# 8.0 RESULTS OF GEOTECHNICAL INVESTIGATIONS

## 8.1 MINE INTERCONNECTION, INTERFLOW

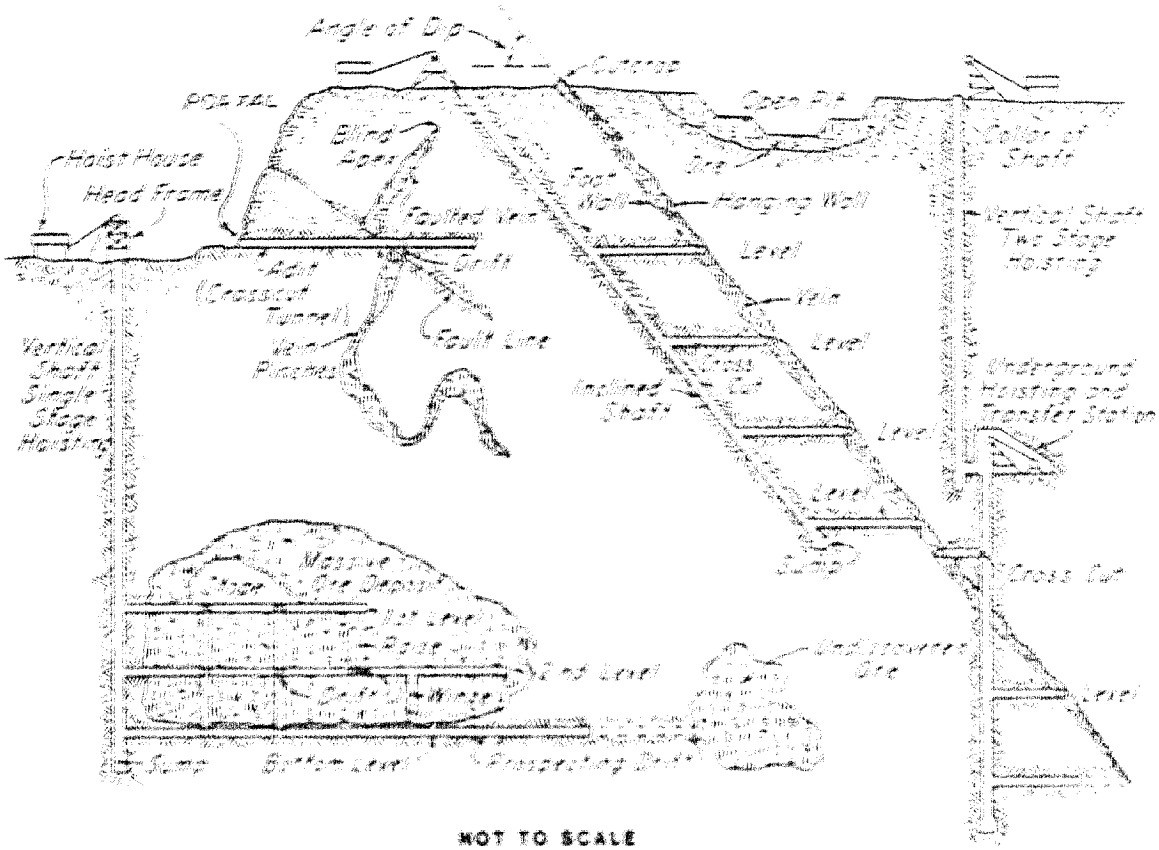
The structural geology of the Clear Creek/Central City site is significant to development of remedial measures due to the interconnection of abandoned and active mines and tunnels constructed to drain these mines. Data were gathered from published reports, historical mine maps, and existing geological maps and cross-sections of the five tunnels. This information is summarized in this section and assesses the structural integrity of the mine workings and portals, locates faulting and general fracture zones, and describes hydrologic communication between workings.

### 8.1.1 MINE METHODS

For the convenience of the reader who may not be familiar with the mining terms used in this report, an illustration showing typical underground mining terms is presented as Figure 8-1.

Due to the typically low topographic relief in the Central City area, mines in the district were developed through shafts. In comparison, a significant number of mines in the Idaho Springs area were developed by adits (tunnels) and shafts.

Shafts were generally sunk on the ore vein rather than in wall rock, thus they were straight in only one dimension. Levels were driven from the shaft along the strike of the vein every 50 to 100 feet of depth to block out ore zones for eventual stoping. Because of the small size of the early lode claims and diverse ownerships, sometimes a multitude of deep shafts were sunk to excessive depths on parallel courses on the same vein. Similarly, parallel veins that may have been tens of feet apart spatially

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Source: Gormley Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY RI/FS

MINING TERMINOLOGY

Reference: Lewis & Clark, 1987

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were often developed by separate shafts, without cross-cut connections between the two sets of workings ever being driven, even for safety purposes.

As mining progressed to greater depths, the handling of ground water became a problem. It was difficult, if not impossible, to keep the mines dry and hoist sufficient amounts of ore simultaneously because hoisting equipment was utilized for dewatering. According to one reference, most mines were dewatered by bailing (hoisting water in ore buckets); a few were drained by steam pumps or Cornish pumps. The California mine, whose 2,250-ft deep shaft was the deepest in the district prior to 1900, was reported to have bailed water for two shifts for every shift spent hoisting ore.

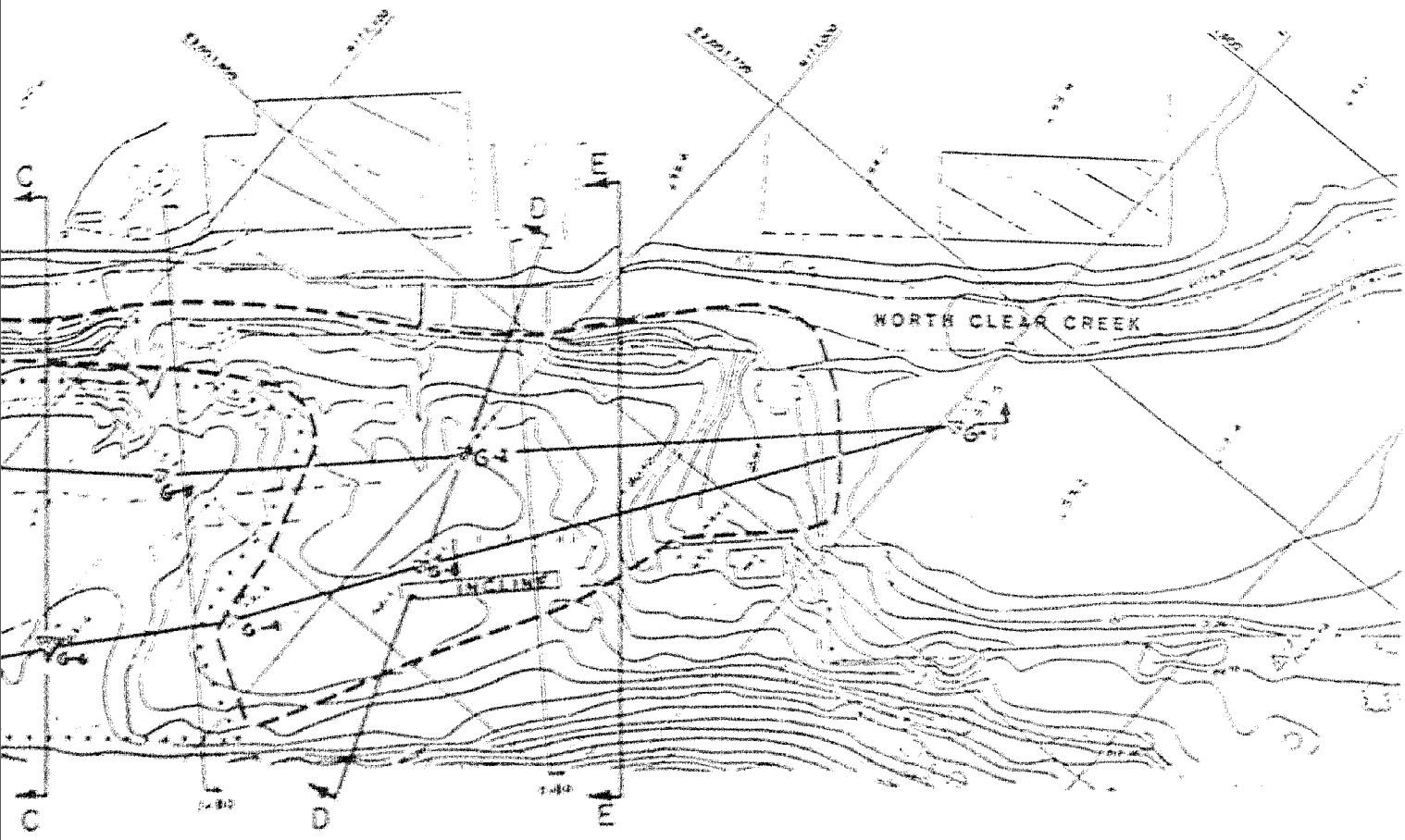
It appeared that if the mines were idle for even a short time, water levels would rise to pre-mining conditions unless adjacent properties kept pace with the inflows or a tunnel was providing drainage.

Ore was removed in open stopes generally from six to twenty feet wide. Raymond (1871) reported that most stoping was underhand, following the ore chutes downward, leaving mined out areas above supported by timbers. Mr. Norman Blake, a local mining authority, reported that early stoping recovered oxidized ore and that sulfide ore on the sides of the stopes was subsequently recovered by slabbing operations.

### 8.1.2 GREGORY INCLINE

The Gregory Incline is located on the southwest side of North Clear Creek, just northwest of the Town of Blackhawk, Gilpin County, Colorado. The portal to the Incline is located on an abandoned mine waste rock/tailings dump. The portal site encompasses a small portion of approximately 3.5 acres of land which lies at the base of a steeply sloping hillside. A plan view is shown on Figure 8-2. Elevations of the site range from 8,050 feet above sea level in the southeast to 8,080 feet in the northwest. The site consists of a series of a few slopes and benches. The embankment along the

-DESIGNATED SECTIONS USED IN SLOPE STABILITY ANALYSIS

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Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

PLAN VIEW
GREGORY INCLINE

CAMP DRESSER & MCKEE INC.

