present at the tailings surface, reducing surface flux to 0.4 inches/year ($9.1 \cdot 10^{-5}$ ft/day) over the finer tailings and to 1.1 inches per year ($2.5 \cdot 10^{-4}$ ft/day) over the coarser tailings (see chapter 5). All other boundary conditions were equivalent to those of the steady-state solution. The transient simulation was run until "steady-state", i.e. until the seepage losses at the base of the tailings equal the net infiltration through the cover.

4.4.3 Model Assumptions

The main assumptions in our approach to modeling seepage through the tailings are as follows:

- the tailings can be classified into coarse and fine tailings; these units are homogeneous at the scale of the analysis; horizontal layering within the tailings can be expressed as vertical anisotropy; flow through the tailings can be simulated using Darcy's Law;
- seepage through the tailings in section 35 is predominantly vertical; the base of the tailings in section 35 are free-draining; horizontal flow components can be neglected;
- the flux through the soil cover can be simulated as a steady-state flux (seasonal recharge is smoothed within the tailings profile); the simulated flux rates through a 9 inch thick alluvial cover layer (chapter 5) are applicable; and
- the process of tailings consolidation can be neglected in this analysis.

It is emphasized again that both seepage models (vertical column as well as the cross-sectional model) significantly simplify the actual site conditions. The objective of this seepage analysis was not to develop a detailed "site model" but rather to illustrate the controls on tailings dewatering and to provide order-of-magnitude estimates of seepage losses over time.

4.5 Results

4.5.1 Vertical Column Model

Figure 4.8 shows the simulated decline in the water table for the various column runs (except for the case of the very permeable sandy tailings (Runs 1a and 2a, Ks = 2.8 ft/day) which desaturated within a matter of hours. The water table in the tailings decreases at a near-constant rate as a result of gravity-driven drainage (i.e. saturated flow with unity gradient). The decline in the water table is largely controlled by the (vertical) hydraulic conductivity of the tailings. The water table in the coarse tailings declines 1-3 orders of magnitude faster than in the fine tailings (Figure 4.6). Note, that the presence of a soil cover on the coarse tailings does not significantly

influence the decline in the water table (compare Runs 1b and 2b). This follows from the fact that the surface fluxes (with or without soil cover) are only a fraction of the initial seepage losses (equivalent to the saturated hydraulic conductivity). In other words, the decline in water table is largely controlled by the seepage losses at the free-draining base of the column and not by the (small) surface flux.

It is important to note that the decline in water table shown in Figure 4.6 represents only the very early stages of dewatering, i.e. when the pores just desaturate. The amount of water that needs to be released from storage to cause this initial decline in water table is very small. At the same time the free-draining column drains at a maximum rate since the tailings column is still saturated (below the water table). The result is an often very rapid decline in the water table (Figure 4.6). Once the entire tailings column is desaturated (water table at the base of the column) any further dewatering of the tailings (approaching steady-state conditions with respect to the reduced surface flux through the cover) slows down significantly (see below).

Figure 4.7 shows the simulated lower boundary flux, or seepage loss, for the coarse tailings as a function of time (Runs 1a to 2b; compare Table 4.1). All four simulations using coarse tailings show an exponential decline in seepage losses over time (Figure 4.7). This rapid decline in seepage losses over time is a direct consequence of the dewatering of the tailings, which reduces the (unsaturated) hydraulic conductivity of the tailings column (compare Figure 4.4). In other words, the process of tailings dewatering slows itself down resulting in progressively smaller seepage losses.

The seepage fluxes reporting from the base of the tailings column continue to decrease over time until the system approaches steady-state conditions, in which the seepage losses equal the net infiltration at the tailings surface. In those model runs where a high surface flux of 6 inches is assumed (representing net infiltration into uncovered tailings), steady-state is reached after approximately 6-11 years (see Runs 2a and 2b, Figure 4.7). In those model runs where a low surface flux of 1.1 inches is assumed (representing net infiltration through a soil cover), steady-state is reached after approximately 27-37 years (see Runs 1a and 1b, Figure 4.7). Simulated depth profiles of total head and volumetric moisture content for steady-state conditions are shown in Appendix D.

Note that a reduction in surface flux (attributed to cover placement) does not significantly influence the exponential decline in seepage rates during the early stages of dewatering (Figure 4.7). These model results suggest that, although the cover placement reduces the steady-state flux through the coarse tailings, it may not significantly accelerate the process of dewatering per se.

Figure 4.8 shows the simulated lower boundary fluxes, or seepage losses, for the fine tailings as a function of time. The simulated boundary fluxes through the fine tailings also decrease exponentially (Figure 4.8). However, the rate of decline is much smaller than for the coarse tailings (compare Figures 4.8 and 4.7). Steady-state conditions in the fine tailings are reached after approximately 50 years in run 3a (w/ $K_s=5\cdot10^{-6}$ cm/s or $1.4\cdot10^{-2}$ ft/day) and after approximately 60-70 years in run 3b (w/ $K_s=5\cdot10^{-7}$ cm/s or $1.4\cdot10^{-3}$ ft/day) (Figure 4.8). Simulated depth profiles of total head and volumetric moisture content for steady-state conditions are shown in Appendix D.

Note that the times required to reach steady-state conditions in the fine and coarse tailings do not differ as much as one might expect considering the large differences in saturated hydraulic conductivity. However, dewatering of the tailings is, for the most part, controlled by unsaturated flow. Once the tailings desaturate, the hydraulic conductivity function of the coarse tailings declines much more rapidly than that of the fine tailings owing to the differences in the soil water characteristic curves of these two tailings types (compare Figures 4.3 and 4.4).

4.5.2 Cross-sectional Model

The cross-sectional model was first run at steady-state conditions to determine appropriate initial conditions for the transient analysis. In particular, it had to be determined whether the tailings are free-draining at the base or not. Under free-draining conditions, the tailings should just be saturated (no ponding) with a (steady-state) unit flux at the surface being equal to the vertical hydraulic conductivity of the tailings. Figure 4.9 shows the steady-state solution for an assumed surface flux equal to the vertical hydraulic conductivities of the tailings (i.e. $1.8 \cdot 10^{-2}$ ft/d in the southern portion and $1.4 \cdot 10^{-4}$ ft/day in the northern portion). The total head contours in the northern portion are near horizontal and approximately equal indicating the fine tailings are free-draining (Figure 4.9). In the southern portion, however, the model predicts significant ponding (about 10 feet) indicating that the coarser tailings in this area are not free-draining (Figure 4.9). In other words the shallow aquifer system represents an impediment to tailings seepage for these high seepage rates. It also follows that the surface flux through the coarse tailings must be less than its (assumed) vertical hydraulic conductivity because this portion of the tailings impoundment does not usually experience ponding.

The surface flux over the southern portion (coarser tailings) was subsequently reduced to saturate the tailings throughout the cross-section without any significant ponding. Figure 4.10 shows the steady-state solution for a unit flux in the southern portion equal to $2.9 \cdot 10^{-3}$ ft/d, i.e. approximately half of the vertical hydraulic conductivity. This reduced surface flux produces a saturated tailings profile without ponding. The total seepage flux from the tailings in this steady-state solution was approximately ~ 8 ft^3/day (per foot of cross-section). Note that this seepage loss is orders of magnitude lower than the groundwater flows in the shallow aquifer system (~71 ft^3/day per foot of cross-section). The total head distribution of the steady-state solution shown in Figure 4.10 was used as initial condition for the transient simulation of tailings dewatering.

Preliminary results of the transient simulation of the cross-sectional model show a similar exponential decline in the seepage fluxes from the tailings as simulated for the vertical columns. The dewatering of the fine tailings in the northern portion of section 36 was similar to that simulated for the free-draining column model. The dewatering of the coarse tailings in the southern portion of section 36 was slower due to a lower (assumed) hydraulic conductivity as well as the influence of the shallow groundwater table (preventing free-drainage). This modeling work is on-going and the results of additional simulations will be presented as part of the Questa Mine closure plan.

4.6 Discussion and Implications

The modeling results of this parametric study on tailings seepage suggest the following with respect to dewatering of the tailings in time:

- the tailings begin to dewater whenever the surface flux into the tailings is reduced to less than the vertical (saturated) hydraulic conductivity of the tailings; the coarse tailings of the tailings impoundments at Questa are sufficiently permeable to allow natural dewatering, even without cover placement; the fine tailings probably require a cover to achieve dewatering;
- seepage fluxes at the base of the tailings ("seepage losses") decrease exponentially with time (assuming the tailings are allowed to drain by discontinuing discharge of tailings slurry and/or by placing a soil cover); and
- the time to reach steady-state conditions after closure, i.e. when seepage losses equal net infiltration through a soil cover, are estimated to be in the order of 27 – 37 years for the coarse tailings and 50 to 70 years for the fine tailings (assuming free drainage at the base of the tailings).

The seepage analysis clearly illustrates that the seepage losses will decline significantly over time. At the same time the contaminant concentrations in the tailings seepage are expected to decrease over time as well (SRK, 1997). The overall result will be a significant reduction in contaminant load entering the groundwater system over time.

Molycorp is currently intercepting contaminated seepage using trenches and extraction wells below Dam No. 1. The seepage analysis for the section 36 tailings area suggests that the tailings seepage, once entering the shallow groundwater system beneath the section 36 impoundment, is flowing in a near horizontal direction toward and beneath the dam (see Figure 4.10). In other words the existing interception system should be collecting most, if not all, of this tailings seepage.

The reduction in seepage losses due to cover placement will not be immediate but, depending on the location of phreatic surface at the time of cover placement, will take years to several tens of years. Until such time as the combined effects of decline in seepage flux and improvement in tailings pore water quality result in acceptable groundwater quality, the tailings seepage will have to be intercepted by the interception system.

Current proposals for mine closure provide for cover placement to reduce the seepage flux combined with maintenance of the interception well system, until the intercepted groundwater quality improves sufficiently to allow interception to be discontinued. The likely time periods of operating such an interception system will be estimated once final dam configurations and cover systems have been selected as part of the closure plan.

Figures

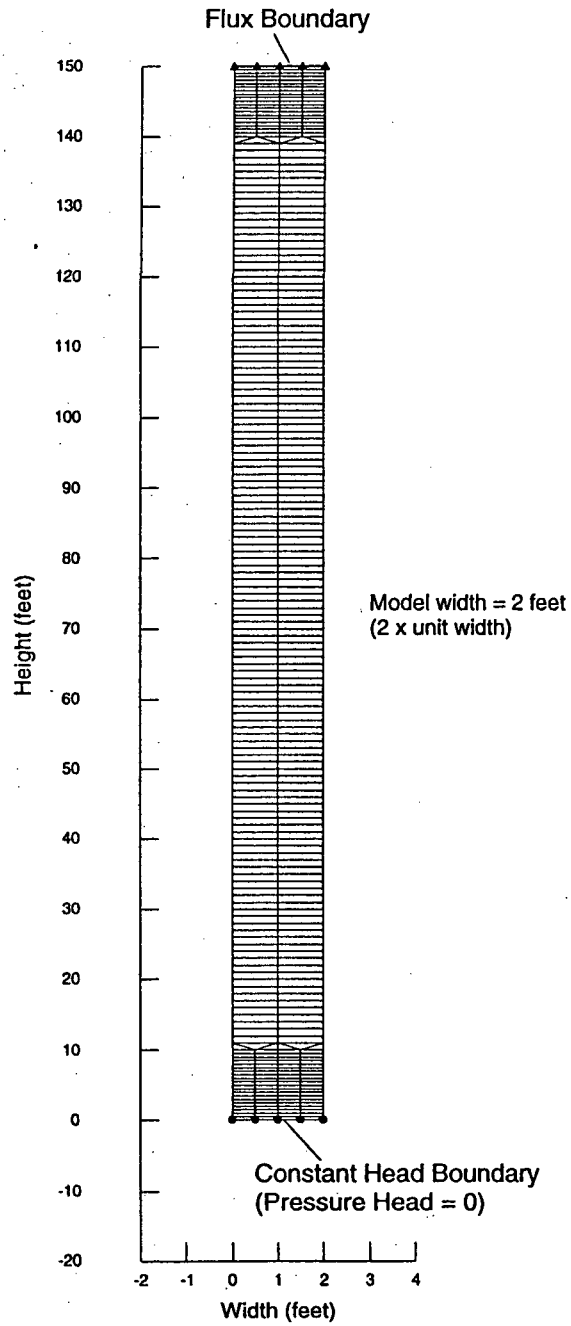


Figure 4.1.
Set-up of Column Model used to simulate Seepage in Section 35 Tailings.

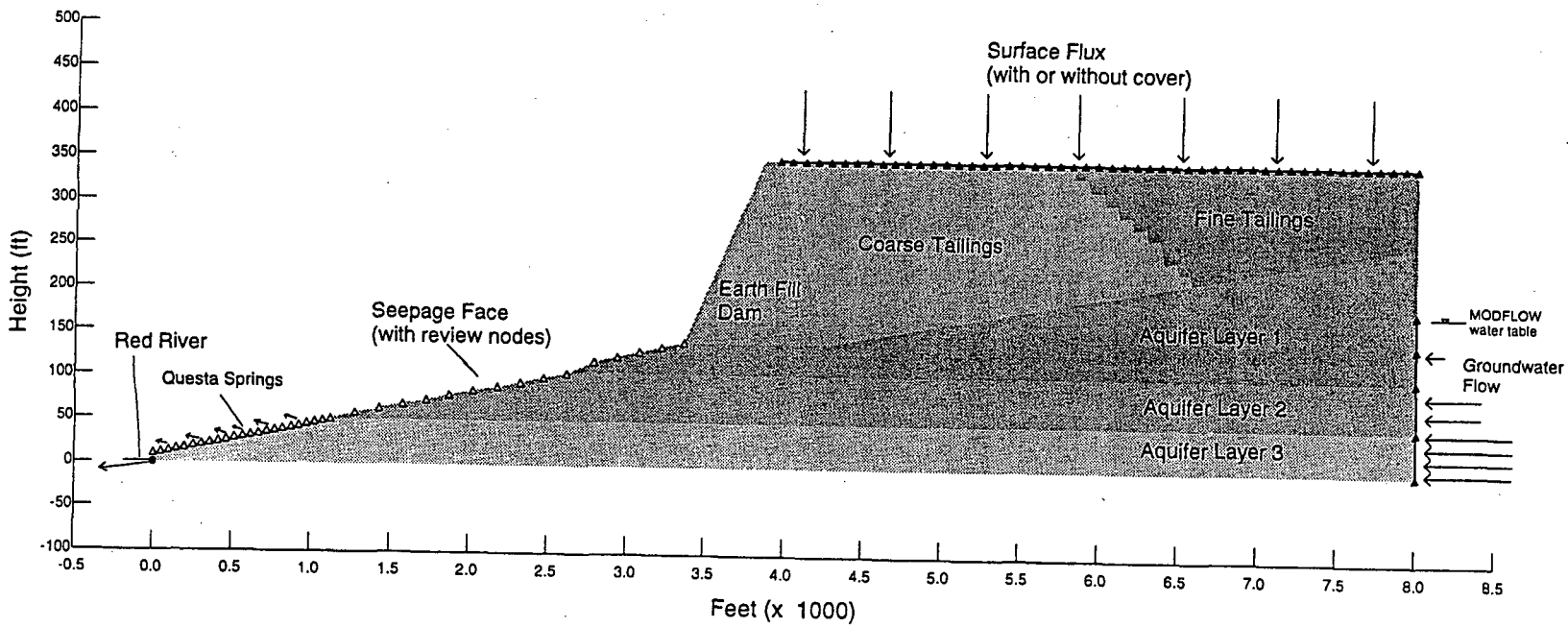


Figure 4.2.
Cross-sectional Model used to simulate Seepage in Section 36 Tailings.