CDM

environmental engineers, scientists, planners, & management consultants

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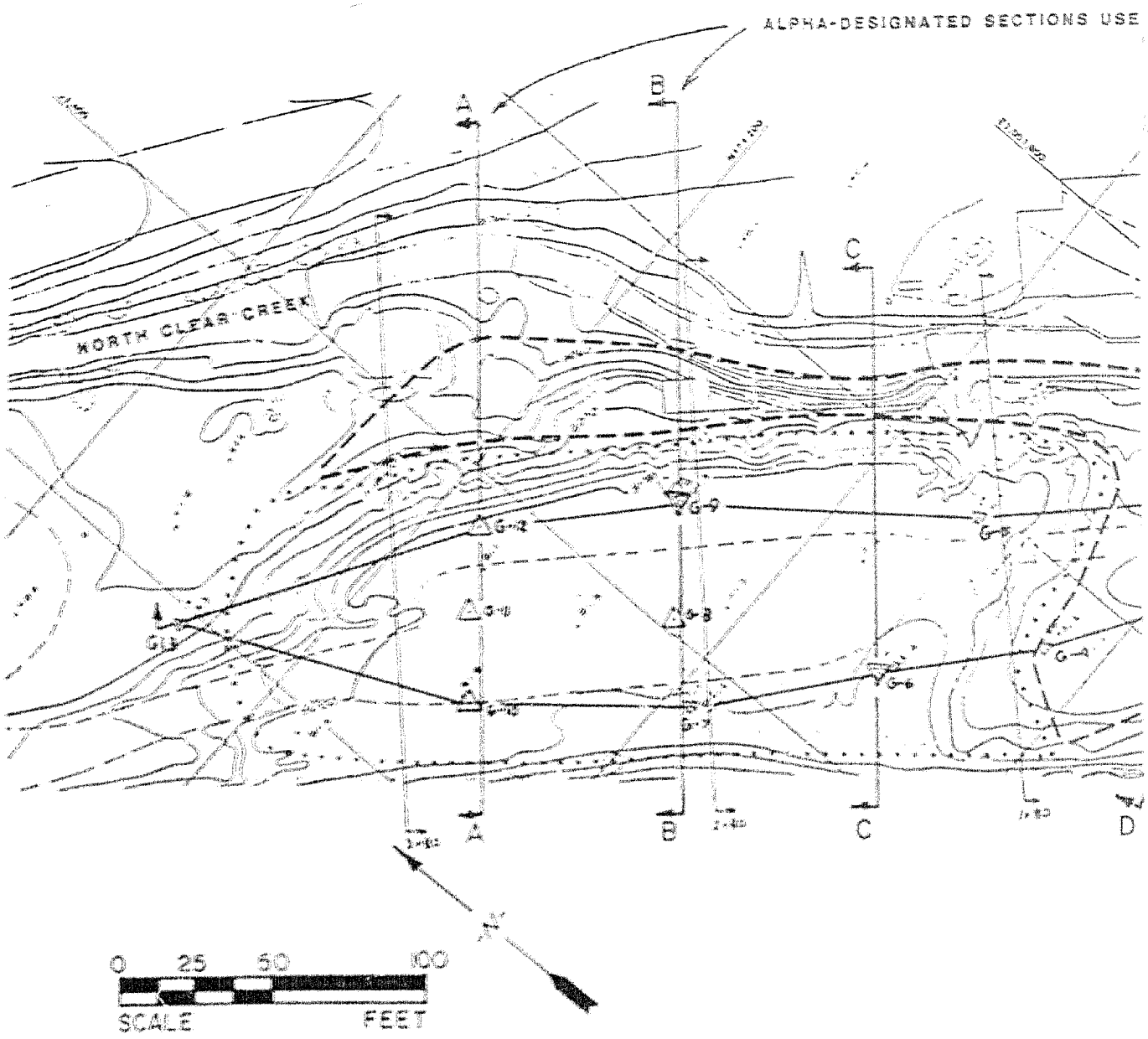



— — — APPROXIMATE BOUNDARY OF WASTE ROCK ON THE SURFACE

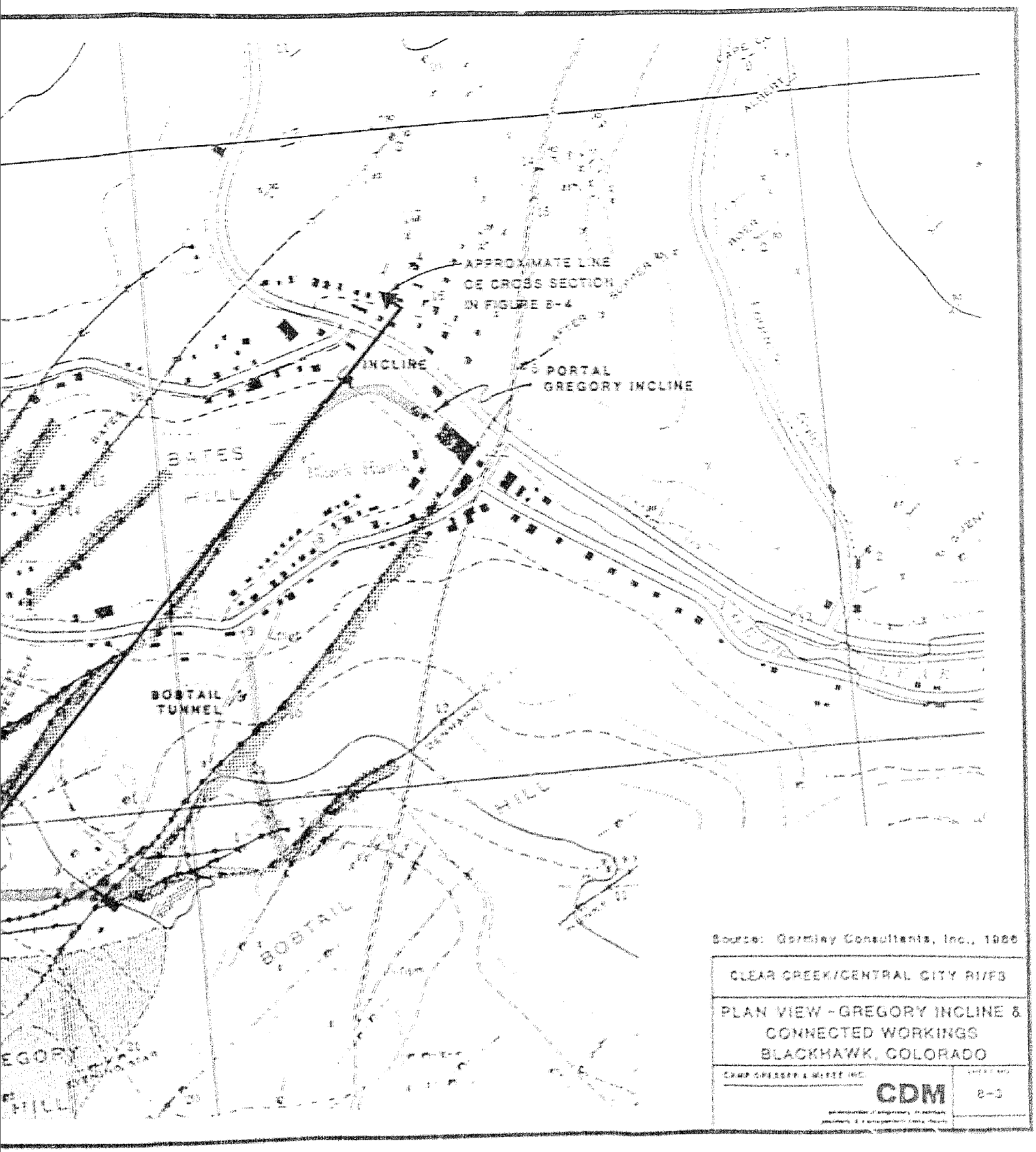
. . . . . APPROXIMATE BOUNDARY OF TAILINGS ON THE SURFACE

stream slopes at about 2.0E : 1.0V to the top of the tailings; a major portion of the dump along the stream is contained by a highly deteriorated timber crib wall. The height of the dump above the creek is nominally 20 feet. Due to the acidic and rocky nature of the surface material, no vegetation exists on the site.

The Gregory Incline is a curving inclined adit that reportedly slopes down at approximately 25 degrees for a length of 1,709 feet to a point on the Gregory Vein, 700 feet below the surface (Figure 8-3). The Gregory Incline portal slopes to the northwest and reportedly curves toward the southwest to intersect the Gregory Vein. The portal opening is supported vertically and laterally by 8-inch square timbers with timber lagging. Near the surface, both timber and lagging are in a weathered, rotted condition; however, the condition of the timber improves with depth. The floor of the incline is strewn with trash and muck. A rusted 3-inch, cast iron pipe follows the floor of the incline, disappearing into the muck that plugs the incline's face about 30 feet inside of the incline. The material on either side of the incline is waste rock. Tailings material is encountered approximately 20 feet northeast of the point where the incline disappears underground.

Photographic data indicate that from 1869 through approximately 1880, the site was occupied by several small stamp mills that recovered gold from ores of the district. These mills were constructed perhaps several feet above the level of North Clear Creek, directly on top of alluvial gravels. The banks of North Clear Creek were protected at that time by what appears to be stacked timbers. The creek level in 1880 appears to have been similar to its present level.

Historical data indicate that the Gregory Incline was driven sometime in the period 1880-1889 since this is the first appearance of the rock crib structure in site photos. In 1912, at the time of a U.S. Geological Survey investigation that resulted in Professional Paper 94, Bastin and Hill reported that the Gregory Incline workings were inaccessible and most of




Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

PLAN VIEW - GREGORY INCLINE & CONNECTED WORKINGS
BLACKHAWK, COLORADO

CAMP DRESSER & MCKEE INC.
CDM

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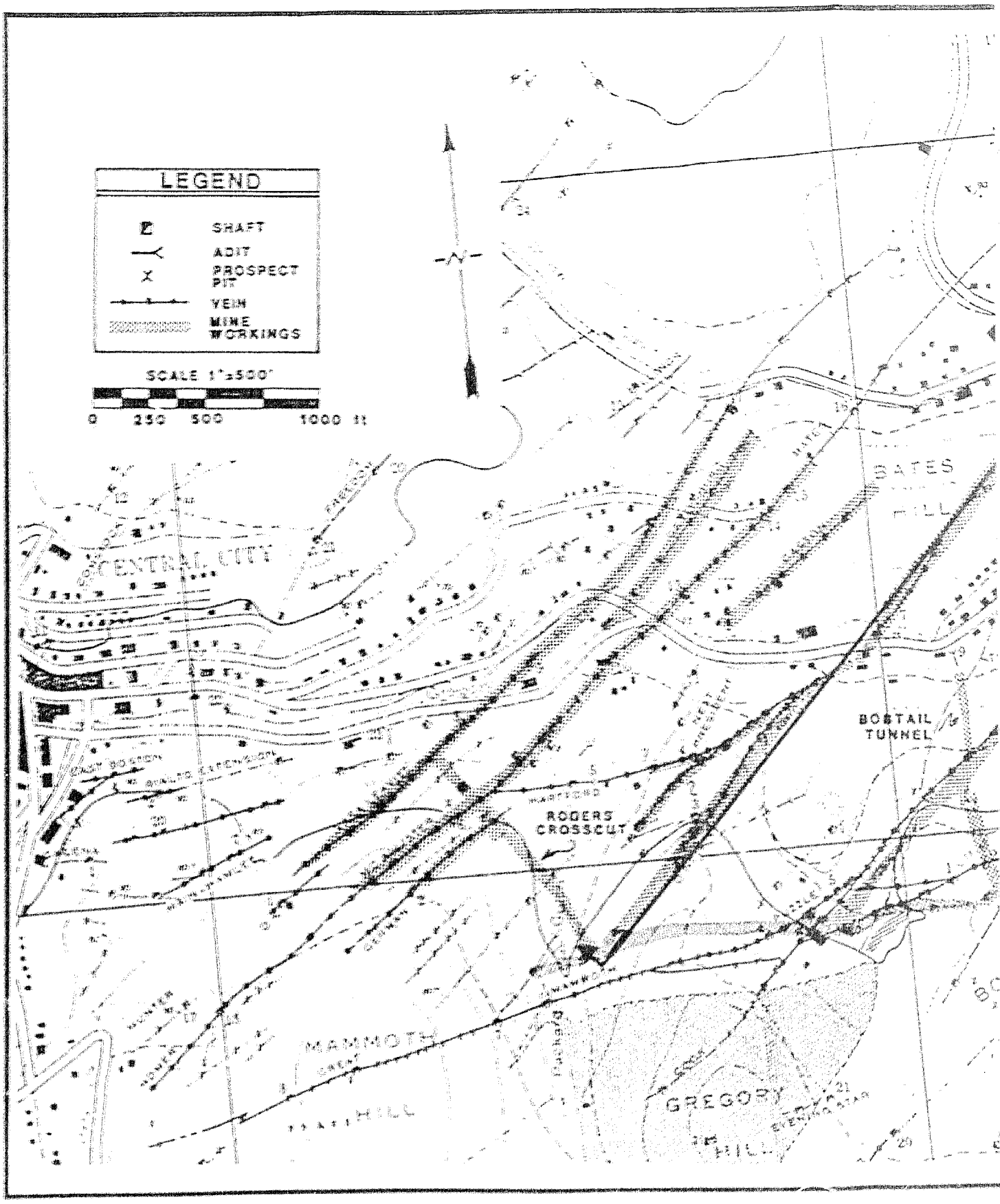
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N
CENTRAL CITY
BATES HILL
BOBTAIL TUNNEL
ROGERS CROSSCUT
MAMMOTH
GREGORY HILL

the ore in the area was being hoisted out of the Bobtail tunnel and shaft system. The Incline and surrounding workings were apparently controlled by the Fifty Gold Mines Company, which consolidated many of the smaller claims in the area.