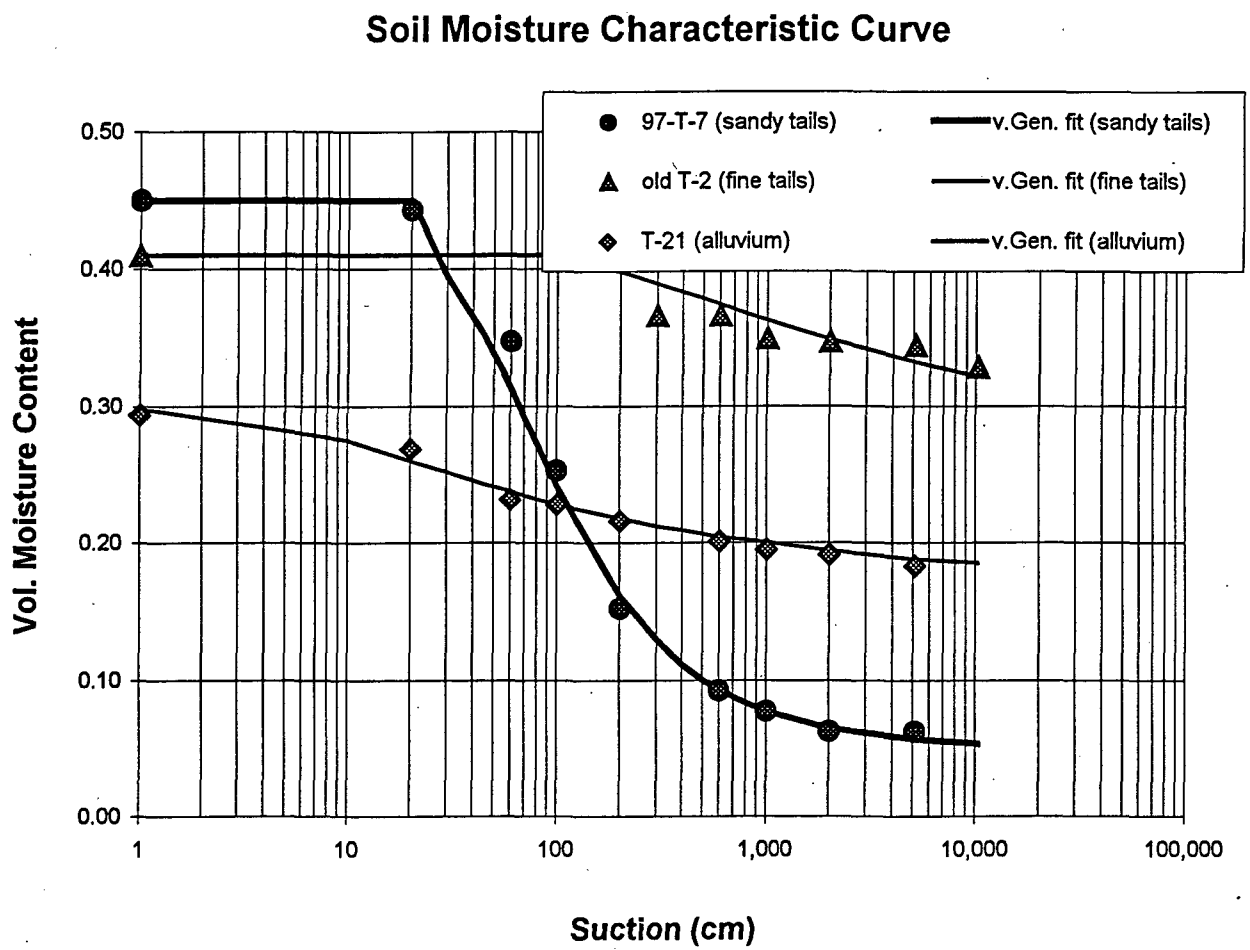


Figure 4.3.
Soil Moisture Characteristic Curves for various soil types.

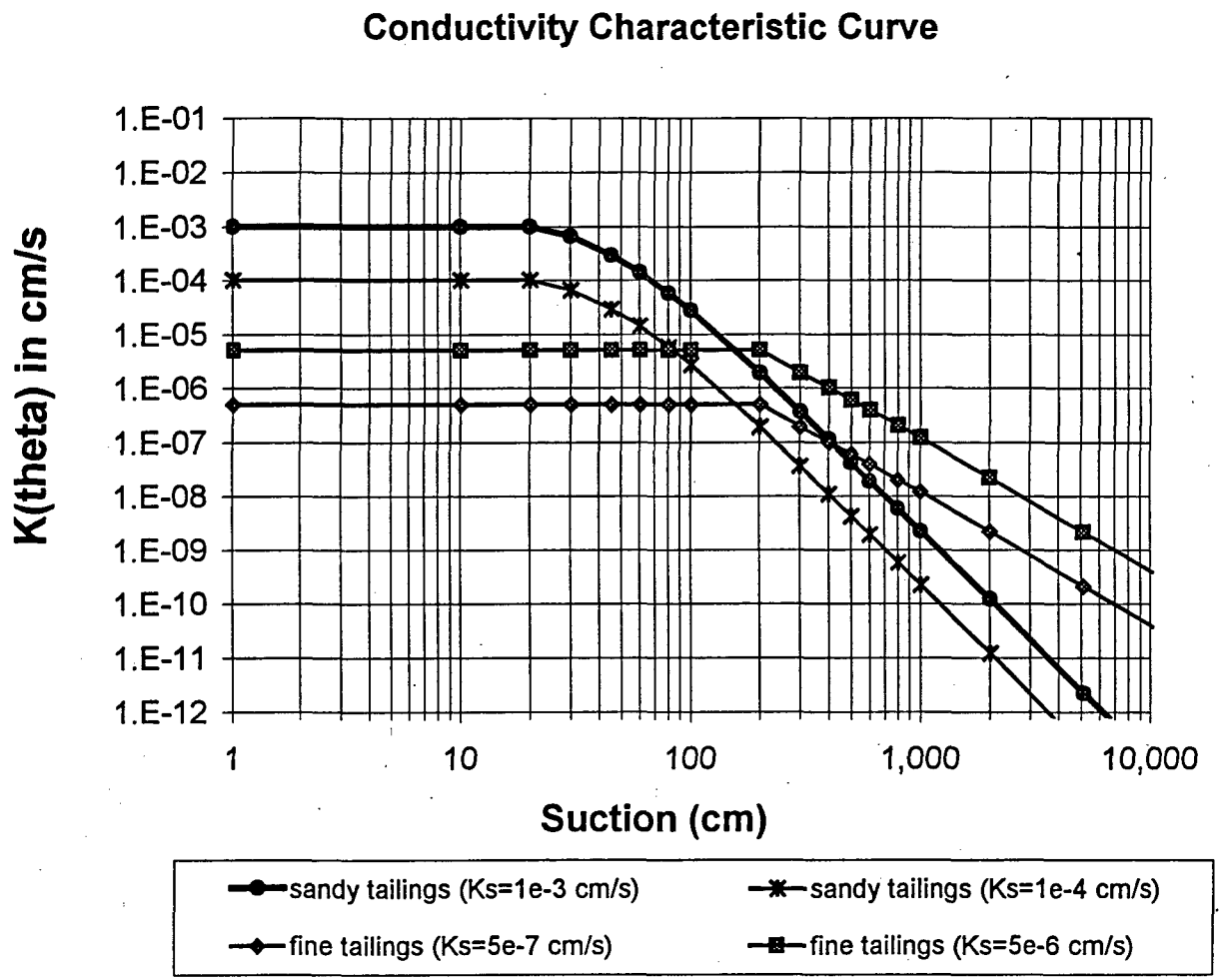


Figure 4.4.
Hydraulic Conductivity Functions for Tailings.

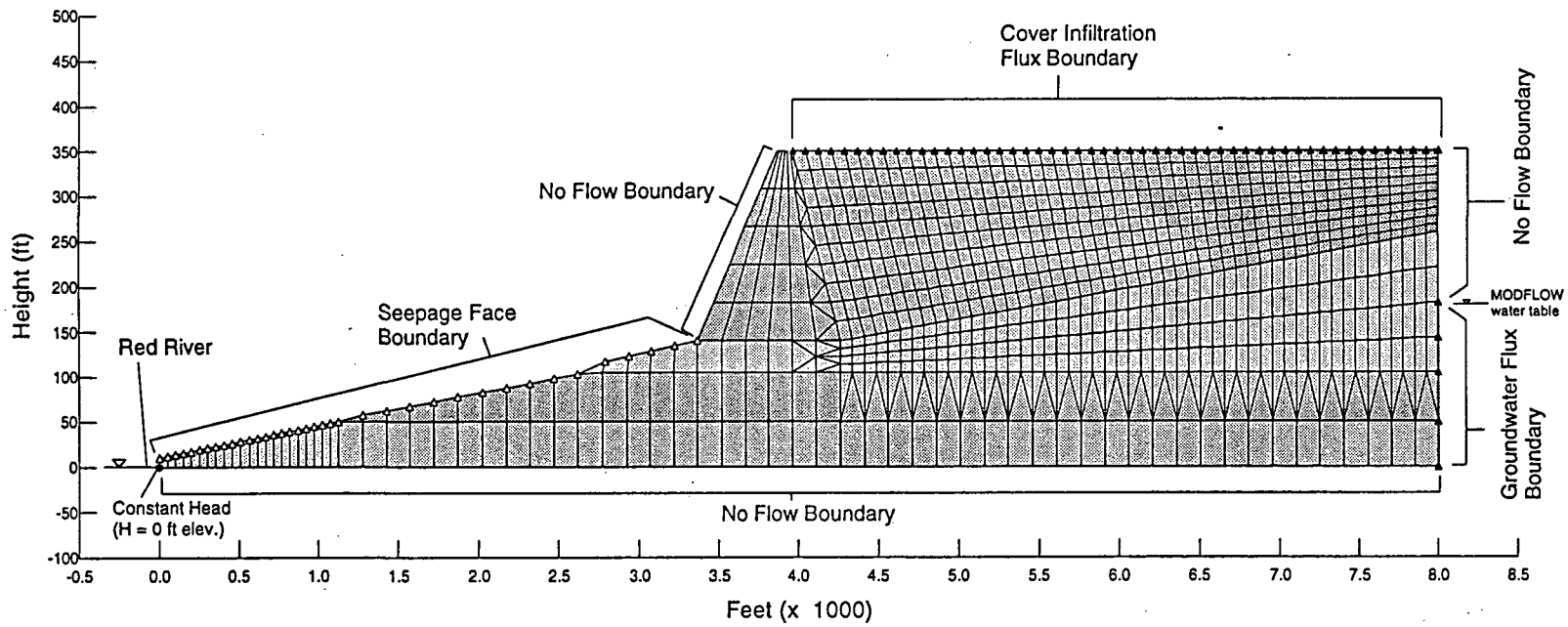


Figure 4.5.
Finite Element Grid and Boundary Conditions for Cross-sectional Model.

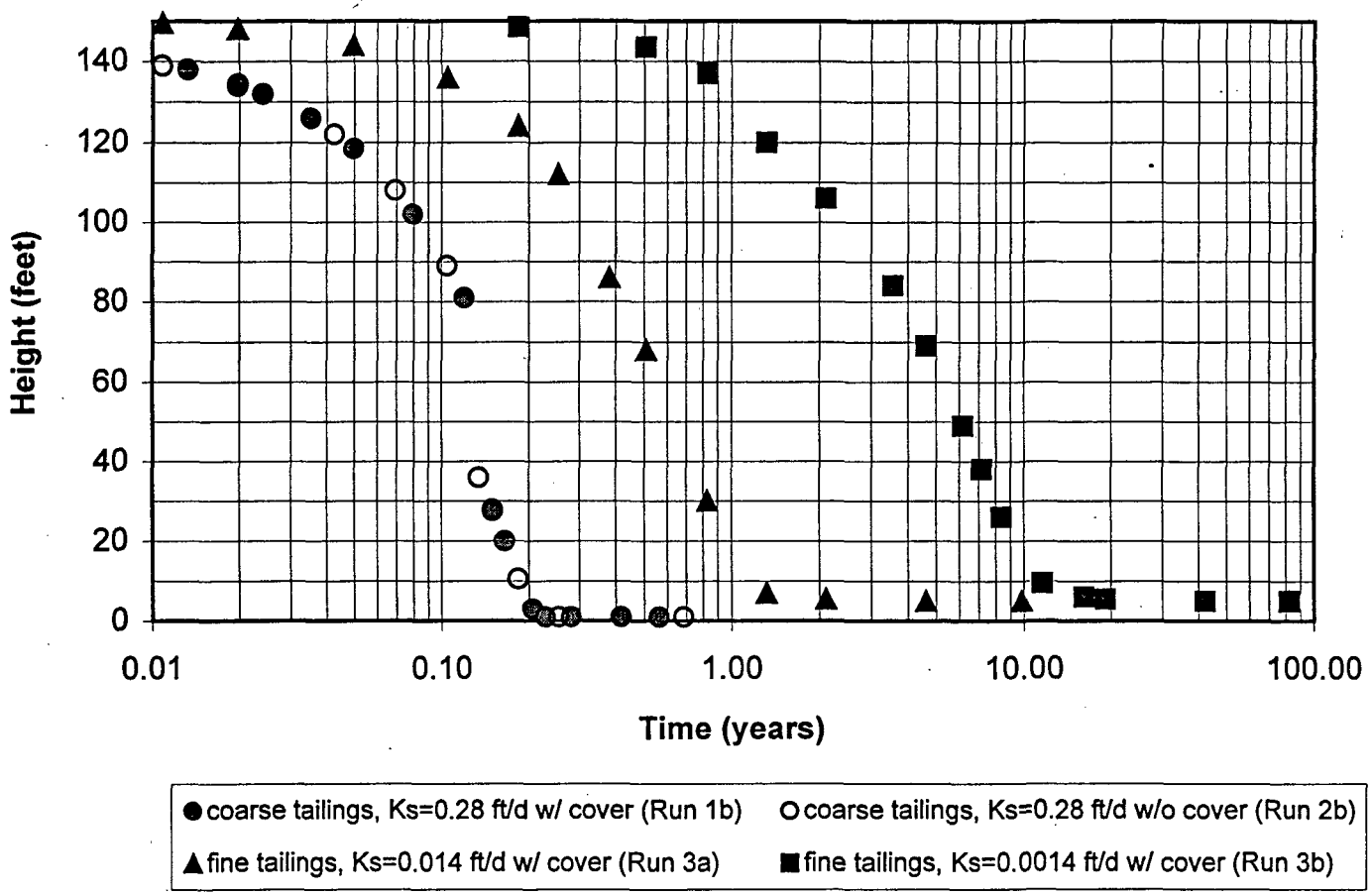


Figure 4.6.
Simulated Height of Water Table as a Function of Time.

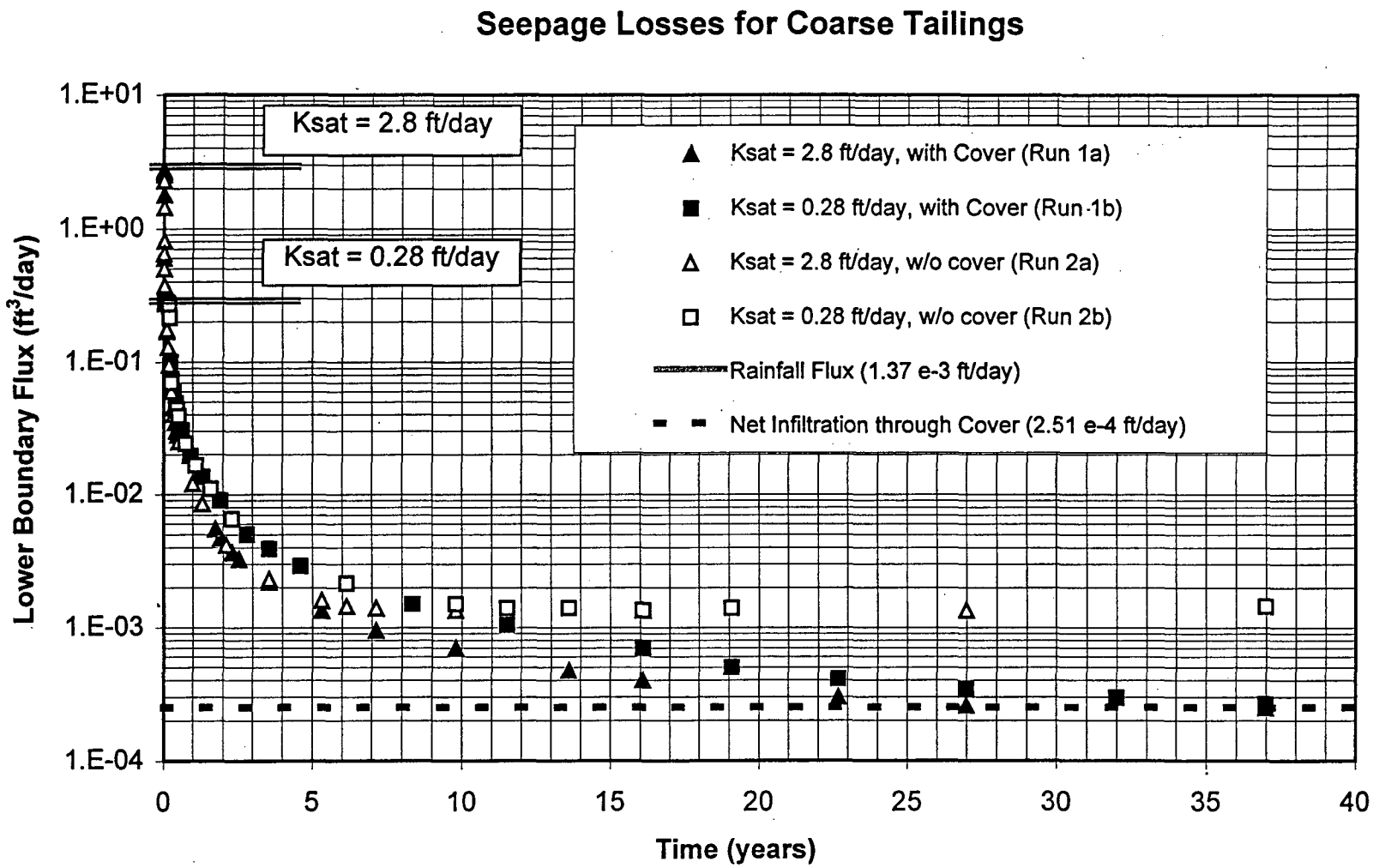


Figure 4.7.
Simulated Seepage Losses from the Coarse Tailings over Time.