As shown in Figures 8-3 and 8-4, the Gregory Incline is connected to the Gregory vein workings themselves and, through a single drift on the vein, to the Bobtail workings which connect to miles of nearby mine workings. The entire mine system that could be connected to Gregory Incline is extremely complex, if not unknown, in extent due to the questionable reliability of the available mine maps. It is believed that the Gregory Workings (the Incline, stopes, shafts, drifts, and crosscuts) are connected to seven other nearby vein systems. These are:

- Vasa Leavitt
- Gettysburg
- Bates/McAllister
- Gaston
- German
- Briggs/O'Neil
- Great Mammoth, Puzzle, Cook/Fisk, Sleepy Hollow

It is likely that all of the veins, including the Gregory, have been stoped to the surface. Stopes in the Vasa Leavitt, Gettysburg, Bates, and Gregory are very likely to be sources of water recharge (via flow in Gregory Gulch) to the mine workings connected to the Gregory Incline. In fact, water was observed flowing from Gregory Gulch into a shaft on the Vasa Leavitt during a field investigation phase of this study.

Historical data concerning mine dewatering are sparse. However, the limited data indicate that the fault/fracture system closely associated with the vein system is the principal natural conduit that carries surface water into the mine workings. This is supported by reports in the literature that as mining advanced to greater depths, "pockets" of great

volumes of water would be intersected. At the beginning of a shift, the mine workings would be relatively dry (the existing dewatering system was sufficient) and immediately after a blast round was shot, the pumps would be submerged.

Hydrologic communication between workings not necessarily on the same vein and not connected by mining crosscuts was common in this locality. This is supported by reports that the mine with the deepest shaft in the Gregory Gulch area usually had the most serious drainage problems while surrounding, more shallow mines were dry.

Typically, mine drainage discharge rates were on the order of 250 gallons per minute (gpm) according to pump data cited in 1871 (Raymond) for the Sterling Shaft at a point 250 feet below the level of the Bobtail Tunnel, whose portal is in the Gregory Gulch and is open as a tourist attraction. Mr. Norman Blake, a local mining authority, recalled that the Bobtail workings pumped approximately 300 gallons per minute when the workings were 600 feet deep and 600 gallons per minute when the workings reached the 1,200-ft depth mark. He also reported that in 1937, water was continuously discharging from the Gregory Incline at about the same rate at which it is currently; approximately 0.19 cfs.

Mr. Blake was recently in the lower workings below the Bobtail tunnel and reported the water level to be 250 feet below the tunnel level. The Gregory Incline discharge is approximately 120 feet below the Bobtail Tunnel and 130 feet above the reported water level below the Bobtail Tunnel. These observations indicate that the local hydraulic gradient is from the incline, toward the lower Bobtail workings. The hydrologic implications of these data are complex. There are two plausible explanations:

- The recharge zone (Gregory Gulch) recharges in more than one direction, with gradients toward the Bobtail Tunnel as well as the Gregory Incline.

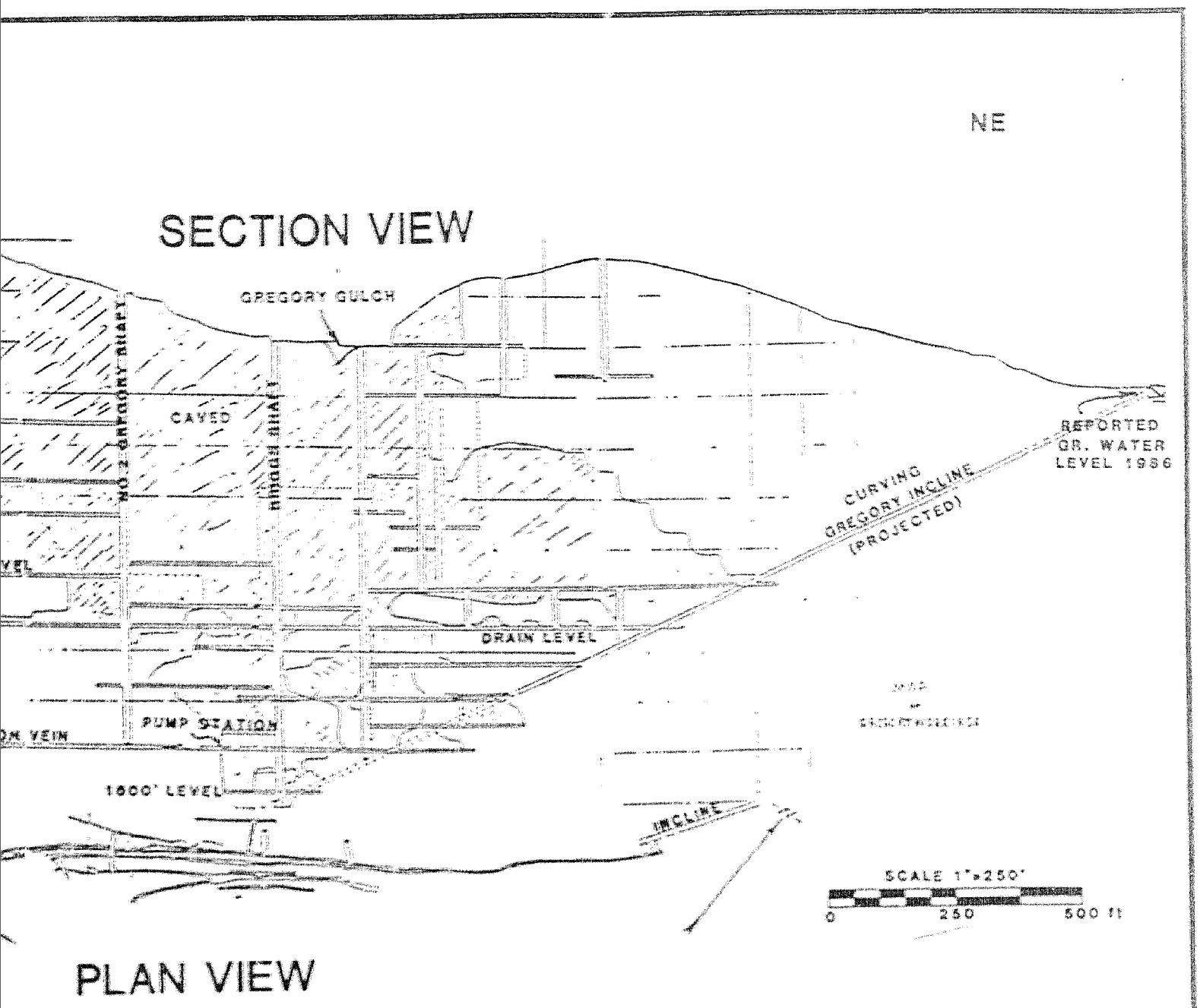
- The interconnections between the Gregory workings and the Bobtail Tunnel are poor for water movement as a result of cave-ins.

### 8.1.3 NATIONAL TUNNEL

The National Tunnel site is approximately 3,000 feet southeast of the Town of Blackhawk in Gilpin County, Colorado, on the south side of North Clear Creek. A plan view of the National Tunnel is shown on Figure 8-5. As shown on Figures 8-6 and 8-7, the Tunnel portal is at an approximate elevation of 8,050 feet. The tunnel itself is not driven on a vein. Historical data (Bastin and Hill, 1917, and Simms, et al. 1963) indicate that the National Tunnel is approximately 3,130 feet long driven on a trend of S 25 W, connecting to the Senator Shaft and the sixth level of the Clay County Mine in Lake Gulch (Figure 8-7). Ore from the Clay County Vein was apparently hauled through the tunnel between 1905 and 1941. The Clay County Mine also operated between 1891 and 1899, and a modern-day mining operation is reported working the Clay County Vein on the west side of Lake Gulch. The mine is apparently on standby status.

The Clay County Mine history apparently parallels the history of the National Tunnel and a short discussion of the Clay County Mine is appropriate. The Clay County Vein, in Lake Gulch, apparently was stoped to the surface where production prior to 1899 came "...almost entirely from ore that came from above the third level of the Clay County shaft" (Bastin and Hill, 1917). After 1905, it appears that all production from the Clay County Mine was hauled through the National Tunnel. Production records indicate ore shipments as late as 1941. No attempt to determine recent production was made.

A cursory inspection of the Clay County Mine site indicated that water flowing through the site along Lake Gulch was likely providing some, if not most, of the recharge water that flows out the National Tunnel portal some 1,000 feet away. The "new" Clay County Mine appears to have an inclined portal on the west side of Lake Gulch, a concrete ore bin, several mill buildings, and construction trailers. A minor amount of water (less than