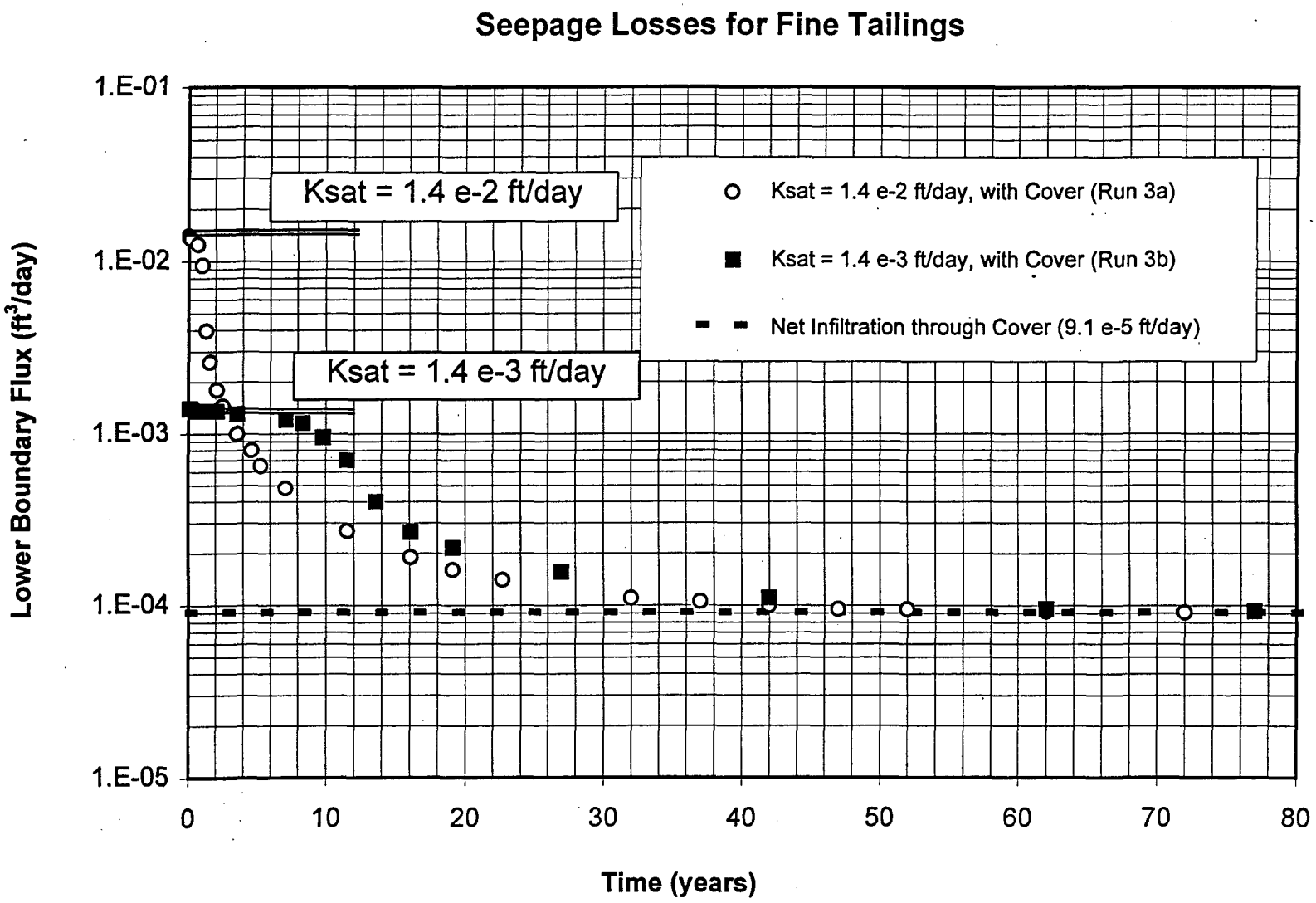


Figure 4.8.
Simulated Seepage Losses from the Fine Tailings over Time.

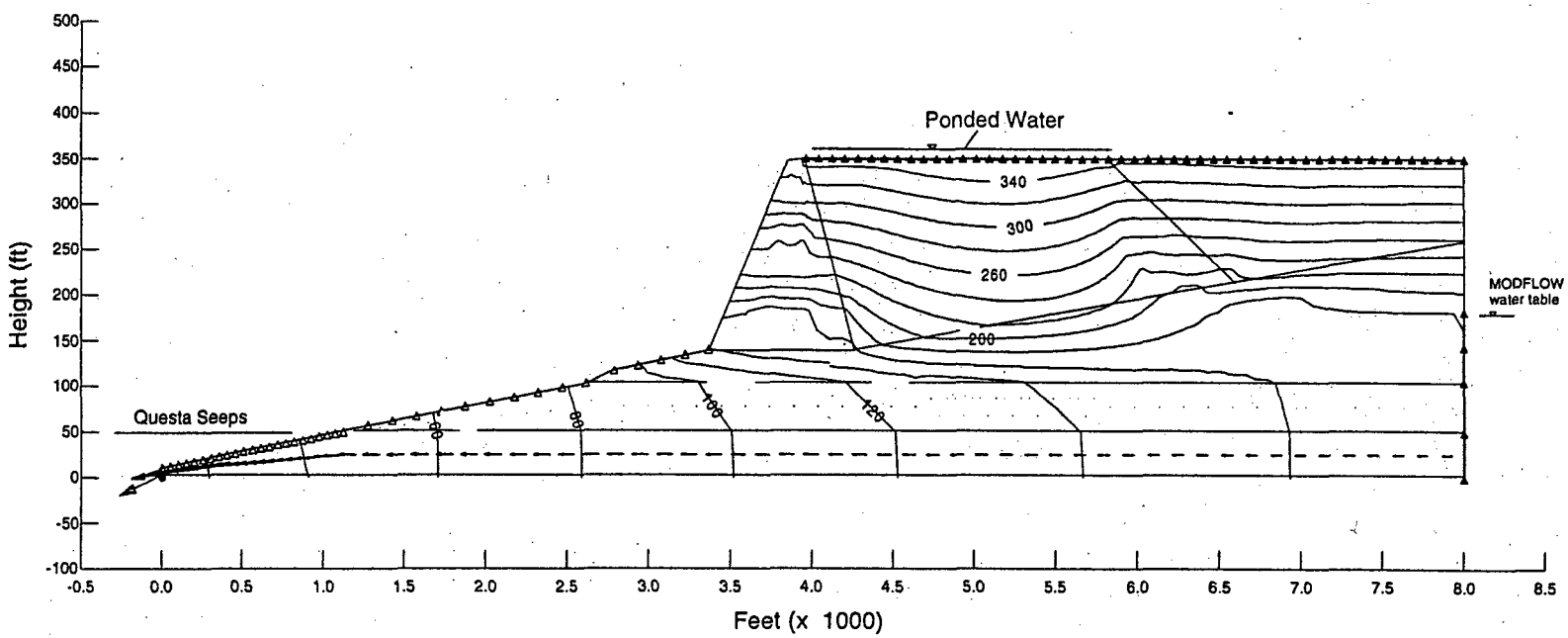


Figure 4.9.
Simulated Hydraulic Head Contours in Tailings and Shallow Aquifer System with Surface Flux equal to vertical Hydraulic Conductivity of Tailings.

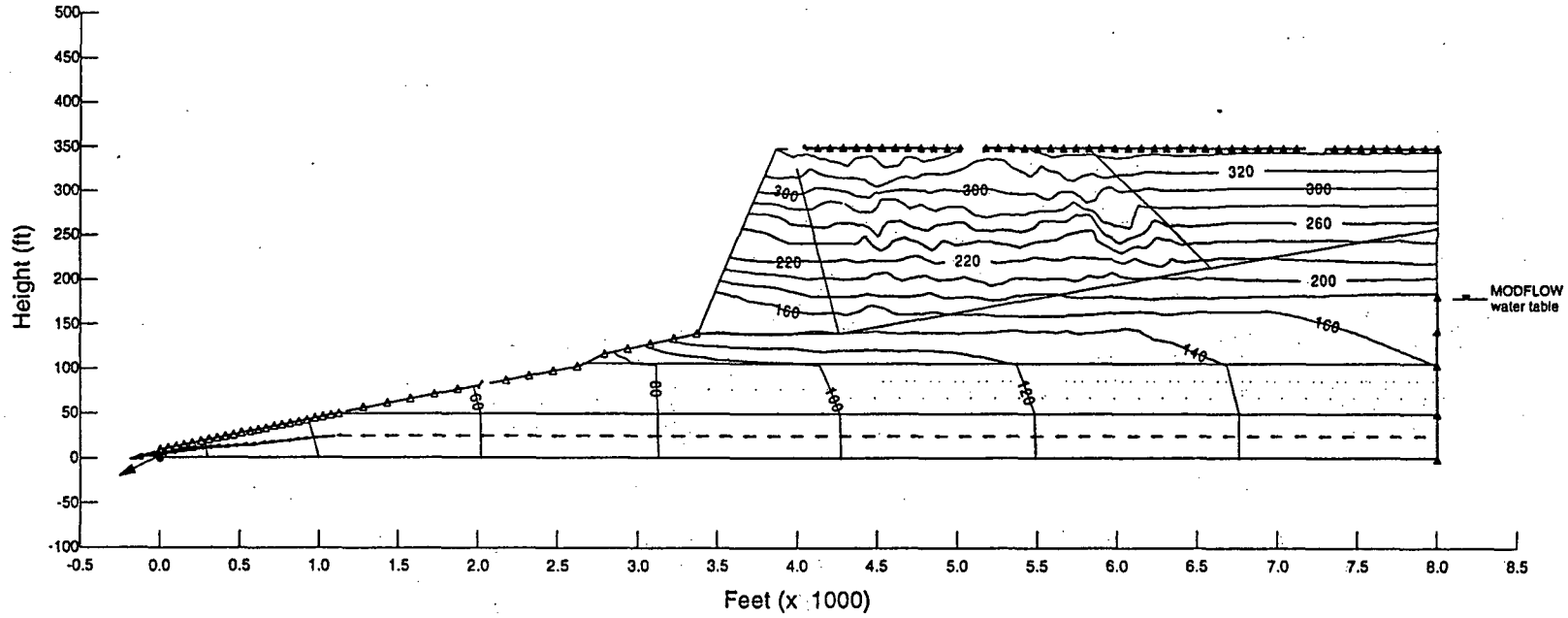


Figure 4.10.
Simulated Hydraulic Head Contours in Tailings and Shallow Aquifer System with Surface Flux reduced to avoid Ponding.

Section 5

5 Cover Performance Analysis

On closure of the tailings facilities, the upper surface of the impoundments will be shaped and contoured to establish positive drainage. A permanent cover will be established to return the surface of the impoundment to a beneficial land-use equivalent to, or better than that which existed prior to tailings dam development.

The purpose of this alluvial cover would be at least four-fold:

- control dust from exposed tailings;
- avoid surficial erosion of exposed tailings;
- support a vegetative cover; and
- control movement of water through the tailings (seepage) in the long-term.

The current 9" alluvial gravel cover has demonstrated that it provides excellent dust and erosion control and is supporting vegetation typical of the surrounding area.

This section of the report evaluates the performance of soil covers, constructed from locally available alluvial soils, with respect to controlling infiltration into, and therefore seepage out of the tailings.

5.1 Objectives of Cover Performance Analysis

Briefly, the objectives of the cover performance analysis are as follows:

- determine key parameters influencing cover performance, i.e. reduction in infiltration through cover and underlying tailings;
- estimate the net flux of water through alluvial covers as a function of cover thickness and cover layer sequence; and.
- determine, if there is any material benefit to be gained from the construction of more complex and costly multi-layered covers.

The high-energy erosion events responsible for the deposits of alluvial soils occurring in the vicinity of the Questa tailings facilities resulted in predominantly permeable gravel deposits. Occasional layers of silt are encountered within the sequence of alluvial gravels, apparently the result of shallow lake sediments. The silts are of relatively low but not very low permeability. No thick deposits of clay suitable for construction of very low permeability cap layers have been observed in the vicinity of the tailings impoundment. This performance analysis evaluated the effectiveness of alternative cover designs using the locally available alluvial gravel's and silts.

5.2 Conceptualization and Model Construction

5.2.1 Concepts

Seepage of precipitation through the tailings impoundments at the Questa Mine, New Mexico, could carry oxidation products such as metals and sulfate from the oxidizing tailings into the underlying groundwater aquifer.

The infiltration and seepage through the tailings may be reduced by placing a permanent soil cover over the tailings. The design of such a cover including type of cover material(s) and cover thickness should be adapted to the local climatic conditions at the site. For the arid climate conditions prevailing at Questa there are three principal options to reduce infiltration into the tailings:

- place a low permeability cover material layer on top of tailings to reduce infiltration ("conventional cover technology"). This type of cover typically requires additional, protective soil layers to minimize deterioration of the cover layer by means of erosion, frost action, air drying, animal burrowing and/or plant rooting;

- place a coarse cover material on top of tailings ("capillary barrier") to impede downward movement of soil moisture. This type of cover requires an additional cover layer of regular soil material to store any infiltrating precipitation during wet periods. During dry periods the stored soil moisture is then removed from this upper soil profile by evapotranspiration. Downward seepage would only occur if the soil above the capillary barrier becomes saturated; or

- place a soil cover that allows for maximum root penetration to maximize soil water uptake by plant roots (natural evapotranspiration). This type of "storage cover" relies entirely on the ability of evapotranspiration by the plants to control deep seepage. The cover material serves primarily as a medium for plant growth and to avoid wind erosion of the tailings. The root zone is not limited to the cover layer but may extend into the upper layers of the tailings.

There are concerns with the long-term performance of a conventional cover (Option 1) in that low permeability layers (typically low permcability silts or clays) are prone to cracking in response to air-drying and/or freeze-thaw cycles in climates such as observed at Questa, New Mexico (Morris and Stormont, 1997). Other factors causing potential breakdown of the clay layer as a barrier to infiltration include animal burrowing and root penetration.

The latter two cover designs both depend on dry climate conditions, characterized by limited precipitation and rates of evapotranspiration much greater than those of precipitation.

The climatic conditions at the Questa site favor the use of either cover options 2 or 3 for construction of a permanent cover. Here we focus on evaluating the performance of "storage covers". This cover type can be constructed entirely from local material without material screening simplifying construction and thus greatly reducing construction costs.

5.2.2 Conceptual Model

Figure 5.1 illustrates the conceptual model used here for modeling a storage cover. The typical cover profile consists of a single layer of alluvial soil (say 9 inches) overlying sandy (or fine) tailings. It is assumed that shrub vegetation (see below) is well established on the cover with a well-developed root zone extending from 0.05 to 1.05 m below ground surface. An active root zone depth of 1m is considered conservative for a mature semi-arid shrub community. Note that much of the root zone is actually located within the tailings. In other words the tailings themselves are an essential part of the "storage cover". The entire soil profile modeled here is assumed to be unsaturated with the water table (if any) well below the upper say 10m of the soil profile.