Source: Gormley Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY RI/FS

PLAN & SECTION VIEW
GREGORY WORKINGS CIRCA 1883
BLACKHAWK, COLORADO

CAMP DRESSER & MCKEE INC.
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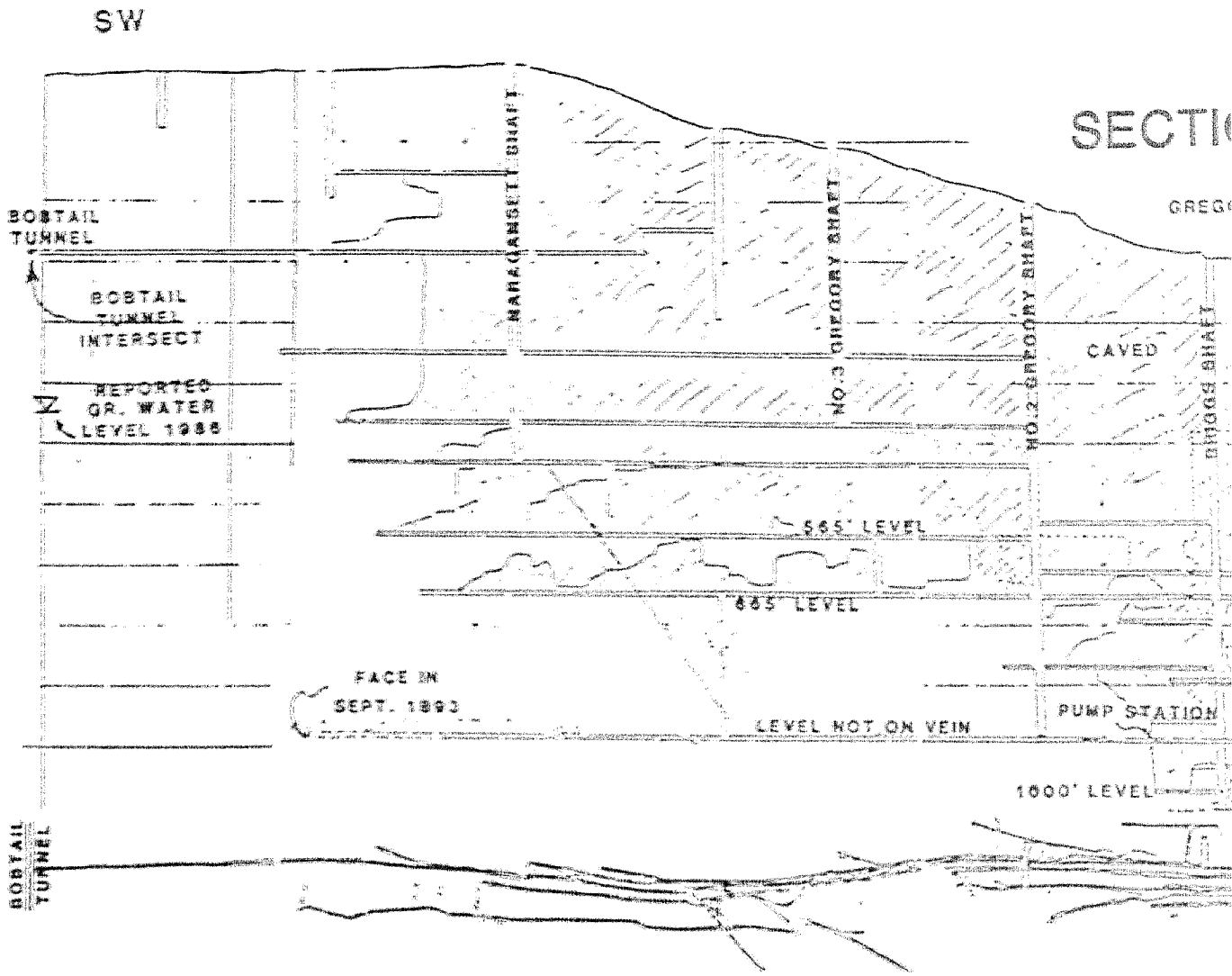
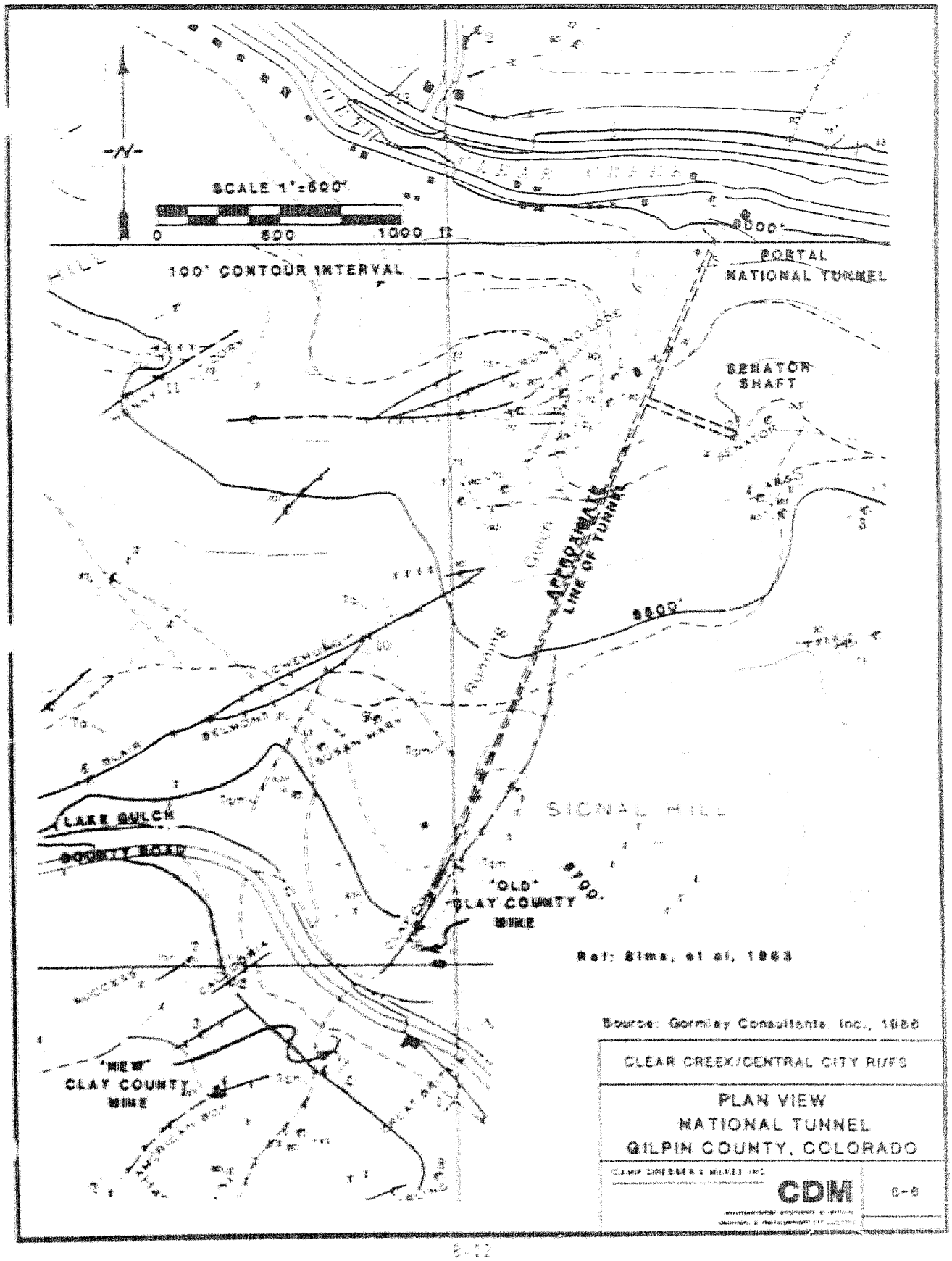



NOTE: At least eight veins parallel to and connected to the Gregory workings could have similar extensive development.

SOURCE: Tracing of original map on file at Colorado Historical Society Library, Denver, CO.


-N-
SCALE 1"=500'
0
500
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100' CONTOUR INTERVAL
PORTAL
NATIONAL TUNNEL
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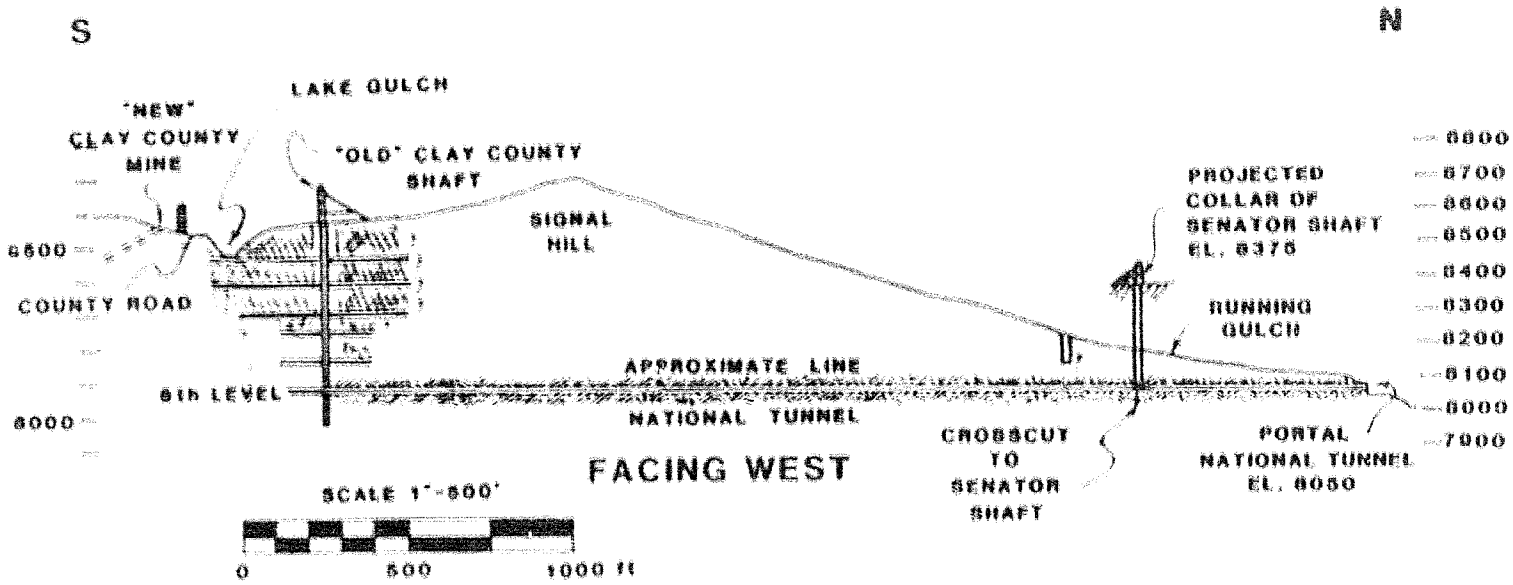
8500'
SIGNAL HILL
LAKE GULCH
COUNTY ROAD
'OLD'
CLAY COUNTY
MINE
8100'
'NEW'
CLAY COUNTY
MINE
Ref: Sims, et al, 1963
Source: Gormley Consultants, Inc., 1988
CLEAR CREEK/CENTRAL CITY RI/FS
PLAN VIEW
NATIONAL TUNNEL
GILPIN COUNTY, COLORADO
CDM
6-9




Source: Dames & Moore Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RIFS

APPROXIMATE SECTION VIEW
NATIONAL TUNNEL
GILPIN, COLORADO

CDM

8-7

1,000 cubic feet) is being impounded in Lake Gulch (probably for sediment control) in the approximate locations where abandoned stopes intersect the surface.

A description of conditions at the National Tunnel portal follows. The first 15 feet of the portal is approximately 8 feet high and 7.5 feet wide, and is lined with 10-in. by 10-in. treated timber on approximate 3-ft centers, with timber lagging covering the spaces between the timbers. The timbers are lagged on the sides and top of the portal. Based on observations, the tunnel appears to be open for at least 300 feet from the portal.

The lagging atop the portal is covered with the local colluvium for a distance of about 12 feet from the portal entrance; the remaining three feet of lagging is covered by colluvium that has sloughed off the hills above the lagged portion. The slope of the hillside beneath the local colluvium is approximately 30 degrees.

Competent rock, probably Idaho Springs schist, is encountered 15 feet in from the portal. No major joint system was observed although the shape of the adit indicates minor joint sets dipping at about 45 degrees to the west and a conjugate set dipping at about the same angle to the east. The rock around the periphery of the 8-ft by 8-ft opening was weathered to a depth of about 0.5 inches. Some fractures were observed to be filled with an iron oxide precipitate, probably from local ground water flow.

The invert of the portal has a stream of heavily iron-laden water flowing in it. At the point where the lagging meets the competent rock, the mine discharge passes through a 16-in. culvert which is, in part, covered by waste rock.