At the soil surface, precipitation (rain and/or snow) is infiltrating into the soil profile. The rate of infiltration is a function of the permeability (and indirectly of the soil moisture) of the soil. If the (daily) rate of precipitation is greater than the maximum rate of infiltration, the water is assumed to run off (i.e. ponding is not allowed).

Once infiltrated, the water slowly percolates downward through the cover material and into the tailings. As it moves through the root zone, some (if not all) of the water is taken up by the plant roots and transpired back into the atmosphere. Some water, in particular close to the soil surface, is also evaporating and leaving the soil profile as water vapor. In this study, we use a lumped parameter approach, in which the atmospheric removal of soil moisture via evaporation and transpiration is simulated by specifying potential rates of evapotranspiration. The actual rate of evapotranspiration depends on the soil moisture actually available within and near the root zone. A more sophisticated approach modeling the processes of evaporation and transpiration deterministically (see e.g. Wilson, 1993 and Flerchinger and Pierson, 1997) was not considered warranted considering the lack of detailed site-specific climatic data required for these models.

Note that the vegetation is assumed to develop an active root zone not only in the cover material but also in the tailings themselves. In October 1997, test pits were dug on sandy tailings covered by 9" alluvial cover to evaluate the extent of root zone development. The test pits were dug in an area where the invading shrub communities, predominantly rubber rabbit shrub (*chrysophmnus nauseus*) and big sagebrush (*Artemisia tridentata*), were well-established (alluvial cover placed in the early 1980's). The survey indicated that the plant roots extend at least 3 feet deep into the cover and underlying tailings. (Anecdotal evidence suggests that the roots may go as deep as 4 to 6 feet). It was also noted that the root system in the tailings consisted predominantly of fine roots, a clear indication that the invading shrub species take up water within the tailings.

Any soil moisture not taken up by the plant roots (in particular during the winter months) will gradually percolate deeper into the tailings profile and eventually will become "net infiltration", i.e. water which will move through the tailings and emerge as seepage at the base of the tailings. Note, however, that the plant roots are able to create upward hydraulic gradients drawing soil moisture from deeper in the profile back up into the root zone. The exact depth of the zone of influence for evapotranspiration depends on soil conditions, transpiration rates (plant type), and climatic conditions.

5.2.3 Soil Parameters

Several soil samples including coarse and fine tailings, alluvial cover material and fine alluvial silt were taken in the fall of 1995 and in the spring of 1997 and analyzed in the SRK laboratories in Denver, Colorado for relevant physical and hydrological properties (see App. C for details).

The following four representative soil samples were used as input for this model study:

- sandy (coarse) tailings (sample "97-T-7");
- fine tailings (sample "T-2");
- alluvial cover material (sample "T-21"); and
- fine alluvial silt (sample "AL-2").

Some important physical and hydrological properties of these four representative soil samples are summarized in Table 5.1. The soil water characteristic curve, i.e. volumetric moisture content as a function of soil suction (negative heads), of the four soil types measured in the laboratory are shown in Figures 5.2. The van Genuchten closed form equation was visually fit to these lab data (see lines in Figure 5.2).

Table 5.1.

Physical and Hydrological Properties of Representative Soil Samples used in Cover Performance Analysis.

Parameter	sandy tailings 97-T-7	fine tailings T-2	alluvial cover material (T-21)	fine alluvial silt (AL-2)
Soil Description (USCS)	silty sand (SM)	silt (ML)	clayey gravel w/ sand (GC)	silty clay w/ sand (CL or ML)
K_s (in cm/s)	$1*10^{-3}$	$5*10^{-7}$	$3*10^{-4}$	$1*10^{-7}$
Porosity, $Ø_s$ (1)	0.45 (0.44)	0.41 (0.41)	0.29 (0.30)	0.35 (0.41)
Residual moisture content, $Ø_r$ (1)	0.10 (0.05)	0.36 (0.27)	0.14 (0.17)	0.31 (0.27)
Van Genuchten Parameters				
α (in cm^{-1})	0.015	0.04	0.14	0.01
n (-/-)	2.2	1.15	1.3	1.4

Notes: values in brackets obtained from van Genuchten fit to soil water characteristic curve and used as input to model

The permeability of the various soil types as a function of soil suction (negative head) was estimated using the (measured) saturated permeability and the van Genuchten model (see Figure 5.3).

The alluvial cover samples analyzed in the laboratory showed significant variation in particular with respect to grain size distribution and therefore (saturated) permeability. The cover sample chosen for this analysis ("T-21") is considered a conservative selection in that it has a relatively high permeability compared to other cover samples analyzed (see App. C for details). These uncertainties in parameter estimation are further addressed in sensitivity analyses (see below).

5.2.4 Climate and Vegetation Data

As described above the conceptual model for the storage cover requires two critical atmospheric parameters as model input:

- (daily) rates of precipitation; and
- (daily) rates of potential evapotranspiration.

Molycorp does not operate a weather station directly at the tailings impoundments. However, the weather station at Cerro, NM (elev. 7665'), located only three miles to the north of the impoundment, can be considered representative for the actual site conditions. The Cerro weather station has been recording daily precipitation, and daily min/max temperatures since 1932. The long-term averages for monthly and annual precipitation for the observation period are listed in Table 5.2. The long-term average annual precipitation equals 12.24 inches.

It was felt important to evaluate cover performance not only for typical moisture conditions but also for extremely wet conditions to represent a "worst-case scenario". Based on a review of all years on record, 1984 was selected as an average wet year (Precip=13.76") and 1993 was selected as an exceptionally wet year (Precip=19.29", i.e. second wettest year on record with very high precipitation both in summer and winter). The monthly totals are listed in Table 5.2 for comparison. The daily precipitation values used as model input for 1984 and 1993 are shown in Figure 5.4.

The second required atmospheric parameter, potential evapotranspiration (pot. ET), is difficult to measure in the field. In past studies, the potential ET rates have been related to the potential evaporation rates at a given site (Hearney and Dewey, 1986). These authors used scaling factors to relate the pot. ET rates of different plant species to (measurable) rates of potential evaporation for a hydrologic analysis of the Rio Grande Basin to the north of the study site.

The scaling factors differed depending on the dominant plant species at the site. A recent field survey on the tailings impoundments by Molycorp's staff agronomist in October 1997 has shown that rubber rabbit shrub (*chrysophmnus nauseus*) and big sagebrush (*Artemisia tridentata*) are the dominant plant species invading the already covered areas of the tailings. Both shrubs are evergreen and similar in form and growth type. Hence, Hearney and Dewey's scaling factors for sagebrush were used in our analysis using the following equation:

(daily) potential evapotranspiration = scaling factor (sagebrush) x pan evaporation

Hearney and Dewey's scaling factors for sagebrush are listed in Table 5.2.

Table 5.2
Summary of Climate Data (in inches)

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	TOTAL
Precipitation [1] (in inches) average for 1932-1997	0.63	0.58	0.74	0.83	1.19	0.95	1.78	2.07	1.43	1.00	0.71	0.73	12.24
1984	0.62	0.74	0.91	1.24	0.51	0.50	0.90	2.59	1.20	1.92	1.17	1.46	13.76
1993	1.18	1.52	1.47	0.58	1.99	0.06	0.87	6.71	1.21	0.95	2.05	0.70	19.29
Scaling Factor [2] Pan EVP -> pot. ET	0.50	0.50	0.50	0.60	0.80	0.80	0.71	0.53	0.50	0.50	0.50	0.50	
Pan Evaporation [3] (in inches) average for 1960-1997	n/a	n/a	n/a	7.40	8.79	10.4	8.95	7.63	6.48	4.94	n/a	n/a	
1984 [4]	1.15	2.13	3.91	6.39	9.19	9.73	9.33	7.86	7.13	4.89	2.51	1.39	65.61
1993 [4]	1.15	2.13	3.91	6.39	8.98	9.28	9.95	7.65	6.95	4.89	2.51	1.39	65.18

Notes:
(1) data for Cerro, NM (elev. 7662')
(2) from Hearney and Dewey, 1986 (USGS Report 86-4113)
(3) data for Alamosa, Co (elev. 7540')
(4) missing data patched w/ data from old NOAA weather station at Santa Fe, NM (elev. 7200')

Unfortunately, pan evaporation is not recorded at the nearby Cerro weather station. Perhaps the most representative weather station in the area that measures pan evaporation is at Alamosa, Co, approximately 60 miles north of the study site. The potential (pan) evaporation rates are not expected to vary widely between Alamosa and Questa due to similar elevations and geographic location. The long-term averages for monthly totals of pan evaporation at Alamosa (for April to October) are shown in Table 5.2. For the simulations, daily pan evaporation rates were used (adjusted to pot. ET rates using the scaling factor described above). The monthly totals of pan evaporation for the selected years 1984 and 1993 are listed as well in Table 5.2. It is seen that pan evaporation differs very little between those two years despite the significant difference in yearly precipitation.

The daily potential evapotranspiration rates used as model input for 1984 and 1993 are shown in Figure 5.4. In our opinion, the greatest uncertainty in the atmospheric input data lies in the scaling factors used here, as they do not account for possible local variations in plant transpiration (due to exposure, plant maturity, root system etc.). Nevertheless, the overall potential ET rates assumed here (0.11inches/day on average) appear plausible and are considered conservative considering typical ET rates suggested for this area (Wagner, pers,. comm.).

5.2.5 Numerical Model

The infiltration and seepage through a layered soil column (cover material over tailings) was modeled using the finite element code SWMS_2D (Simunek et al., 1994). This code simulates water flow in variably saturated media. The program numerically solves the Richards equation for saturated-unsaturated water flow (see Simunek et al., 1994 for details). The code is shareware and can be obtained with proper documentation from the International Groundwater Modeling Center (Colorado School of Mines, Golden, Co).

The hydraulic soil properties are specified in sub-regions of the flow model by supplying soil water and permeability characteristic curves to the flow model. The data are input using the closed-form solution developed by van Genuchten (1980). The permeability characteristic curve is inferred from the soil moisture characteristic curve using the saturated permeability for a given soil type (see section 5.2.3).

Figure 5.1 illustrates a typical model set-up including finite-element grid, sub-regions, and boundary conditions. The boundary conditions were chosen as follows. At the top, a variable-flux boundary condition is used. Daily rates of precipitation are supplied (see section 5.2.4) and the actual infiltration rate for a given time step is calculated by the model (depending on permeability and soil moisture). The model allows infiltration at the specified rate of precipitation as long as the head at the surface node is less or equal to zero (i.e. ponding is not permitted).

A no-flow boundary condition was chosen for the lower (basal) boundary. The lower boundary was placed sufficiently deep, i.e. 10 m below ground surface, so that the effect of this boundary had no appreciable influence on the flow in the upper profile.

The program calculates the rate at which plants extract water from a specified root zone (here assumed to be 0.05 cm to 1.05 m below ground surface, Figure 5.1). Daily rates of potential evapotranspiration are supplied for this zone (see section 5.2.4) and the model calculates the

actual transpiration depending on the soil moisture conditions. It is assumed that water uptake is uniform throughout the root zone. It is further assumed that plants do not take up water above a suction head of 10 cm and below a suction head of 10,000 cm.

The finite element grid is 10 m deep and 0.01m wide. The vertical finite element grid spacing is variable with very close vertical spacing (dz=0.001 m) at the soil surface and at the base of the root zone and/or transition between different soil types (Figure 5.1). An automatic time stepping scheme was used with a minimum and maximum time stepping of $dt_{min}=1*10^{-12}$ and $dt_{max}=0.1$ day, respectively. The absolute water mass balance errors were typically in the order 0.15 to 1.5 cm^3 (assuming a 0.01 m x 0.01 m surface area for the soil column). The relative mass balance error (relative to the net flux into or out of the model domain over a given time step) ranged from less than 0.01% to 2.5%.

Transient simulations were run for the average year (1984) as well as for an exceptionally wet year (1993) (see section 5.2.4). In order to obtain representative initial conditions for a given year the following procedure was used. First, a uniform soil suction of 5 m (i.e. a head of –500 cm) was assumed across the entire soil profile and the model run for a given year.

Next, the final head conditions of this preliminary run were used as initial conditions for the actual simulation of this year.

5.2.6 Assumptions

The key assumptions made in the conceptual and numerical model outlined above are summarized here for clarity:

- the upper soil profile is (at least initially) unsaturated with the water table at least 10 or more meters below ground surface; movement of water within the cover and upper tailings profile is one-dimensional (vertical) and follows Richard's equation; the soil profile does not freeze during winter;

- the cover material(s) and tailings are homogeneous and isotropic; the measured soil water characteristic curves of the selected soil samples are representative of the respective soil types; the van Genuchten model is applicable for estimating the (unsaturated) permeability as a function of soil suction;

- a mature (shrub) vegetation is established on the covered tailings with a well-established root zone; root zone depth is 1 m and is independent of cover layer thickness and/or underlying tailings type;

- precipitation is the only source of water into the cover; interception by vegetation is assumed negligible; any snowfall is assumed to melt within the same day (no accumulation of snow at ground surface); any water ponding at the soil surface is removed (either via evaporation and/or surface runoff); and

- evapotranspiration is the only mechanism of removal of water back into the atmosphere; Hearney and Dewey's scaling factors for sagebrush are applicable and allow estimation of the potential evapotranspiration rates from pan evaporation rates; extraction of water via evapotranspiration occurs throughout the root zone.

5.3 Results

A total of five different cover scenarios were simulated:

- 9" (0.23 m) thick coarse alluvial cover on sandy tailings ("quest 1");
- 9" (0.23 m) thick coarse alluvial cover on fine tailings ("quest 2");
- 18" (0.45 m) thick coarse alluvial cover on sandy tailings ("quest 3");
- 36" (0.90 m) thick coarse alluvial cover on sandy tailings ("quest 4"); and
- 18" (0.23 m) thick coarse alluvium over 6" (15.25) thick fine alluvium (silt) on sandy tailings ("quest 5").

Each cover scenario was evaluated for average wet conditions (1984) and for exceptionally wet conditions (1993). It is uncertain over which period the rubber rabbit shrub and sagebrush community is actively transpiring ("growing season"). Three different cases were studied here to evaluate the importance of length of growing season for cover performance:

- plants transpire on all days with an average daily temperature of 44°F (7°C) or greater (short growing season);
- plants transpire on all days with a maximum daily temperature of 44°F (7°C) or greater (intermediate growing season);
- plants transpire year-round (long growing season).

The above three cases were simulated for the exceptionally wet year 1993 using the cover scenario of a 9" thick alluvial cover only. The remaining scenarios were simulated for the intermediate length of growing season (transpiration for days with maximum daily temperature equal or greater than 44°F (7°C)), which is considered most representative of actual site conditions.

All cover scenarios studied here show a similar seasonal pattern with predominantly infiltration and storage of water in the soil profile during the late fall and winter months and a gradual depletion of this stored water as a result of evapotranspiration during the spring and summer months. Figures 5.5 and 5.6 illustrate this seasonal response of a storage cover using the example of a 9 inch thick alluvial cover on sandy tailings for 1993 (intermediate length of growing season). Figure 5.5 shows the cumulative atmospheric fluxes in and out of the soil profile, i.e. actual infiltration and actual evapotranspiration, respectively. The difference between these two fluxes is the net atmospheric flux, with fluxes into the soil profile being positive and fluxes out of the profile being negative (Figure 5.5). Figure 5.6 shows the simulated soil suction (negative head) at the soil surface, within the root zone and at 1.5 m (0.5 m beneath the root zone). Early in the year, the plants are still dormant, and all precipitation infiltrates and moves into the soil profile (Figure 5.5). In early spring (around day 70), evapotranspiration sets in (Figure 5.5), gradually removing all available soil moisture from the root zone (note sharp rise in soil suction for the root zone by day 130, Figure 5.6). By this time, evapotranspiration has accounted for all previous infiltration and the net flux is essentially zero. During the remaining summer months and

into fall, all infiltration is quickly taken up by the plants. Note, that even very large storms do not result in increased net fluxes for more than a few days (e.g. more than 8 inches fell from day 225 to 243, which was evapotranspired within a few days, Figure 5.5). Only late in the year, when evapotranspiration ceases, is the soil profile again recharged by infiltrating precipitation.

The final net atmospheric flux (at the end of the year) is a surrogate for cover performance. A positive cumulative net flux indicates that more water has infiltrated than could be given off as evapotranspiration. It is conservatively assumed that any positive net atmospheric flux at the end of the year is equivalent to "net infiltration", i.e. water that has infiltrated passed the root zone and into the deeper tailings profile.