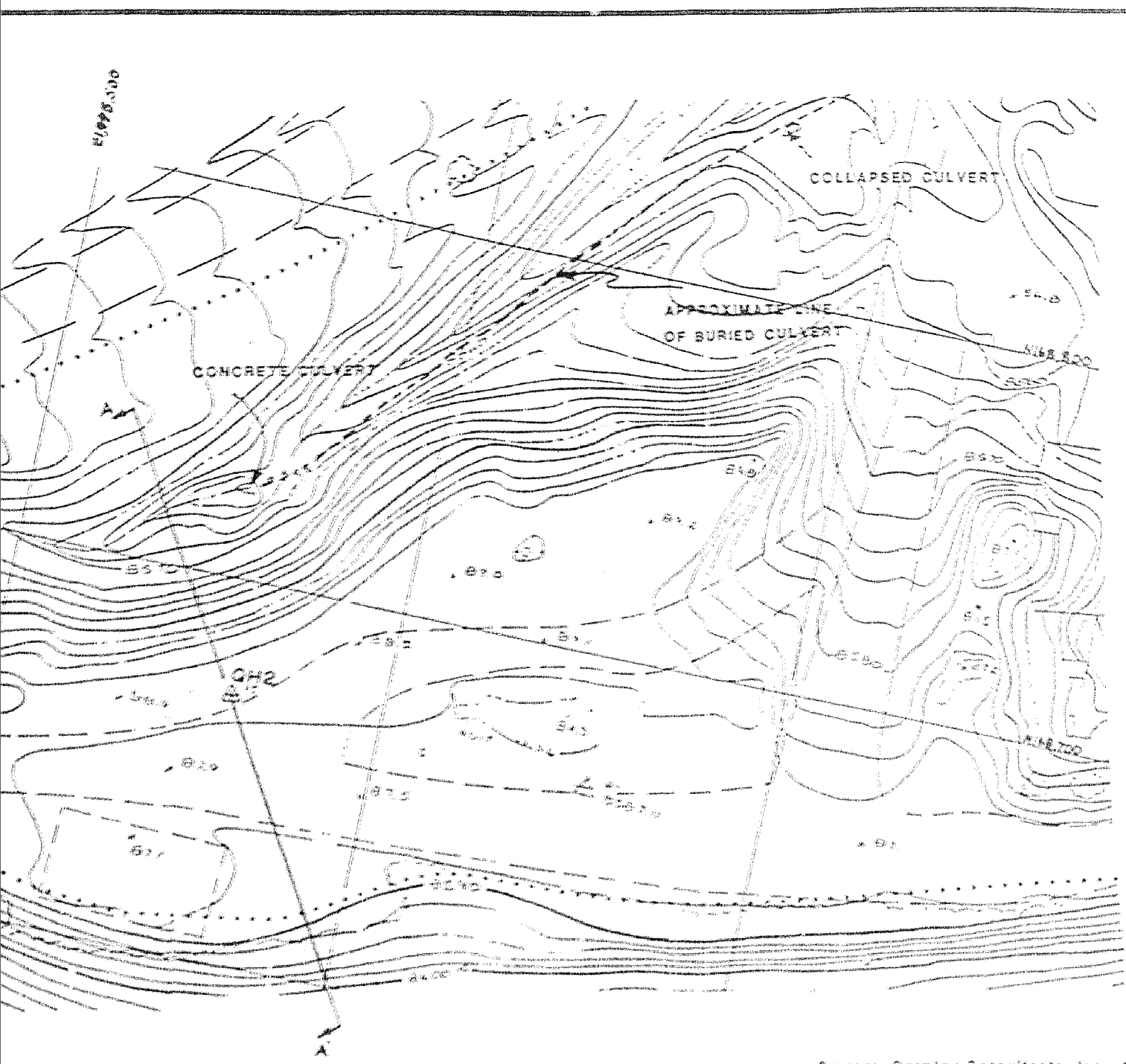
The mine drainage discharges into a small depression which serves as a settling and precipitation pond. The discharge from this settling pond flows down the site access road and eventually discharges into North Clear Creek.

### 8.1.4 QUARTZ HILL TUNNEL

The Quartz Hill Tunnel is located on the southwestern outskirts of Central City, Gilpin County, Colorado, along and adjacent to Nevada Gulch. A plan view of the Quartz Hill Tunnel is shown on Figure 8-8. Quartz Hill is the site of the portal to a tunnel that extends through Quartz Hill and connects with a number of lateral mine workings (Figures 8-9 and 8-10). The Quartz Hill Tunnel has a mine water discharge into Nevada Gulch and the area outside of the mine opening and adjacent to the stream bed is mine waste rock fill.

The Quartz Hill Tunnel was actively being driven in 1876, at which time it was 925 feet deep, cutting ten lodes. The tunneling was reported to be accomplished by "perseverance under difficulties", indicating poor ground conditions. In 1912, according to Bastin and Hill, the Tunnel was about 1,480 feet deep, where it encountered the Helca vein. In 1950, Lovering and Goddard reported the tunnel to be approximately 4,000 feet deep, intersecting the "Patch" deposit at an elevation of 8,622 feet. Sims et al. (1963) reported that the Quartz Hill Tunnel operated until 1935, probably supporting stoping operations on the Helca, Stark County, and Barnes vein and operations in the Patch. Data also indicate that the National mine (no relation to the National Tunnel) is connected to the Quartz Hill Tunnel in the vicinity where the Tunnel encounters the Helca vein.

Most of the ore to the Patch deposit was recovered in a glory hole operation through the La Crosse Tunnel, driven from the northwest to southeast at an approximate elevation of 9,000 feet, some 375 vertical feet




Source: Gormley Consultants, Inc., 1986

.... APPROXIMATE BOUNDARY OF MINE/MILL WASTE ROCK ON SURFACE

CLEAR CREEK/CENTRAL CITY R/FS

PLAN VIEW
QUARTZ HILL TUNNEL

CAMP DRESSER & MCKEE INC.
CDM

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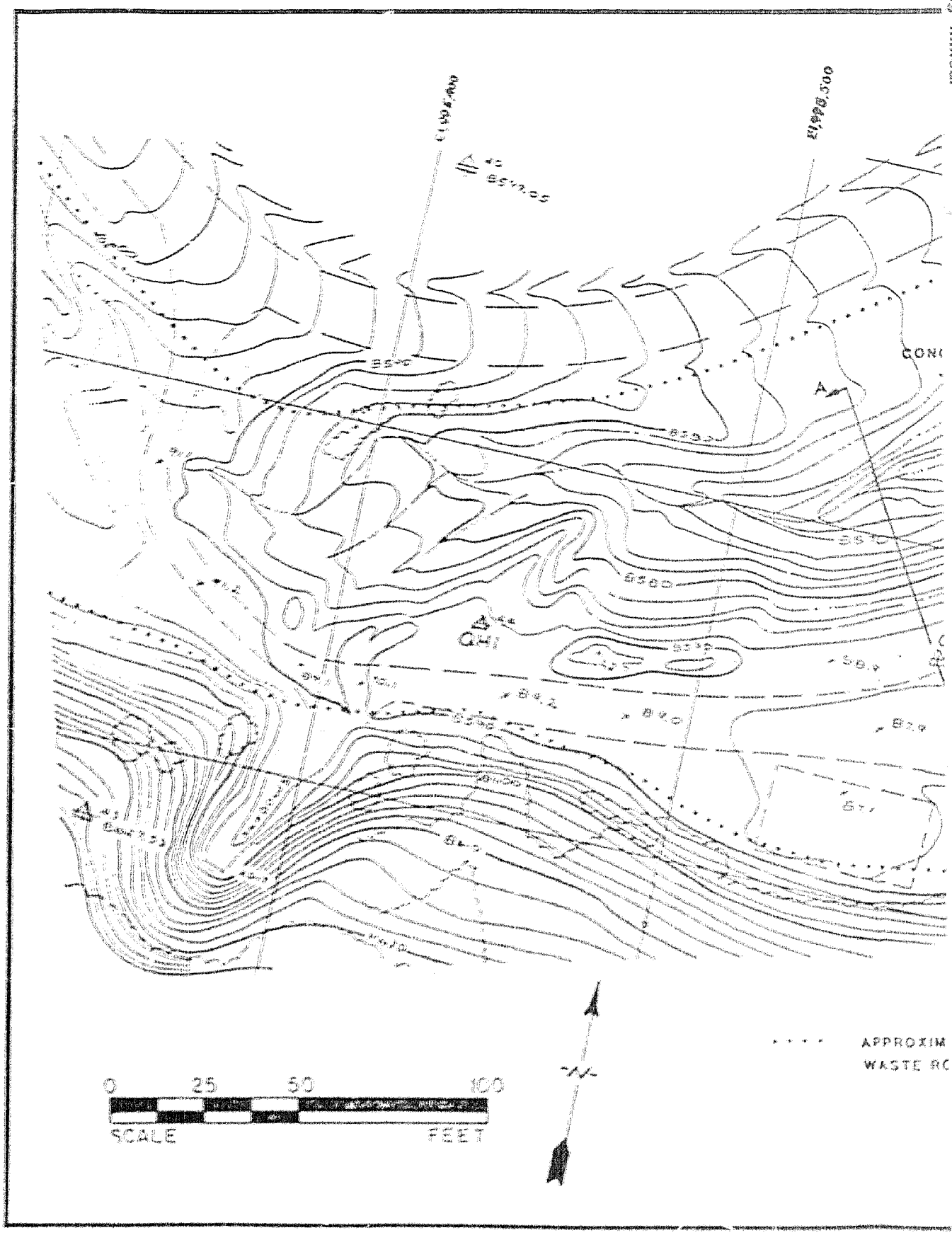


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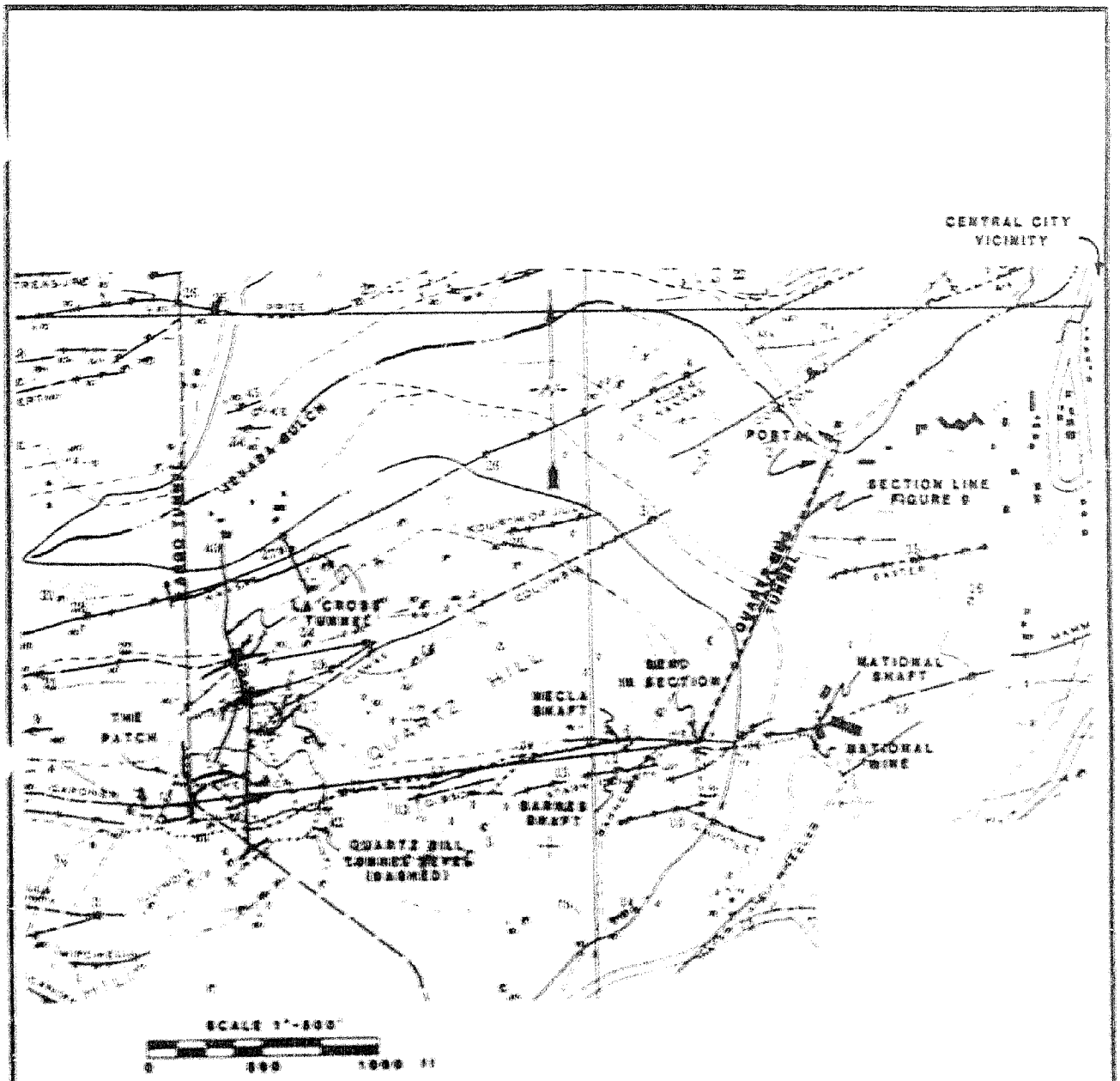