The net atmospheric fluxes for the five simulated cover scenarios are summarized in Table 5.3 (see Appendix E for time-flux plots of all model runs).

The modeling results may be summarized as follows (compare Table 5.3):

- the final net flux (or "net infiltration") is greater through a storage cover placed on sandy tailings than through an equivalent cover placed on fine tailings (compare runs "quest1" and "quest 2");
- the final net flux is significantly greater for an exceptionally wet year (1993) than for a year with typical annual precipitation (1984) (both in absolute as well as relative terms);
- the length of growing season is a critical parameter in cover performance; simulated net atmospheric fluxes (for exceptionally wet-year) range from about 4 inches for a short growing season to –0.1 inches for a year-round growing season;
- the thickness of the alluvial cover does not significantly influence cover performance; net atmospheric fluxes calculated for 9", 18" and 36" thick alluvial covers showed no significant differences neither for average (1984) nor for exceptionally wet conditions (1993) (compare runs "quest 1", "quest 3", and quest "4"); and
- The placement of a low permeability silt layer between the alluvial cover and the tailings improves the cover performance only marginally (compare "quest 1" and "quest 5").

The first three results are straightforward and expected. The last two points, however, are not intuitive at first and require further discussion. A thicker alluvial cover does not reduce the net flux (or net infiltration) because the alluvial material does not have a greater storage capacity than the underlying tailings (at least for the sandy tailings). In fact, the storage capacity of the alluvial cover material appears to be quite limited. Laboratory measurements (using suction plates) suggest that the drainable porosity is only 17%, which compares to up to 40% for the sandy tailings (see Figure 5.2). Note also, that the soil profile (alluvial cover material as well as tailings) remains unsaturated throughout the year (see Figure 5.6) further reducing the storage capacity of both soils.

Note that the permeability of the alluvial cover material is of secondary importance here because the cover is not meant to reduce infiltration but instead store water for plant use during the growing season. Although the (saturated) permeability of the alluvial cover material is lower than that of the sandy tailings it is still sufficiently high to allow passage of all infiltration into the root zone and into the deeper profile. In fact, depending on the degree of saturation, the

(unsaturated) permeability of the sandy tailings could actually be lower than that of the alluvial cover (see Figure 5.2).

Figure 5.7 shows the simulated (daily) flux of water for a 9 inch and 18 inch thick alluvial cover at 1.5 m depth in the soil profile (i.e. about 0.5 m below the base of the root zone). Negative fluxes represent downward movement and positive movement represents upward movement of soil water. It is seen that the fluxes beneath the root zone are very similar for both covers. The bulk of the downward flux of soil moisture occurs during late winter when the soil profile is at its wettest. During the summer months there is some (small) upward flux of soil moisture towards the root zone where very high soil suctions prevail. This figure illustrates that the thickness of the alluvial cover layer does not appear to have a significant effect on the rate of net infiltration and thus cover performance.

The use of a low permeability (alluvial) silt layer between an 18 inch (coarse) alluvial cover layer and the sandy tailings also does not reduce the net infiltration significantly. Figures 5.8 and 5.9 show the cumulative atmospheric fluxes and soil suction in the upper soil profile for this composite cover in 1993 (exceptionally high precipitation as well as intermediate length of growing season). The low permeability silt layer slows down infiltration into the tailings thereby creating much wetter soil conditions in the alluvial cover near the surface and in the upper root zone (compare Figures 5.9 and 5.6). As a result the infiltration is reduced slightly, i.e. only 17.3" (43.4 cm) actually infiltrate into the composite cover compared to 19.2" (49.0 cm) for the 9 inch thick alluvial cover (compare Figures 5.8 and 5.5). However, at the same time the evapotranspiration rate is reduced due to less soil moisture being available in the root zone beneath the low K silt layer (compare Figures 5.9 and 5.6). The net result is only an insignificant reduction in final net fluxes through the cover system (Table 5.4).

Several additional model runs were performed to evaluate the sensitivity of the model results to various input parameters. The net atmospheric fluxes for the various sensitivity runs are summarized in Table 5.4 (see Appendix E for time-flux plots of all model runs). The results of this sensitivity analysis may be summarized as follows (compare Table 5.4) :

- depth of root zone is by far the most critical parameter to cover performance; for every 0.5 m increase in root zone depth the net atmospheric flux is reduced in the order of 2 inches; for a root zone depth of 2.5 m virtually all incoming infiltration is stored and eventually evapotranspired back into the atmosphere;

- the permeability of the tailings underlying the alluvial cover also influences cover performance; the net flux through the cover decreases with decrease in permeability of the underlying tailings;

- the cover performance is not very sensitive to the material properties of the alluvial cover material; neither an increase in drainable porosity nor a reduction in saturated permeability (by one order of magnitude) reduces the net flux through the cover significantly;

Table 5.3
Summary of Cover Performance Analysis
Net Atmospheric Fluxes (inches/year)

Run	Description	1984 total precip. =13.8" pot. ET = 38.1" 2)		1993 total precipitation =19.3" pot. ET = 33.3" 1)		pot. ET = 39.3" 2)		pot. ET = 43.3" 3)	
quest 1	9" (0.23m) alluvial cover on sandy tailings	1.1	(7.7 %)	3.8	(20 %)	1.9	(9.8 %)	0.0	(. %)
quest 2	9" (0.23m) alluvial cover on fine tailings	0.4	(2.9 %)	1.8	(9.2 %)	0.8	(4.3 %)	-0.8	-(4.1 %)
quest 3	18" (0.45m) alluvial cover on sandy tailings	0.9	(6.6 %)	not simulated		2.4	(12 %)	not simulated	
quest 4	36" (0.90m) alluvial cover on sandy tailings	1.3	(10 %)	not simulated		3.4	(18 %)	not simulated	
quest 5	18" (0.45m) alluvium plus 6" silt on sandy tailings	0.8	(6. %)	not simulated		1.7	(8.6 %)	not simulated	

Notes:
1) assuming plants transpire if average daily temperature is greater than 44 degrees Fahrenheit (7 degrees Celsius)
2) assuming plants transpire if maximum daily temperature is greater than 44 degrees Fahrenheit (7 degrees Celsius)
3) assuming plants transpire year round

Table 5.4
Summary of Sensitivity Analysis
Net Atmospheric Fluxes (inches/year)

Run	Description	9" alluvial cover (1) (see quest 1)		18" alluvial cover (1) (see quest 3)	
Base Case	alluvial cover on sandy tailings using 1993 weather data (P = 19.3" & pot ET = 39.32 ")	1.9	(9.8 %)	2.4	(12. %)
sens 1	increase drainable porosity to 30%	1.7	(8.6 %)	1.7	(9. %)
sens 2	reduce permeability of alluvial cover material to $K_{cover} = 3*10^{-5}$ cm/s	1.9	(10. %)	2.4	(12. %)
sens 3	reduce permeability of sandy tailings to $K_{sandy\ tails} = 1*10^{-4}$ cm/s	0.6	(3.1 %)	1.1	(5.7 %)
sens 4	increase antecedent moisture conditions in soil profile (water table at ~6.3 m below ground surface for 9" and 18" cover, respectively)	1.9	(9.6 %)	2.3	(12. %)
		Root Zone Depth (1)			
		0.5m	1.0m	1.5m	2.5m
sens 5	variable root zone depth for case of 18" (0.45m) alluvial cover on sandy tailings only	4.2 (22. %)	2.4 (12. %)	0.6 (3.3 %)	-0.4 -(1.8 %)

Notes:
(1) Values in brackets represent net atmospheric flux as a percentage of annual precipitation.

- the cover performance is not very sensitive to the antecedent moisture conditions in the deeper soil profile; wetter antecedent moisture conditions at depth with a water table at ~6.8 m below ground surface produce very similar fluxes through the cover compared with the base case where the water table is assumed to be below 10 m depth (Table 5.4).

Note however, that wetter antecedent moisture conditions in the upper profile, in particular within the root zone, do indeed reduce the net atmospheric flux (greater storage capacity in root zone at lower suctions).

In summary, the climate and vegetation data are generally more critical to the performance of the storage cover than the material properties and thickness of the alluvial cover layer.

5.4 Discussion and Implications

The modeling results suggest that a storage cover consisting of an alluvial cover layer over tailings would significantly reduce infiltration into the deeper tailings profile, provided the vegetation and its root zone is well-established and reaches well into the tailings. The net infiltration through the root zone may be anywhere from 0 to 20 % of annual precipitation, depending on climate conditions and tailings characteristics. Over the long-term, average climate conditions should prevail which would produce net fluxes through the storage cover in the order of 3 to 8 % of annual precipitation (0.4 to 1.1 inches).

An important finding of this model study is that the thickness of the alluvial cover placed on the tailings is not an important factor in cover performance. In fact, the model results suggest that the alluvial cover is not really needed for the purpose of reducing infiltration alone. It rather serves as a protective layer that prevents erosion of the surficial tailings and prevents dusting. Another reason for placing an alluvial cover may be to provide a growth substrate. Prior to covering the tailings in the 90's, Molycorp commissioned the National Resource Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)), to conduct field studies to evaluate, among other factors, the influence of cover thickness on plant growth (Wolfe and Oaks, 1986). The study concluded that there was no difference in plant growth between an 8 inch and a 12 inch thick alluvial cover, hence a 9 inch thick cover was placed on the tailings.

There is little benefit (in terms of reducing net infiltration) in placing a composite cover layer with low permeability alluvial silt onto the tailings. Yet, there would be concern about the long-term integrity of this low permeability silt layer, in particular since extensive root holes as well as ant and rodent-burrows are expected to develop within and below this silt layer. The root and burrrowing activity on the tailings impoundment is well demonstrated by current experience with the existing cover.

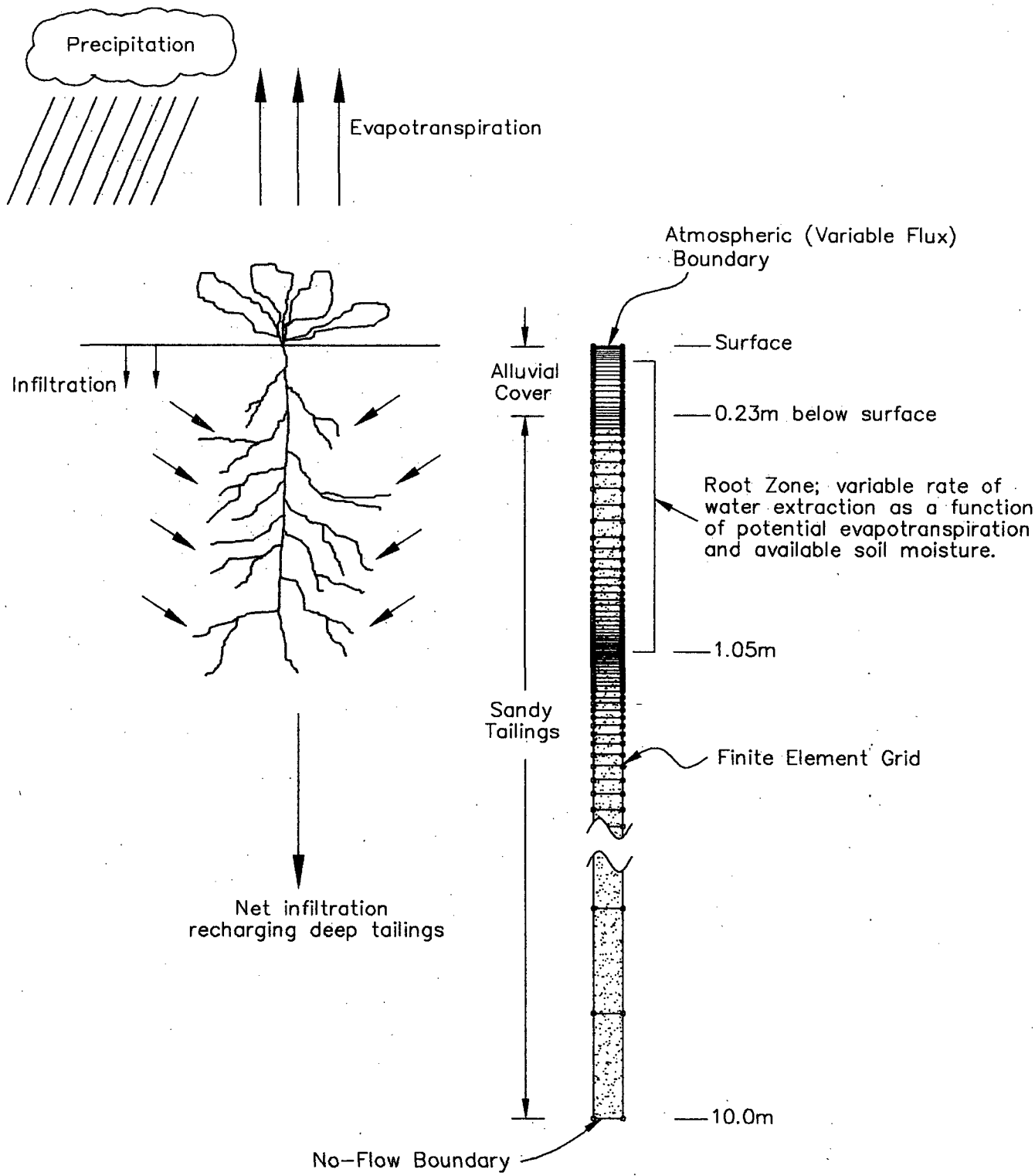
The single most important parameter in evaluating cover performance (net infiltration) is the length of growing season. Flerchinger and Pierson (1997) simulated evapotranspiration from a semi-arid sagebrush rangeland at the Reynolds Creek Experimental Watershed in Idaho, using a simultaneous heat and water flow model. Model calibration against observed field data suggested that big sagebrush may start actively transpiring in the early spring at a temperature of 44°F (7°C). Thus far, we have not been able to obtain site-specific data on length of growing season (or measured evapotranspiration rates) for the shrub vegetation naturally invading the covered tailings. Measurements of actual transpiration rates and length of growing season at the

study site would greatly improve our ability to predict cover performance and rates of long-term seepage through the deep tailings.

Based on the data presently available we recommend that a 9 inch thick alluvial cover be placed onto the tailings after final closure of the tailings impoundments. The net infiltration through this type of cover is estimated to be in the order of 0.75 inches over the entire tailings impoundment's. Using a surface area of the tailings impoundments of approximately 260 ha, the total long-term seepage from the tailings into the groundwater would be in the order of 136 m^3/day or 0.055 cfs from both impoundments combined. This amount of seepage is much smaller than the shallow groundwater flows in the shallow aquifer system (2.1 cfs) and the deep aquifer system (~5.5 cfs) into which the tailings seepage is discharging (see chapter 3).

The cover modeling described above is subject to many assumptions and various input parameters, some of which are not accurately known at present. To provide more confidence in the modeling results we strongly recommend that a field program be conducted to measure the performance of the existing alluvial cover in the field. The field program should be designed in such a way that the field results can be used for model calibration allowing long-term predictions with respect to net infiltration to be made. This field program is outlined in more detail in chapter 7 ("Recommendations"). Such a field program would yield results within two or three years (to allow for some climatic variability) and results could be used to confirm or refine the ultimate cover design well ahead of the tailings facility closure.

Figures



ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

Molycorp - New Mexico

Questa Groundwater and Seepage Study

Conceptual Model of Storage Cover and Numerical Implementation

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052002	Oct. 1997	Not to Scale		5.1

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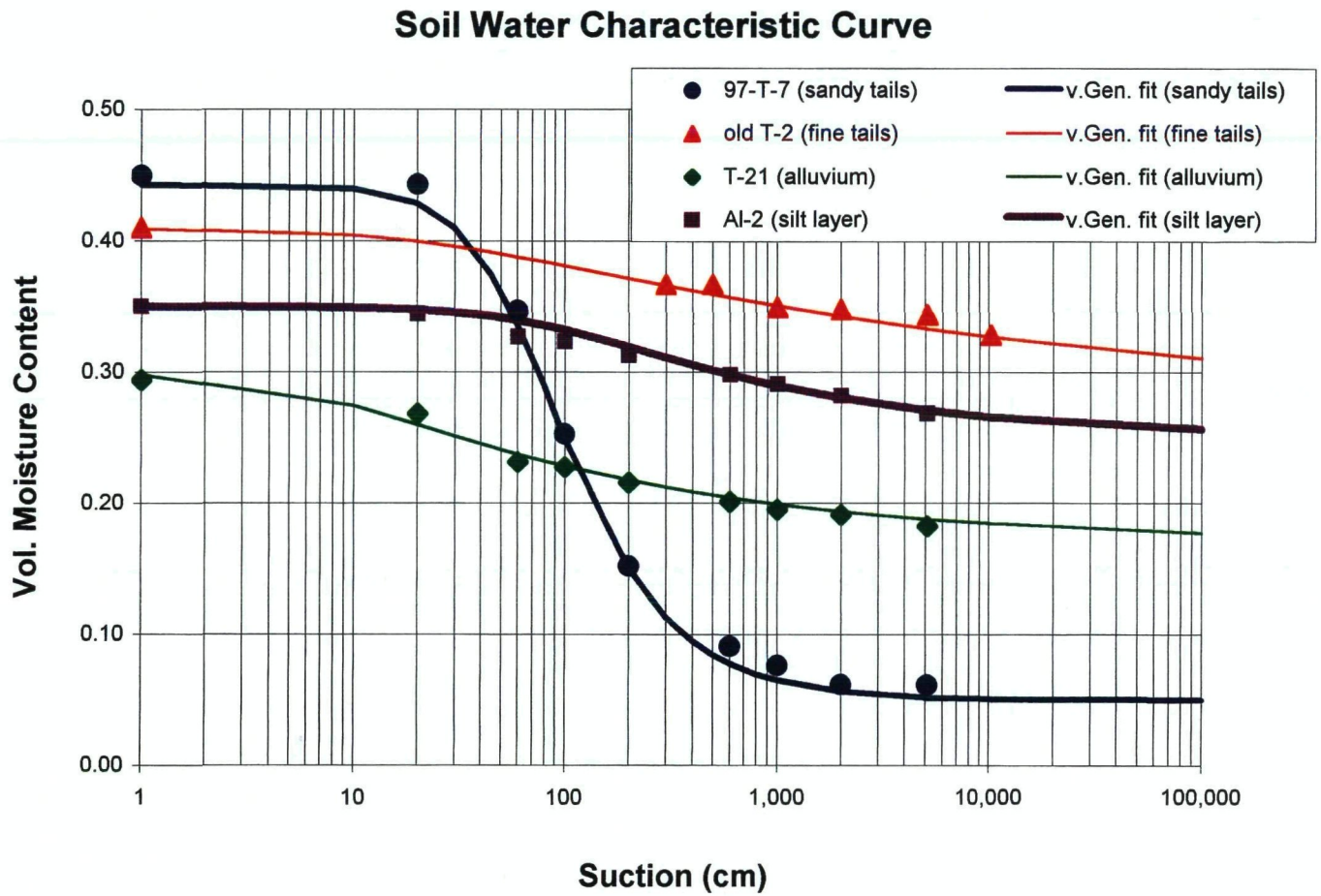


FIGURE 5.2
Soil water characteristic curves for representative soil samples determined in the laboratory (symbols). Lines indicate van Genuchten model fit to the experimental data.

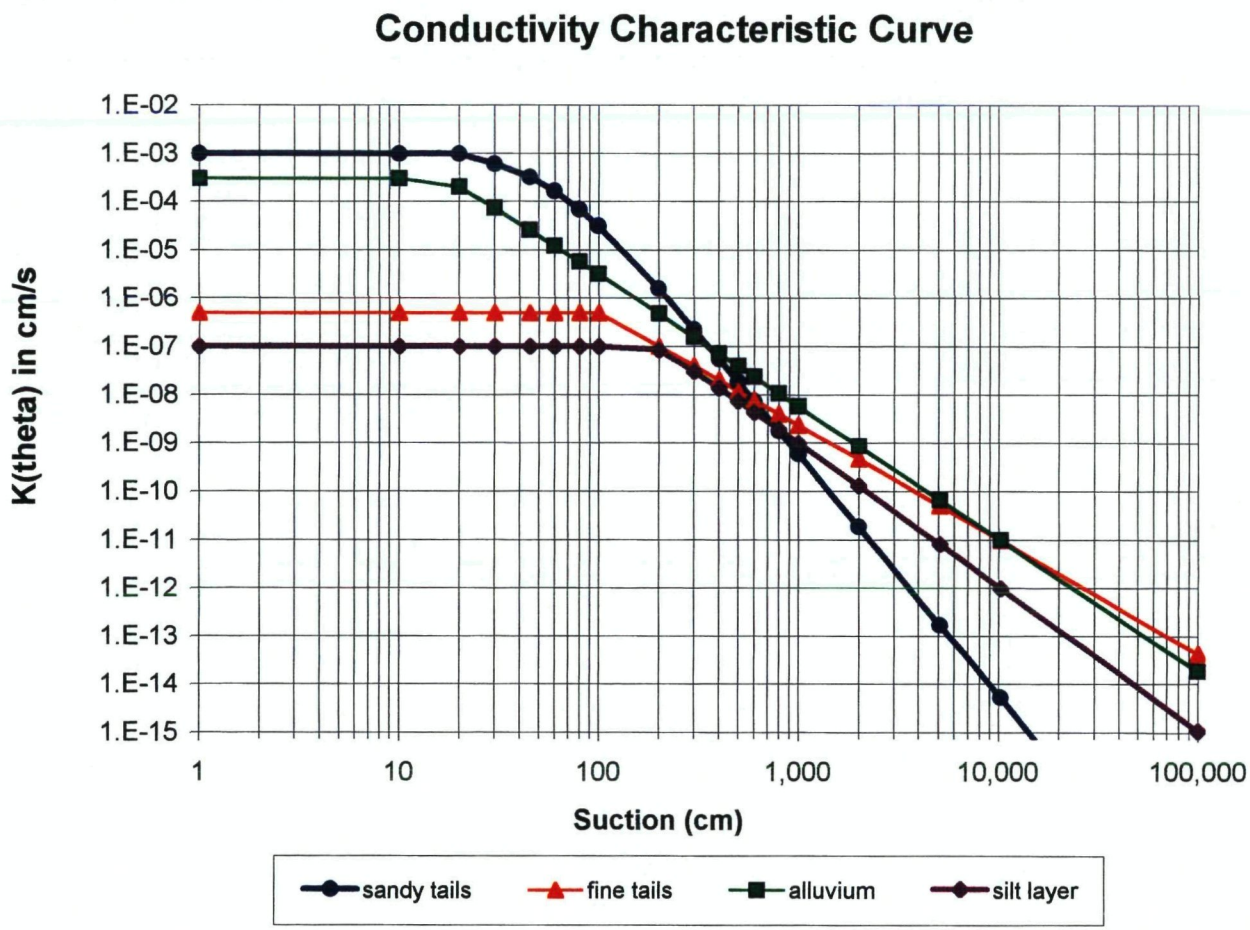
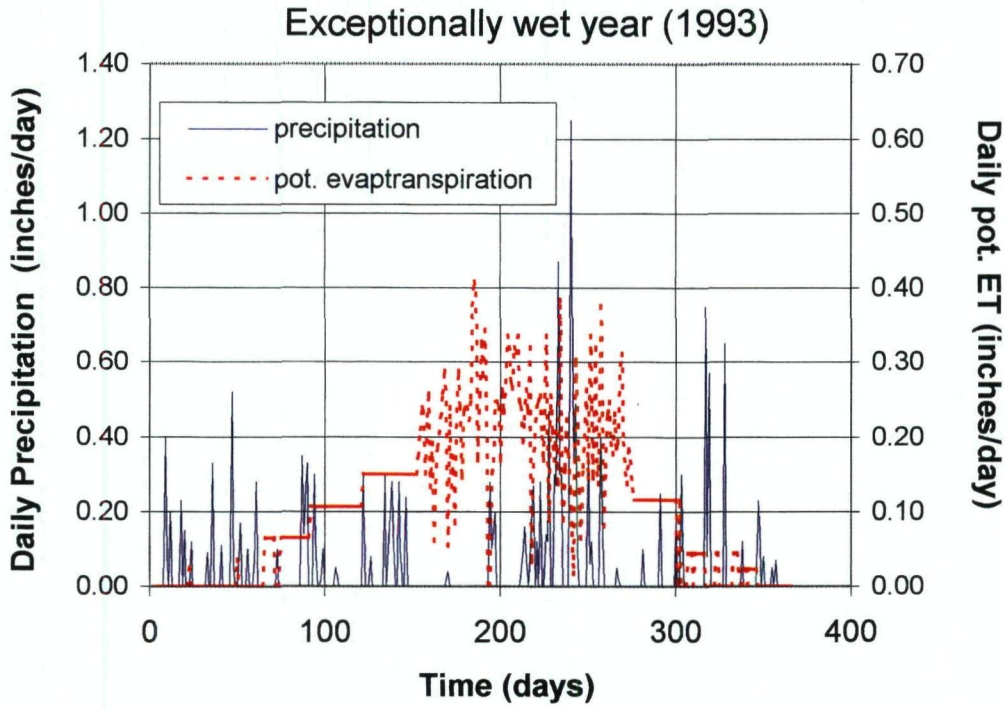


FIGURE 5.3
Conductivity characteristic curves for representative soil samples determined from saturated permeability(laboratory) using the van Genuchten model.



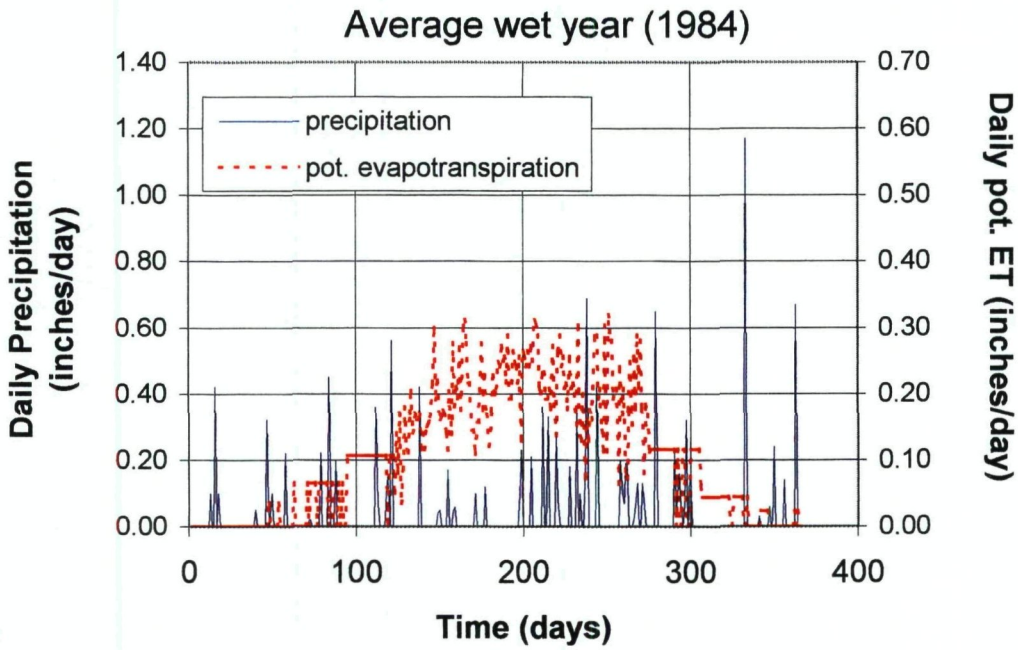


FIGURE 5.4
Daily rates of precipitation and potential evapotranspiration for 1993 and 1984.

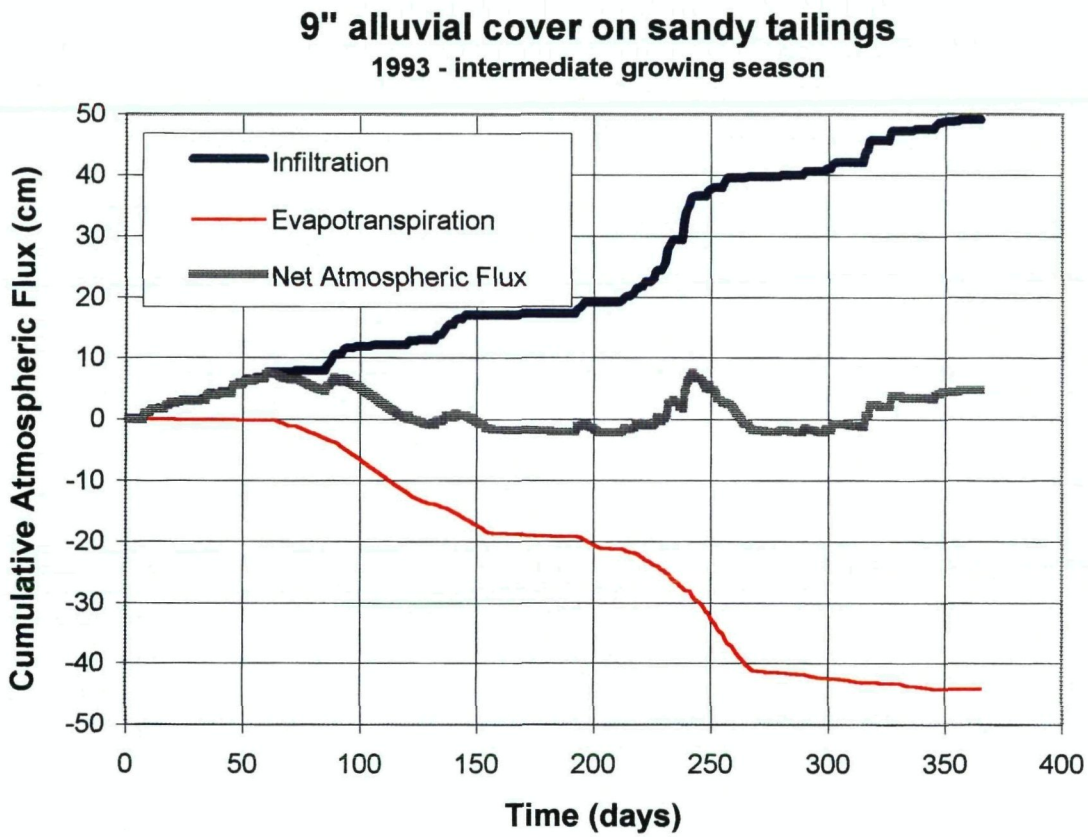


FIGURE 5.5
Cumulative atmospheric fluxes for simulation "quest 1_93b".

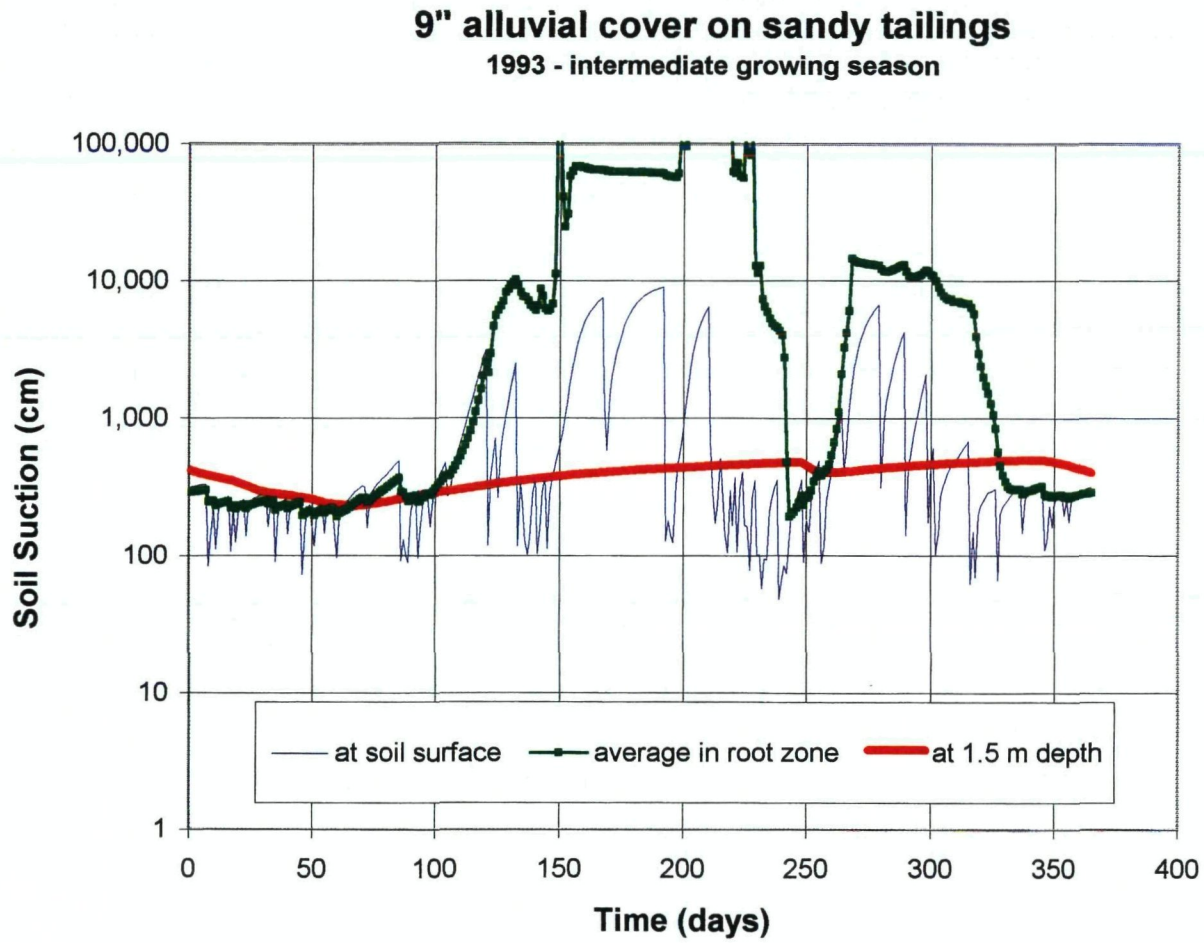


FIGURE 5.6
Soil suction (negative head) in the upper soil profile
for simulation "quest 1_93b".