Source: Gormley Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY RI/FS

PLAN VIEW
QUARTZ HILL TUNNEL
& CONNECTED WORKINGS

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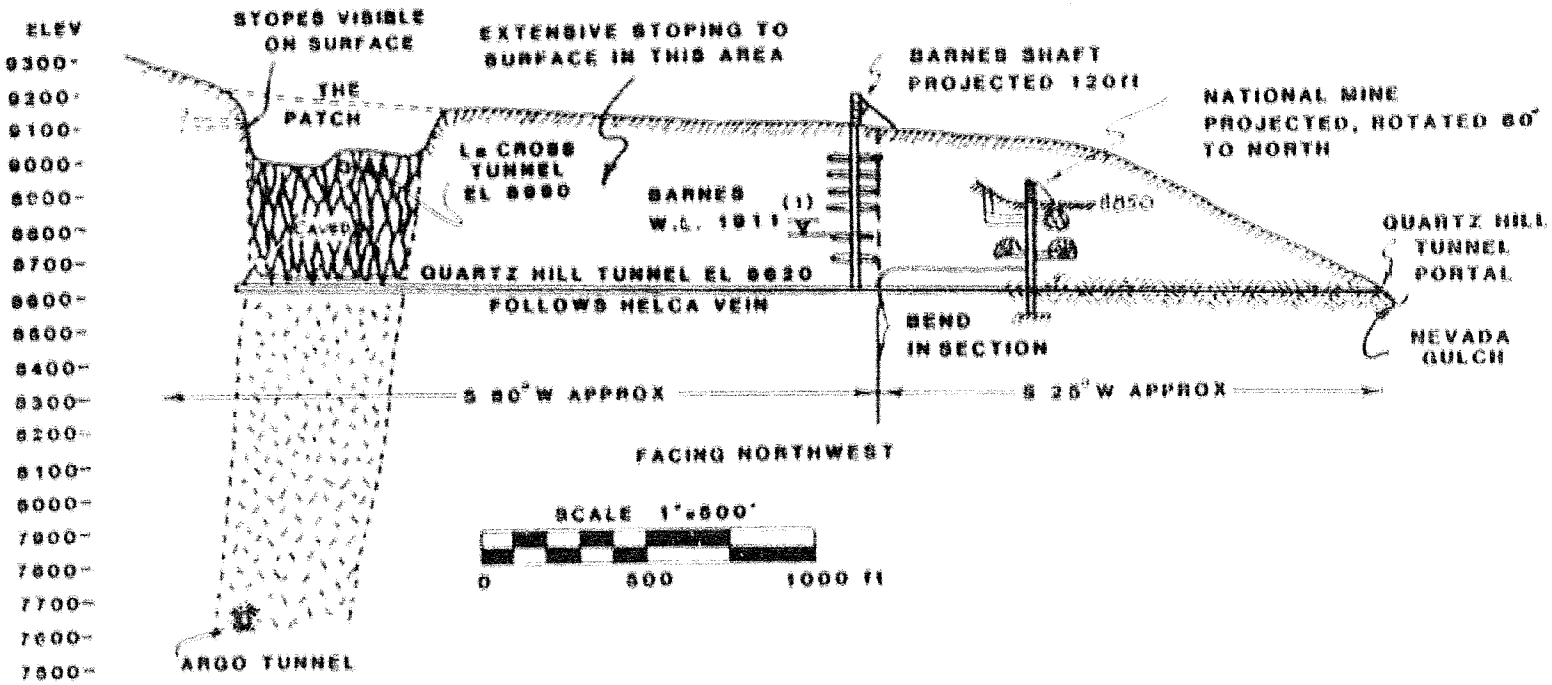


(1) Ref. Professional Paper 94, P 243

Source: Geometry Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY BLVD

VERTICAL SECTION
THROUGH THE
QUARTZ HILL TUNNEL

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above the level of the Quartz Hill Tunnel. The La Crosse Tunnel and its connected workings appear to be connected to the Quartz Hill Tunnel either through ore passes or caved areas. This is supported solely from the layout of the Quartz Hill workings in the area of the Patch. No raises or ore passes are shown on existing mine maps. However, the layout would suggest a drawpoint caving operation on the Quartz Hill level similar to that used in the La Crosse Tunnel. As shown on Figures 8-9 and 8-10, the Argo Tunnel also passes through the Patch, but at a much deeper level. The figure depicts the super position of the workings of the La Crosse, Quartz Hill, and Argo tunnels.

As previously stated, it appears that there was some connection between the La Crosse and Quartz Hill tunnels workings. There is no evidence, however, to support a connection such as an ore pass or raise from the Argo Tunnel to the level of the Quartz Hill Tunnel. Figure 8-10 reflects this lack of connecting evidence.

In summary, according to available mine maps, the Quartz Hill Tunnel trends to the southwest for about 4,500 feet and is known to be open for at least 100 feet which can be observed from the portal. Conditions at the portal are as follows. The first 49 feet of "original" lagged portal is caved. This area is about nine to ten feet wide which would be expected for an 8-ft by 8-ft timbered/lagged portal. The 10-in. by 12-in. round timbering and lagging in the remaining 17 feet of standing portion of the portal before competent rock is encountered is deteriorated and rotting. This remaining portion of the portal is covered by perhaps two to three feet of colluvium that has sloughed off the hillside.

Competent rock begins approximately 66 feet from the point where the lagging first begins. The adit is about 8 feet wide and is 5.5 feet high. It is very likely that there are several feet of waste rock rubble lying in the invert of the adit. About 30 feet in from the portal, the lower 13 inches of the adit are undercut. During monthly site visits in 1985 and 1986 to measure adit discharges, deposits of ice were observed clogging the

portal. The high water mark of previous "ice dams" was evident approximately two to six inches below the roof of the adit.

Three joint sets were observed in the competent rock:

| Strike Azimuth | Dip |
|---|---|
| 230 degrees | 32 degrees to the east |
| 342 degrees | 83 degrees to the east |
| 272 degrees | Vertical |

Joints had generally opened from 0.25 to 0.5 inches.

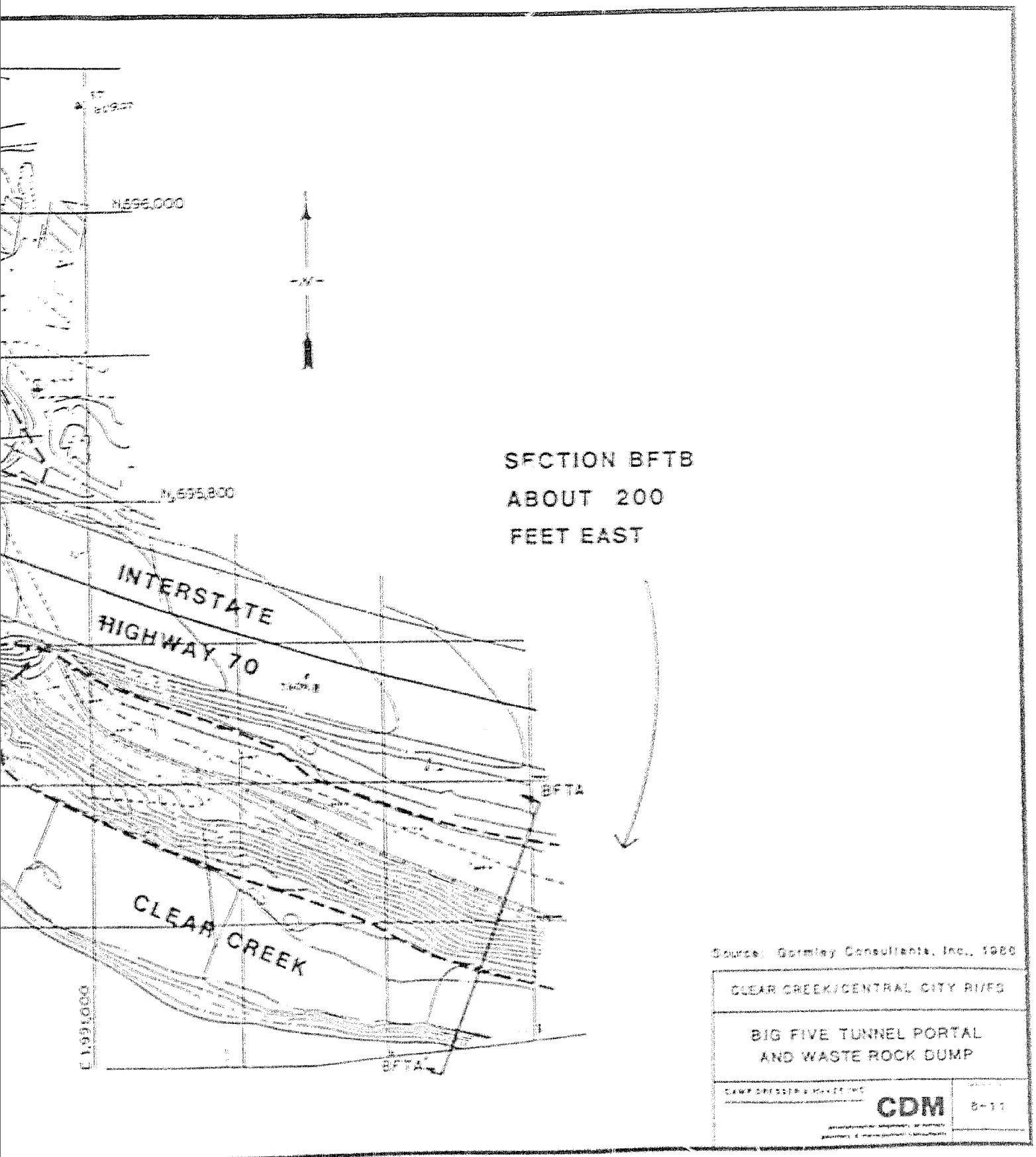
Water flows out the portal and disappears into the waste rock pile in front of the portal and eventually joins the stream running down Nevada Gulch.

8.1.5 BIG FIVE TUNNEL

The Big Five Tunnel, also known as the Central Tunnel, is located on the western side of Idaho Springs in Clear Creek County, Colorado, on the north side of Clear Creek at an elevation of approximately 7,600 feet. A plan view of the Big Five Tunnel is shown on Figure 8-11. The Big Five Tunnel portal is the terminus of an approximately two-mile long tunnel driven due north, that was used for drainage and transportation of ore and waste rock. Mine drainage from the tunnel flows out the portal and into an adjacent pond which apparently used to be a channel of Clear Creek that was cut off during the construction of Interstate 70. The pond water infiltrates beneath the Interstate and discharges through seeps into Clear Creek.

The Big Five Tunnel, which connects with a number of lateral mine workings, was begun in 1901. By 1911, the tunnel had been driven 8,975 feet. As of 1950, the tunnel was reported to be approximately 9,400 feet deep.