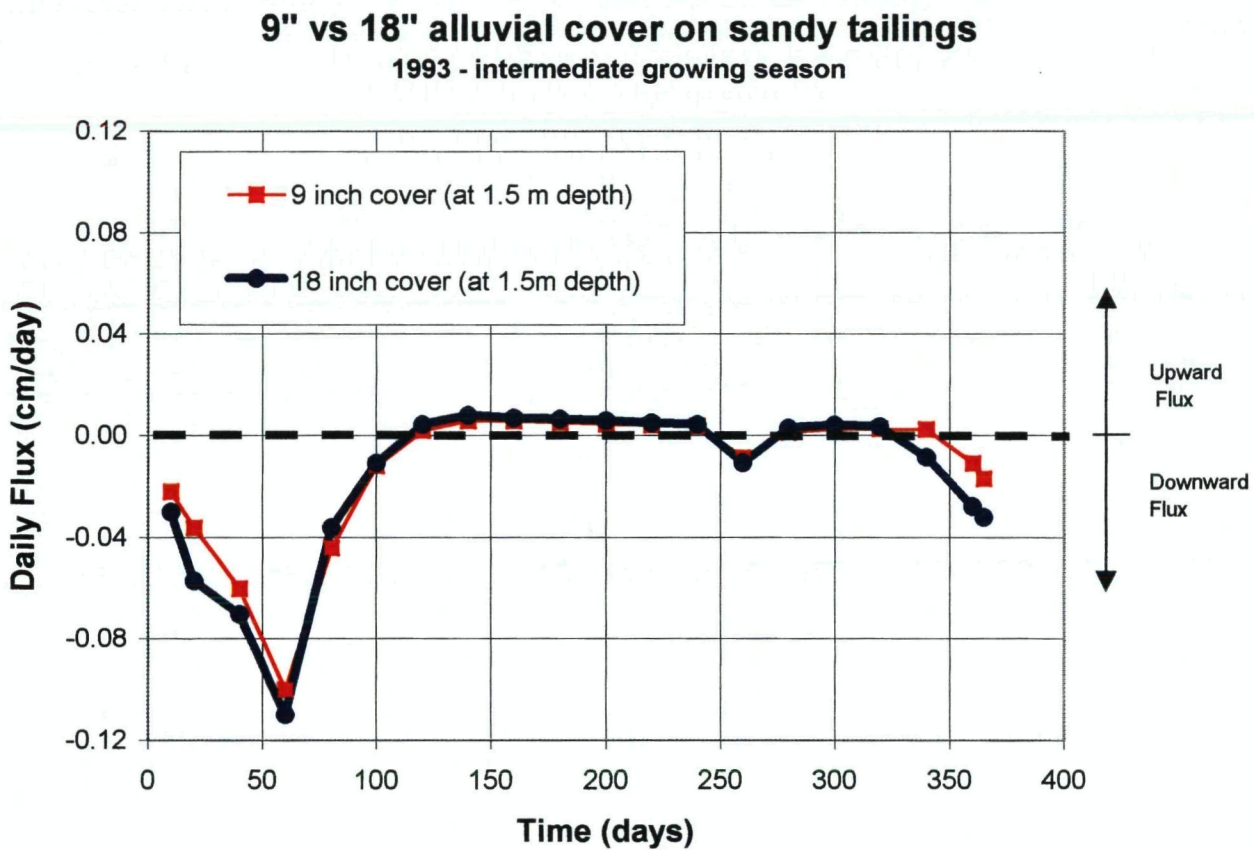


FIGURE 5.7
Comparison of instantaneous water flux below the root zone for a 9" and 18" alluvial cover.

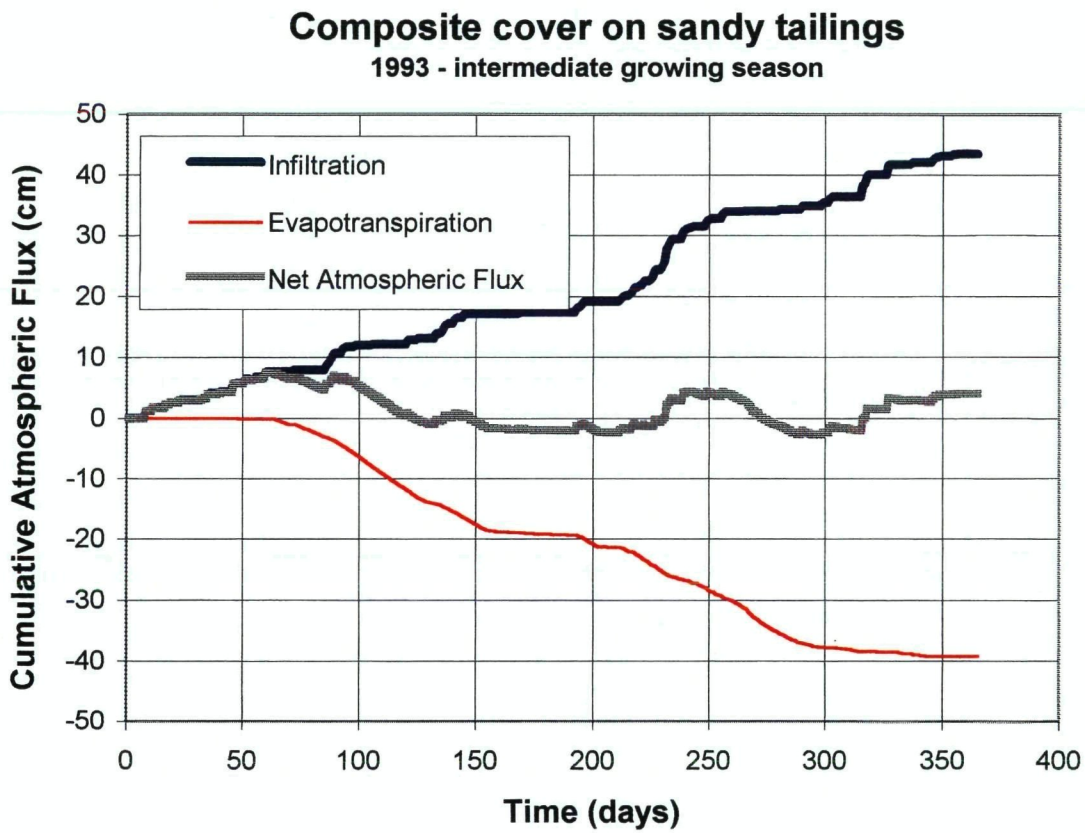


FIGURE 5.8
Cumulative atomospheric fluxes for simulation "quest 5_93b".

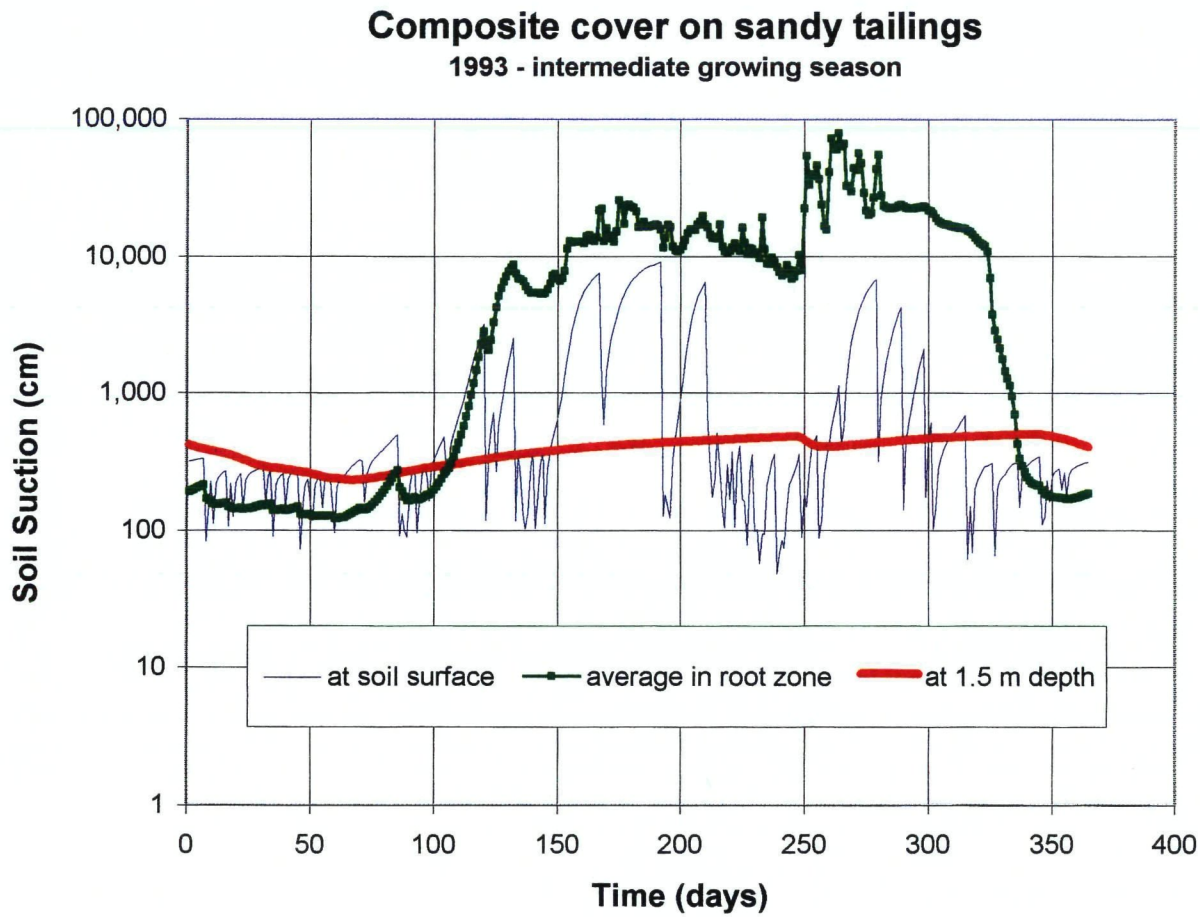


FIGURE 5.9
Simulated soil suction (negative Head) in the upper soil profile for simulation "quest 5_93b".

Section 6

6 Summary of Results

This study of groundwater flow and tailings seepage at Molycorp's tailings impoundments near Questa, New Mexico, was initiated to provide a framework for developing a closure plan for this facility. In order to develop an understanding of the entire flow path, from infiltration and recharge sources to the Red River, the groundwater flow and tailings seepage have been evaluated at four different scales:

- groundwater flow at the regional scale;
- groundwater flow at the local scale;
- seepage flows within the tailings; and
- infiltration through a soil cover.

The results of the regional groundwater flow analysis (chapter 2) can be summarized as follows:

- the regional groundwater system can be subdivided into an alluvial aquifer system east of the Guadalupe Mountain and a volcanic aquifer system beneath and to the west of the Guadalupe Mountains; the volcanics are much more permeable than the (recent) alluvial sediments resulting in much lower hydraulic gradients in the volcanic aquifer compared to in the alluvial aquifer;
- regional groundwater flow is predominantly in a westerly direction in the alluvial aquifer and assumes a southwesterly direction upon entering the volcanic aquifer; the western flank of the Sangre de Cristo Mountains is the area of regional recharge to the groundwater system and the Red River Canyon and Rio Grande Canyon represent the major regional discharge points; a dacite-filled paleo-channel acts as an avenue of high groundwater flow in the plateau area west of the Guadalupe Mountains channeling much of the regional groundwater flow towards the Arsenic Springs in the Rio Grande Canyon;
- total steady-state flux of groundwater in the study region is in the order of 50 cfs; a large percentage of this flow (~90%) occurs above an elevation of 7000 ft (i.e. deep circulation through the Santa Fe sediments does not appear to be significant); and
- seepage from the tailings facilities entering the regional groundwater system all discharges into the Red River upstream of the Fish Hatchery.

The results of the local groundwater flow analysis (chapter 3) can be summarized as follows:

- the local groundwater system can be divided into a shallow aquifer system in the alluvial sediments (above 7220 ft elevation) and a deep aquifer system in the volcanics and (deeper) alluvial sediments (below 7220 ft elevation);

- shallow groundwater flows in a southwesterly direction and discharges to the Red River in vicinity of the Big Springs (including Questa Springs); total flows in these "cold springs" are in the order of 3-4 cfs;

- deep groundwater travels in a westerly direction beneath the tailings impoundments and assumes a south-westerly direction upon entering the volcanic aquifer; groundwater from this deep system discharges in the Red River Canyon above and to a lesser extent below the Fish Hatchery; total flows in these "warm springs" are in the order of 14 cfs;

- the very permeable volcanics act as a drain for local groundwater causing leakage from the shallow groundwater system into the deeper aquifer system; the rate of leakage is controlled by a clay layer (or similar barrier to flow) separating the shallow from the deep aquifer system;

- about 2/3 of the simulated seepage from the tailings facility in section 36 (behind Dam No. 1 and 1c) drains into the shallow aquifer system; the underflow of shallow groundwater beneath section 36 is estimated to be approximately 2.1 cfs;

- about 1/3 of the simulated seepage from the tailings facility in section 36 (behind Dam No. 1 and 1c) drains into the deep aquifer system; the underflow of deep groundwater beneath section 36 is estimated to be approximately 4 cfs; and

- all simulated seepage from the tailings facility in section 35 (behind Dam No. 4 and 5) drains into the deeper, volcanic aquifer; the underflow of deep groundwater beneath section 35 is estimated to be approximately 5.4 cfs.

The results of the tailings seepage analysis (chapter 4) can be summarized as follows:

- the tailings begin to dewater whenever the surface flux into the tailings is reduced to less than the vertical (saturated) hydraulic conductivity of the tailings; the coarse tailings of the tailings impoundments at Questa are sufficiently permeable to allow natural dewatering, even without cover placement; the fine tailings probably require a cover to achieve dewatering;

- seepage fluxes at the base of the tailings ("seepage losses") decrease exponentially with time (assuming the tailings are allowed to drain by discontinuing discharge of tailings slurry and/or by placing a soil cover); and

- the time to reach steady-state conditions after closure, i.e. when seepage losses equal net infiltration through a soil cover, are estimated to be in the order of 27 – 37 years for the coarse tailings and 50 to 70 years for the fine tailings (assuming free drainage at the base of the tailings).

The above paragraphs describe the results of the modeling study on groundwater flow and tailings seepage These modeling results appear to be consistent with piezometric heads and flow estimates observed in the field against which the groundwater flow models have been calibrated.

The results of the cover performance analysis (chapter 5) can be summarized as follows:

- the net infiltration through a 9 inch thick alluvial cover for average climate conditions (e.g. 1984) is estimated to be about 1.1 inches per year for coarse tailings and 0.4 inches per year for fine tailings;
- the length of growing season is a critical parameter in cover performance; simulated net atmospheric fluxes (for exceptionally wet-year) range from about 4 inches for a short growing season to –0.1 inches for a year-round growing season;
- the thickness of the alluvial cover does not significantly influence cover performance; net atmospheric fluxes calculated for 9", 18" and 36" thick alluvial covers showed no significant differences neither for average (1984) nor for exceptionally wet conditions (1993); and
- the placement of a low permeability silt layer between the alluvial cover and the tailings improves the cover performance only marginally.

We trust that the information provided in this report meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned at your convenience.

Respectfully Submitted,

ROBERTSON GEOCONSULTANTS INC.

Per:

Christoph Wels, Ph.D.
Senior Hydrogeologist

Reviewed By:

Andrew MacG. Robertson, Ph.D., P.Eng.
President

Section 7

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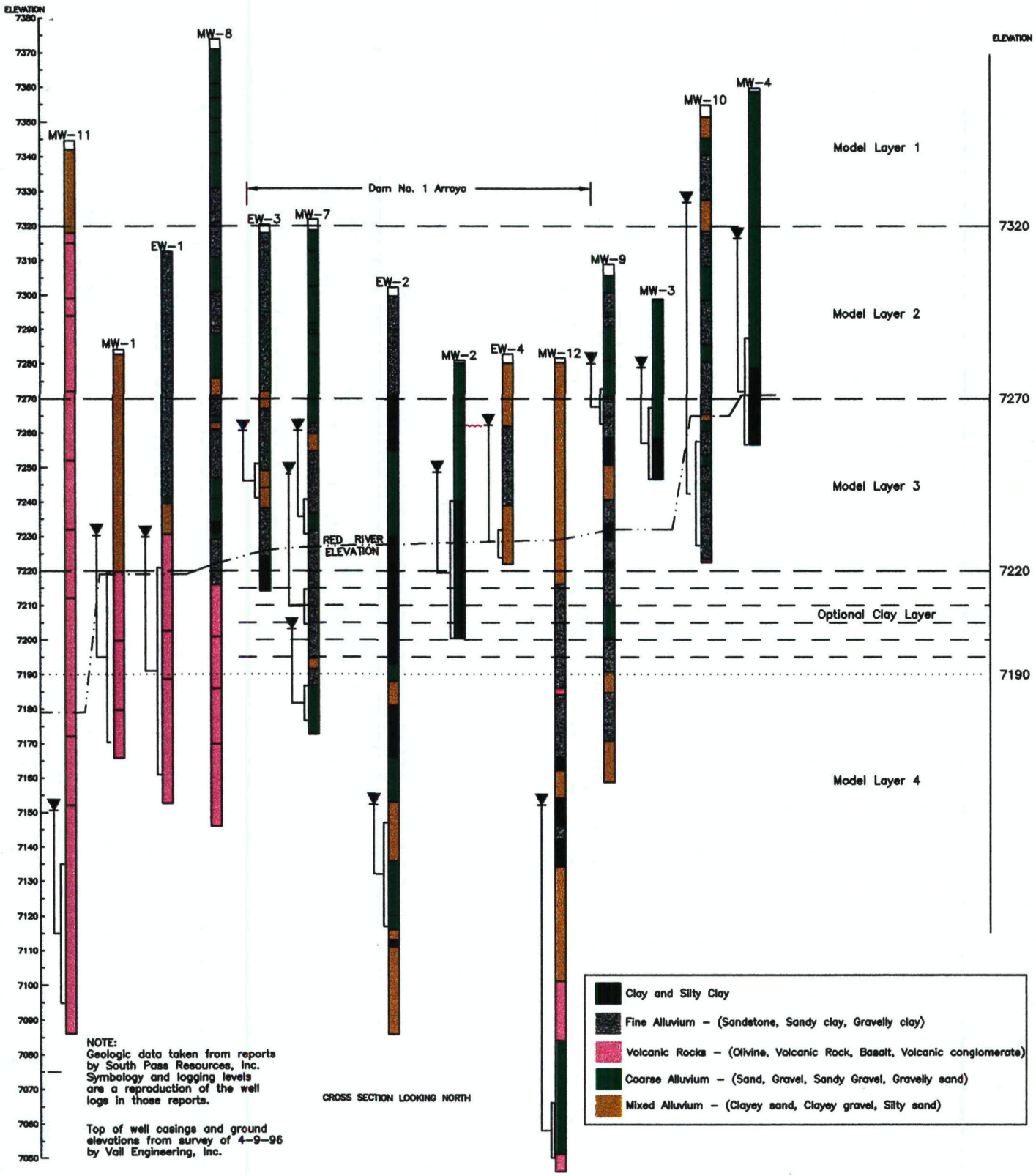

ROBERTSON GEOCONSULTANTS INC.

Consulting Geotechnical and Environmental Engineers

Molycorp - New Mexico

Questa Groundwater and Seepage Study

Borehole Stratigraphy

(Modified from Vail Eng.– 1997)

PROJECT NO.	DATE	APPROVED	FIGURE
052002	Oct. 1997		3.2

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Figure 3.3.
Boundaries and zones of local flow model.

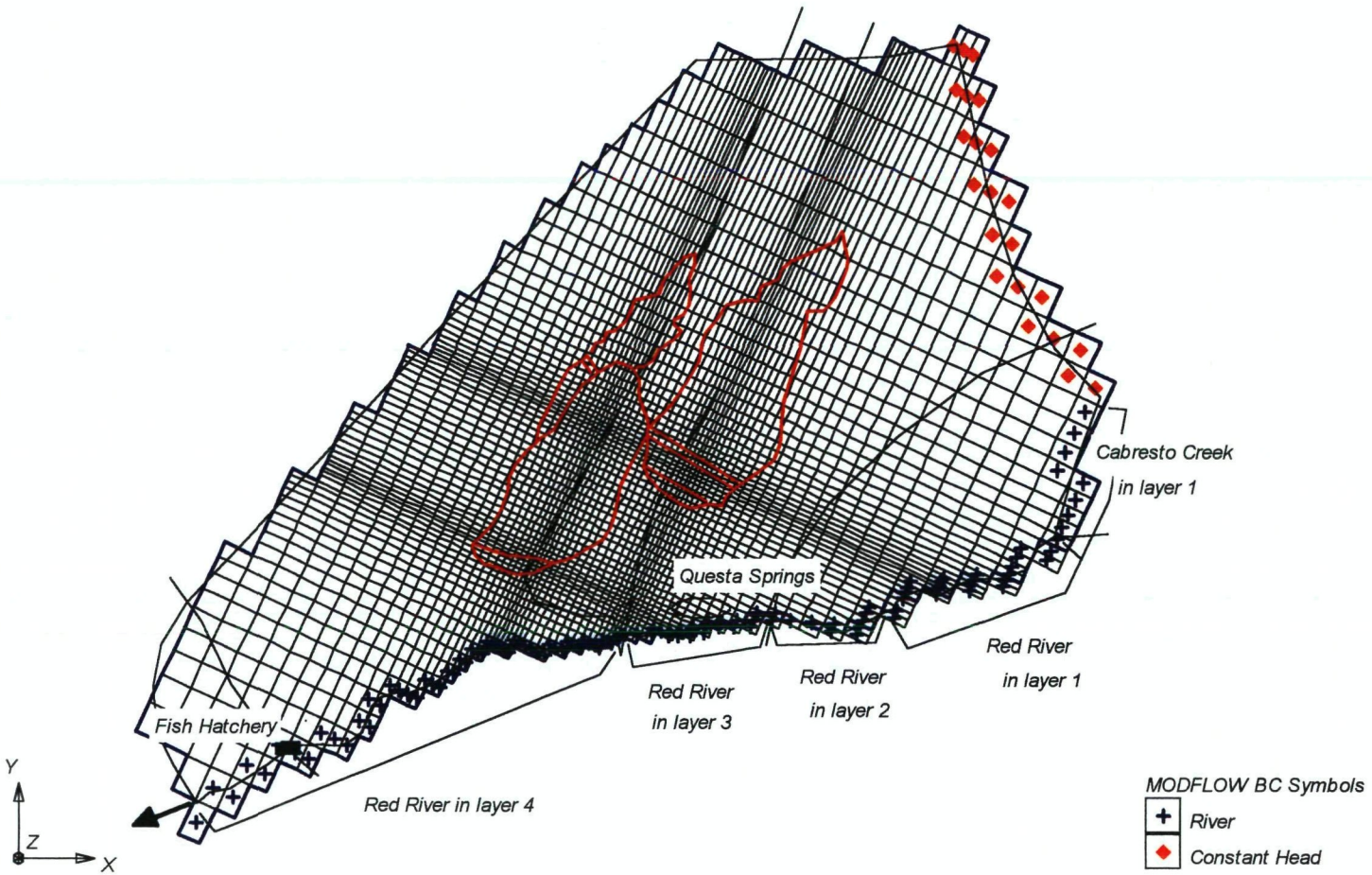

Figure 3.4.
Finite difference grid and boundary conditions.

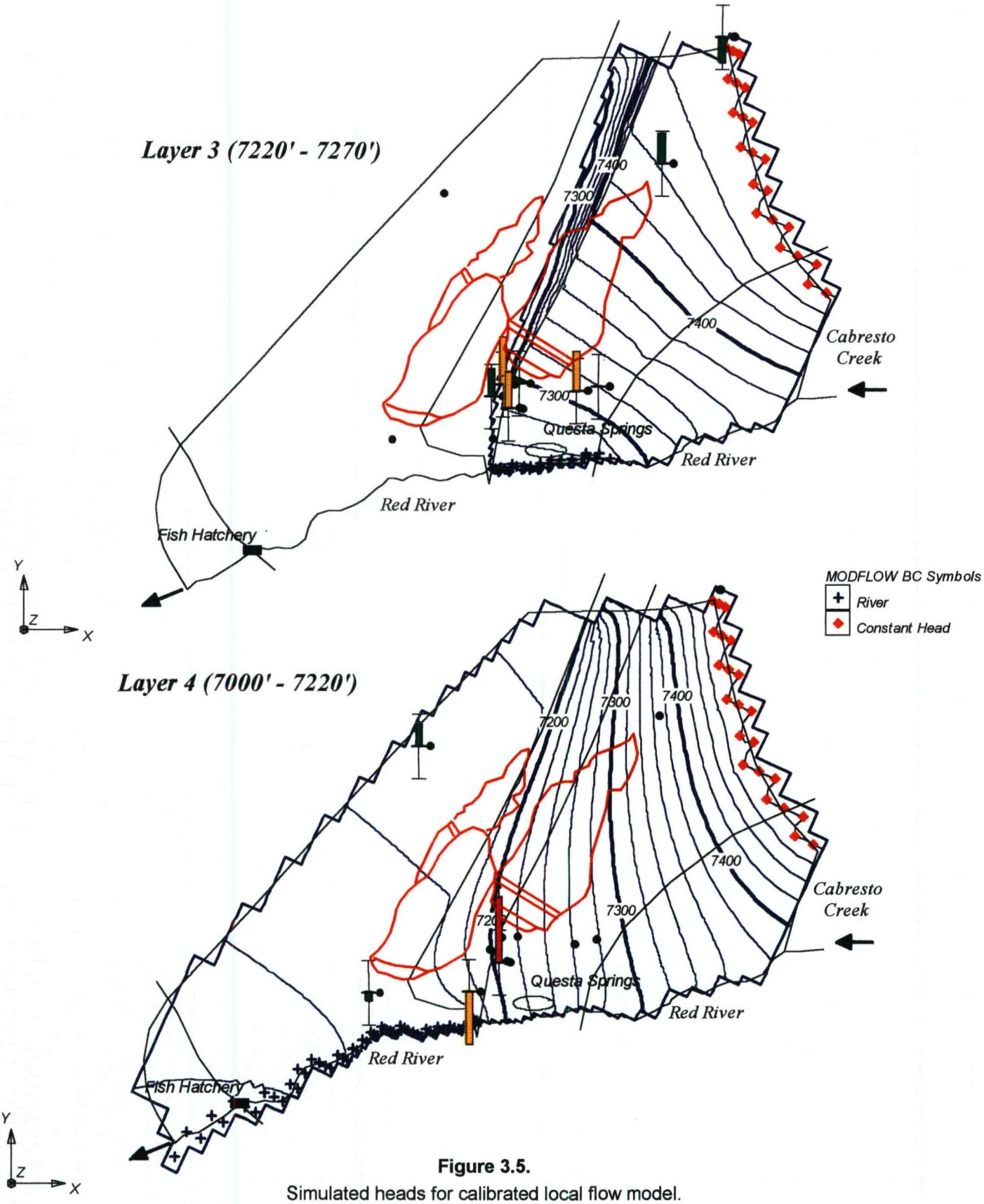

Figure 3.5.
Simulated heads for calibrated local flow model.

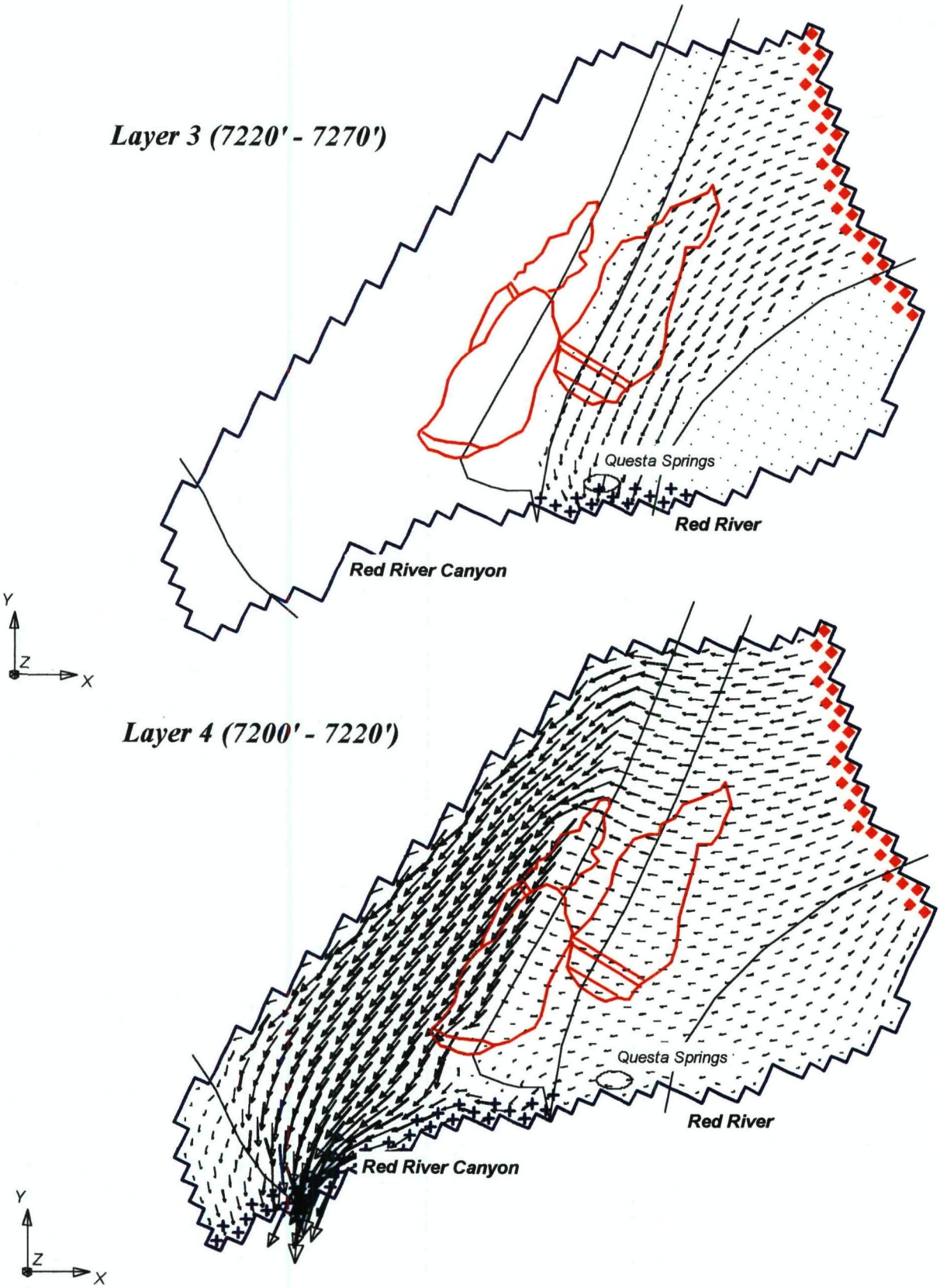

Figure 3.6.
Simulated volumetric flow vectors for calibrated local flow model.