The tunnel cross-section is eight feet by eight feet for the first 1,850 feet, beyond which it is six feet wide with the exception of switching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Source: Gormley Consultants, Inc., 1986
CLEAR CREEK/CENTRAL CITY RI/FS
BIG FIVE TUNNEL PORTAL
AND WASTE ROCK DUMP
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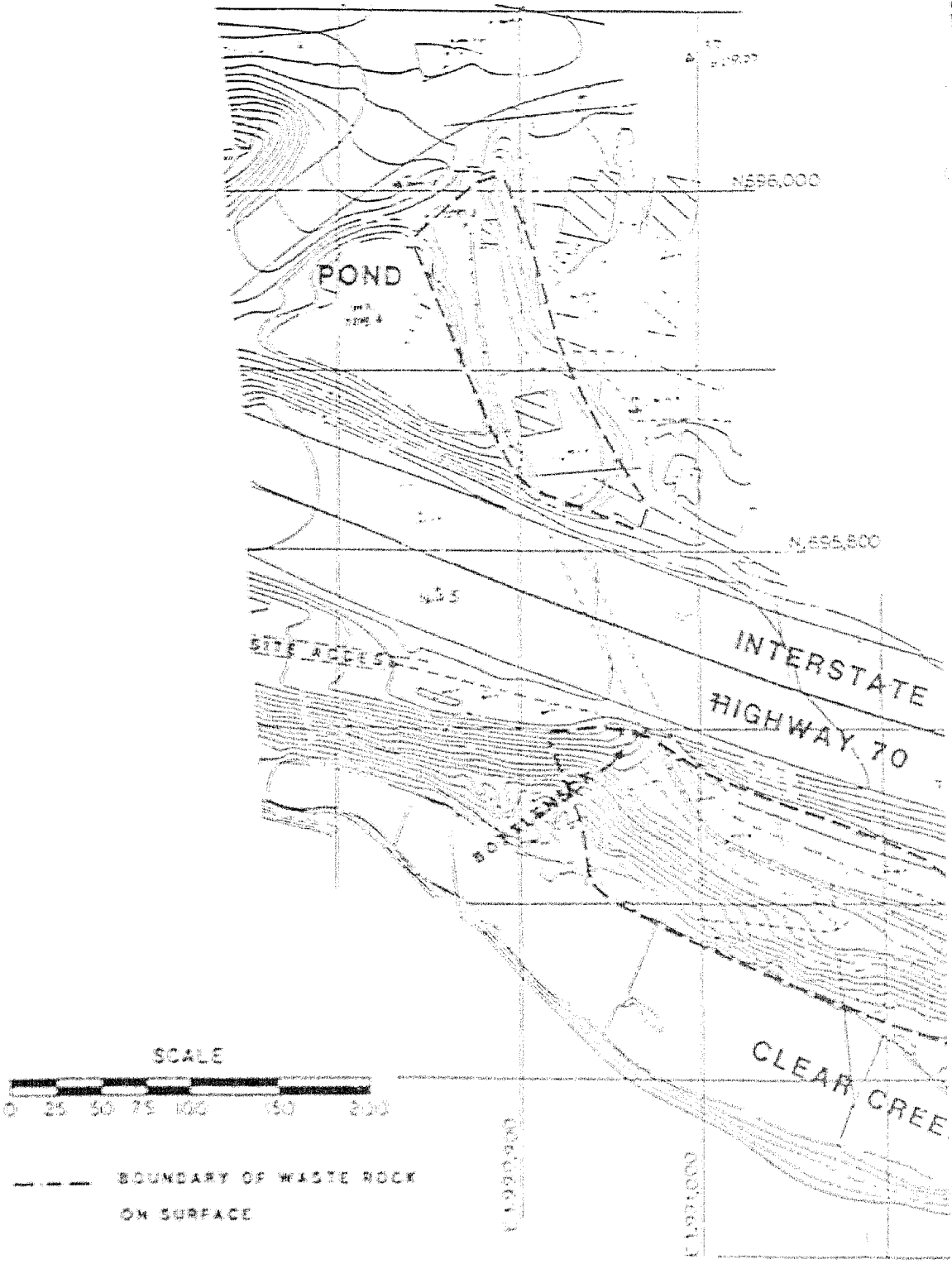


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rooms at several points. The more prominent veins cut by the Big Five Tunnel and their distances from the portal are as follows:

| Vein | Distance (ft) |
|---|---|
| Edith S. | 1,240 |
| Fulton | 2,364 |
| Edgar | 2,510 |
| Jenny Lind | 3,690 |
| Shafter | 4,250 |
| Strong | 5,660 |
| Hudson | 6,445 |
| Good for Nothing/Great Center | 7,000 |
| Kentuck | 7,320 |
| Lake | 8,345 |
| Belman | 8,905 |

Records indicate that not all the mines associated with the veins listed above were directly connected from the surface to the Big Five Tunnel. The mines known to be connected directly are as follows:

- Edgar, connected through the east drift, about 500 feet below the lowest Edgar surface opening.
- Colorado School of Mines Experimental Mine (CSM mine), indirectly connected through the Miami Tunnel to the Edgar workings. The CSM mine uses the Edgar workings for ventilation.
- Shafter Mine, directly connected via a 900-ft long lateral drift on the vein from the bottom of the 893-ft deep Shafter shaft.
- Unknown Mine, active, near Comstock Mine in Virginia Canyon, possibly connected in some fashion.

The mines connected to the Big Five Tunnel listed above have the following remedial alternative design data:

| Mine | No. of Shafts | Stoped Outcrop (ft.) | Lowest Collar Elevation (ft.) |
|---|---|---|---|
| Edgar | 7 | 600 | 8,125 |
| CSM Mine | 1 drift | 0 | 7,880 |
| Shafter | 7 | 2,100 | 8,500 |
| Unknown | 5? | 1,500 ? | 9,150 |
| Totals | 20 | 4,200 | 7,880 Lowest |

The Big Five Tunnel portal is a masonry structure for approximately its first 300 feet according to maps in Bastin and Hill, and shown on Figure 8-12. Wall rock is typically the Idaho Springs formation. Access to the tunnel is prevented by a locked sheet metal gate. The interior condition of the tunnel was cited in a 1966 USGS open file report (Moench and Drake). They reported that Contract Engineering Company of Denver "cleaned out most of the tunnel and gained access to the Lake vein about 8,350 feet from the portal".

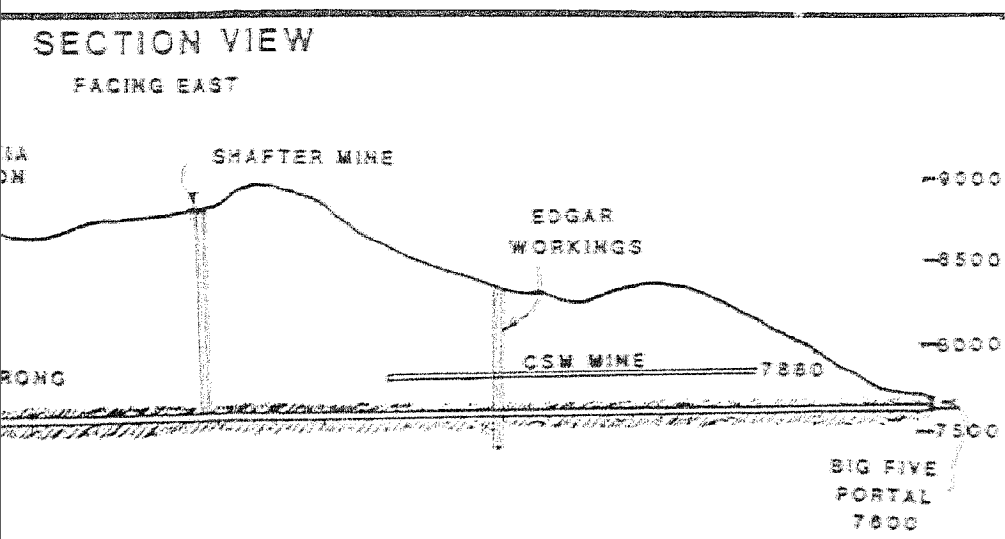
The Edgar Mine is the probable source of mine discharge out the Big Five portal. This assumption is based on observations of the CSM mine staff in the Edgar stope areas on the level of the CSM mine. The CSM staff reported that upon a recent inspection trip into the Edgar workings, flowing water was encountered as soon as the Edgar vein was reached. They did not note the direction or apparent source of the flow. The CSM staff was able to reach a point perhaps several hundred feet short of the main Edgar shaft in Hukill Gulch.

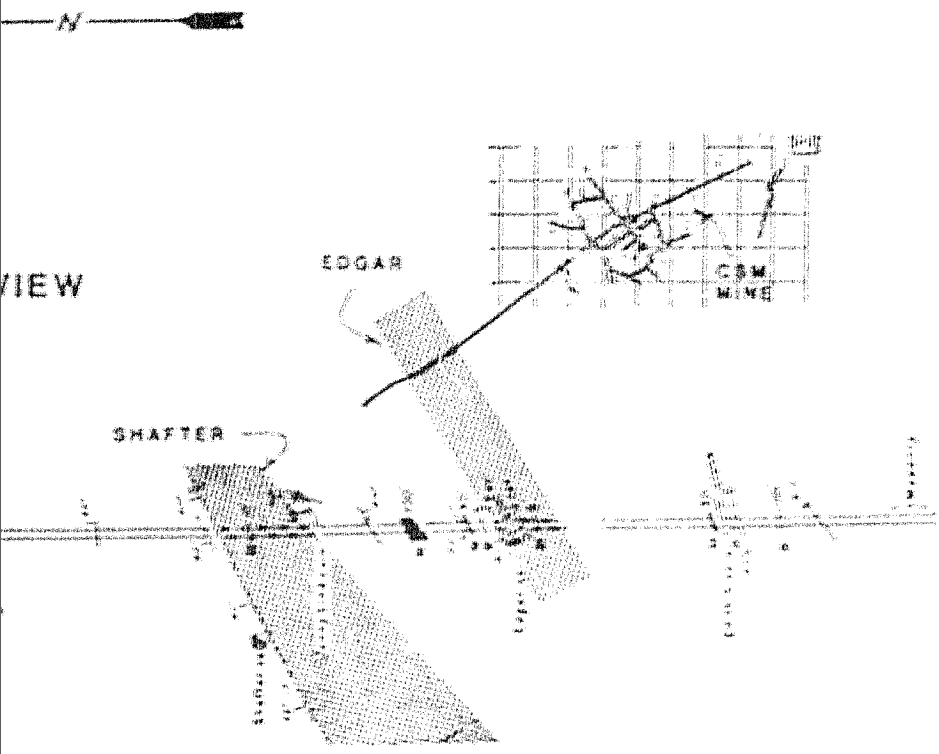
The CSM Mine is maintained in excellent condition year-around by CSM students and staff.

No mine map or inspection data were available for the Shafter Mine or the Unknown Mine in Virginia Canyon.

### 8.1.6 ARGO TUNNEL

The Argo Tunnel, also known as the Newhouse Tunnel, is located north of Clear Creek at an elevation of 7,550 feet, northeast of the central business district of Idaho Springs, Clear Creek County, Colorado. A plan view of the Argo Tunnel portal is shown on Figure 8-13. The 4.16-mile tunnel, which connects with a number of lateral mine workings (Figure 8-14), was driven during the period from 1893 through 1910 on a bearing slightly west of north to a point west of Central City. The Argo Tunnel was used for drainage and transporting ore and waste rock to the old Argo



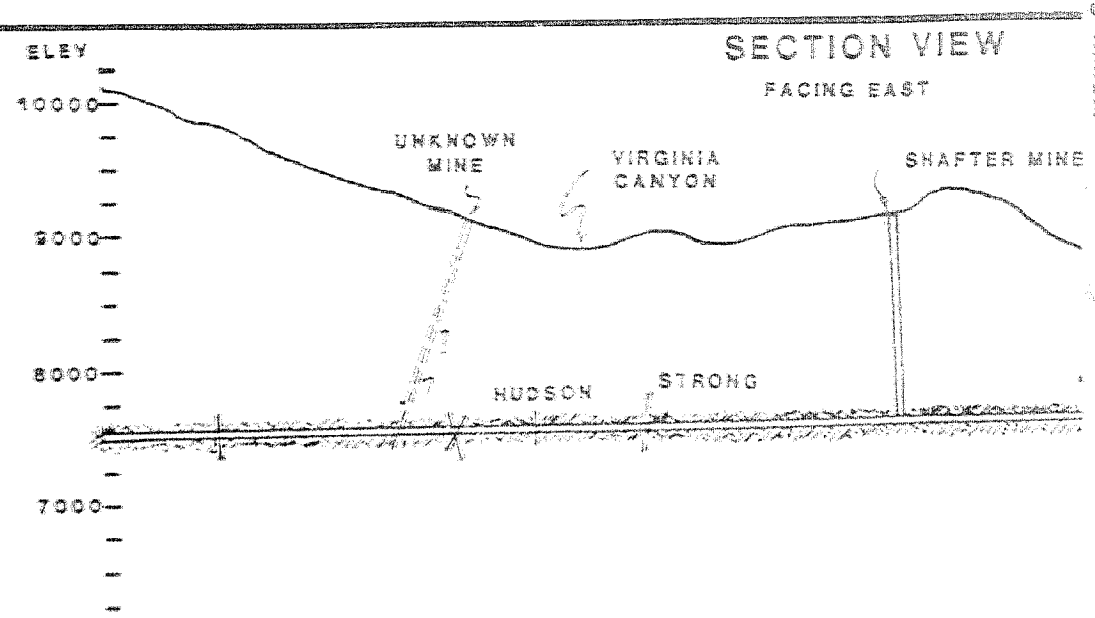

Source: Gormley Consultants, Inc., 1988

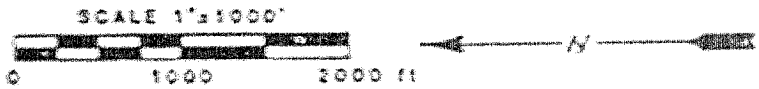
CLEAR CREEK/CENTRAL CITY RI/FS

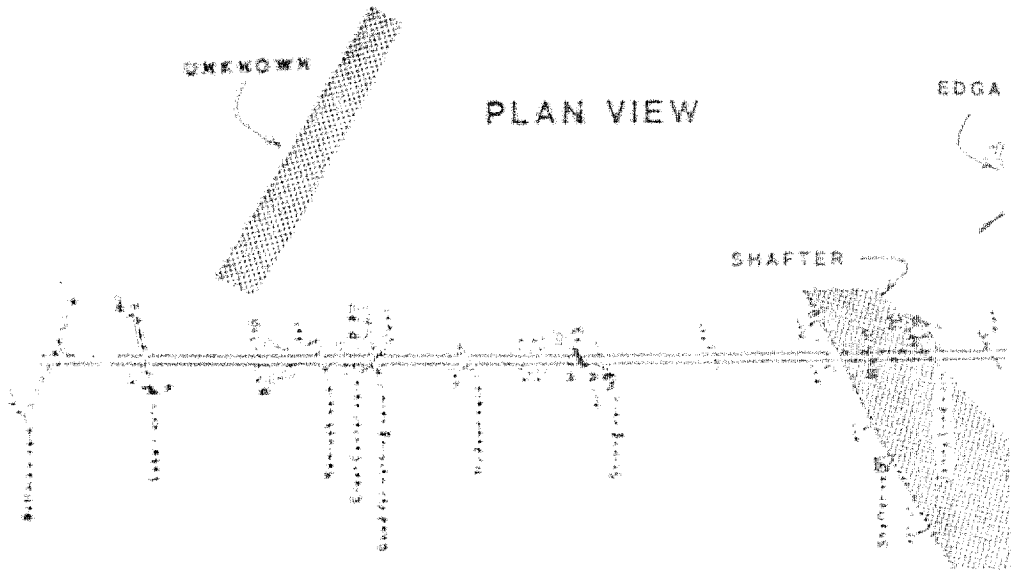
SECTION & PLAN VIEWS-BIG FIVE
TUNNEL & CONNECTED MINES
IDAHO SPRINGS, COLORADO

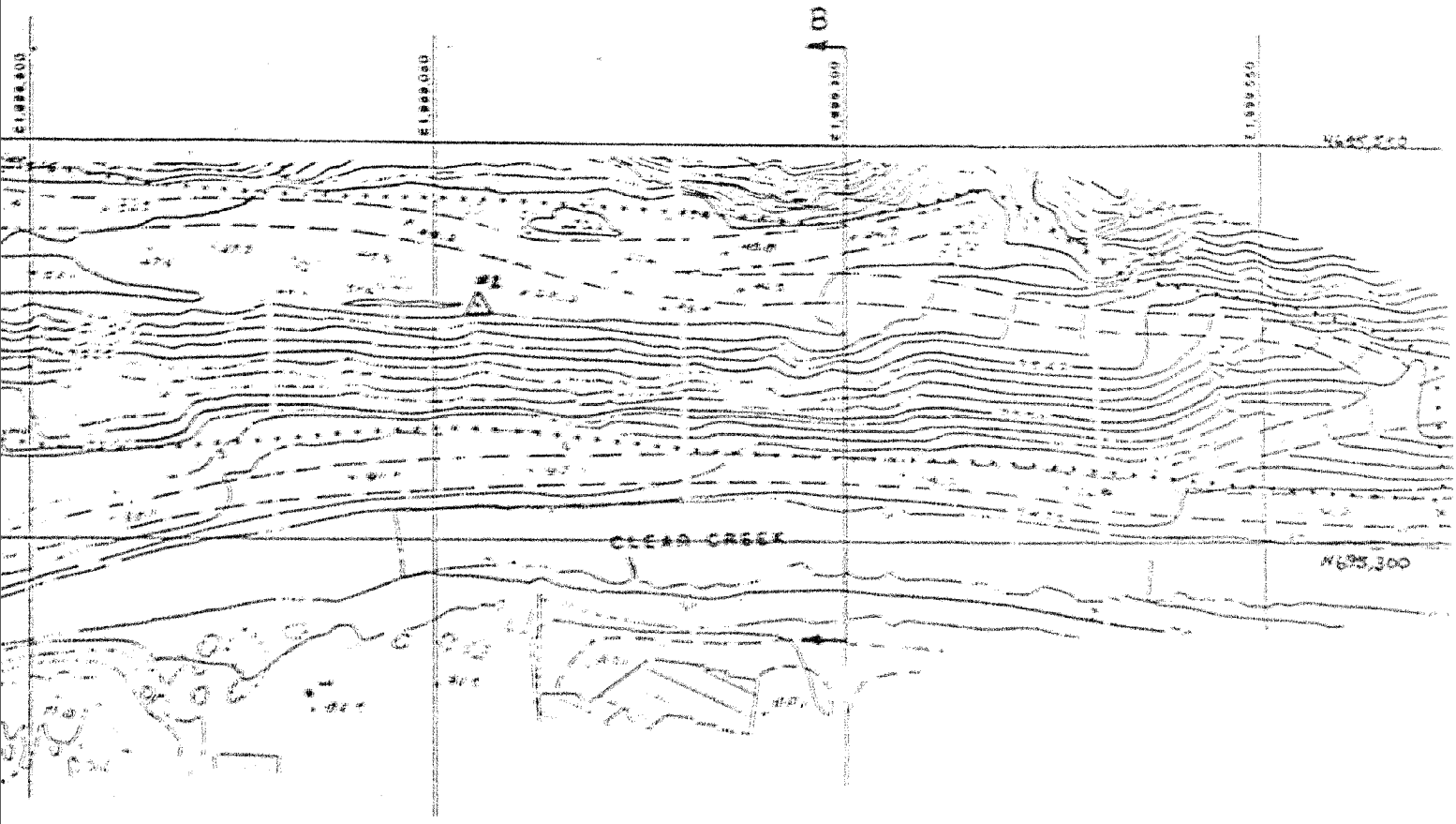
CAMP DRESSER & MCKEE INC.
CDM

5-12


SECTION VIEW
FACING EAST
ELEV
10000
9000
8000
7000
UNKNOWN MINE
VIRGINIA CANYON
SHAFTER MINE
HUDSON
STRONG


SCALE 1"=1000'
0
1000
2000 ft
N


PLAN VIEW
UNKNOWN
EDGA
SHAFTER




Source: Gormley Consultants, Inc., 1988

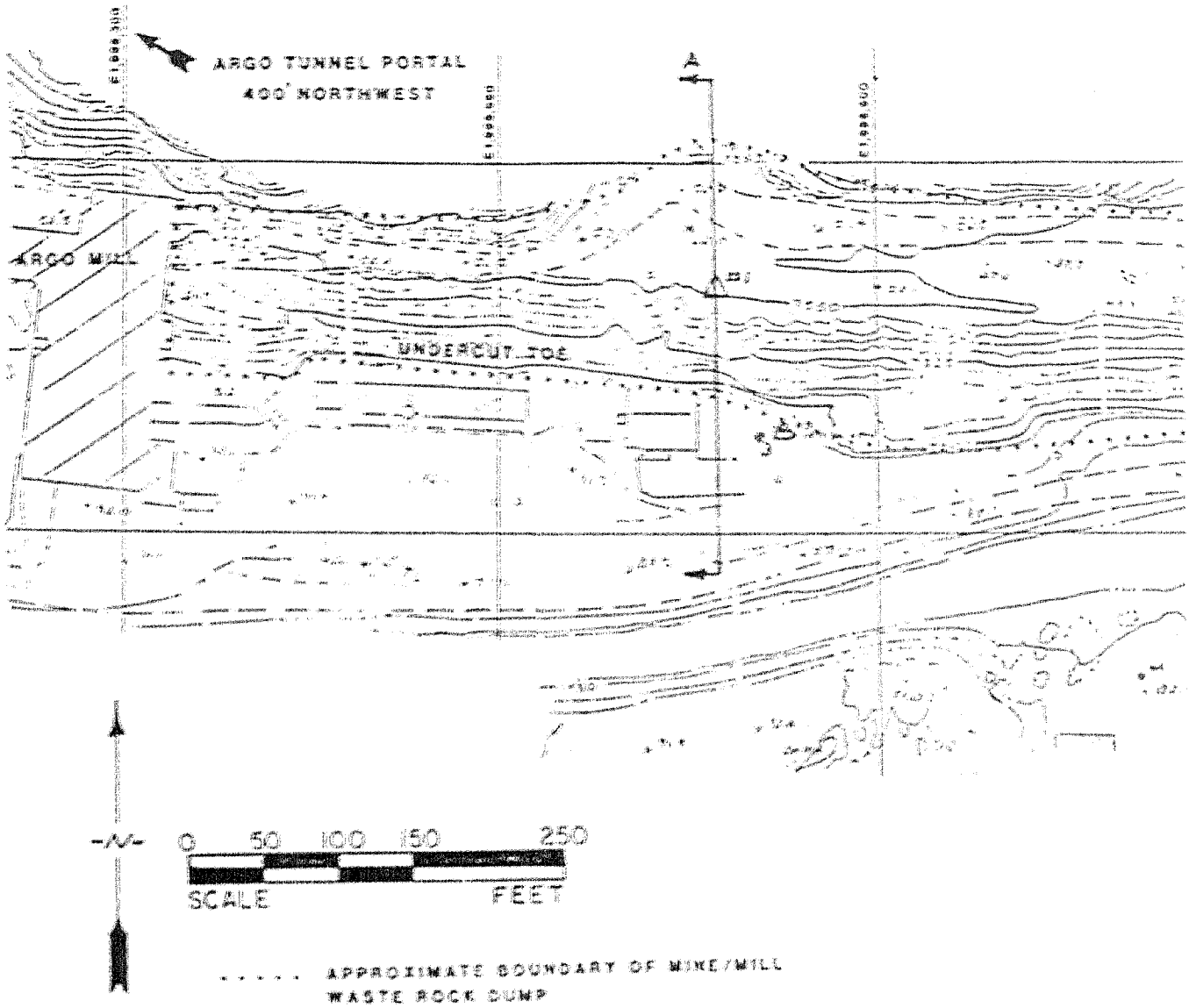
CLEAR CREEK/CENTRAL CITY RIFFO

PLAN VIEW
ARGO WASTE ROCK DUMP

CAMP DRESSER & MCKEE INC.

CDM

8-13


ARGO TUNNEL PORTAL
400' NORTHWEST
A
ARGO MILL
UNDERCUT TOE
B
0 50 100 150 250
SCALE FEET
APPROXIMATE BOUNDARY OF MINE/MILL
WASTE ROCK DUMP

# NOTICE

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PLEASE SEE ORIGINAL,
TITLED [illegible]

AND
NUMBERED 31171

Mill. Currently, the Tunnel discharges approximately 0.4 cfs of mine water into Clear Creek. Water flows out the portal, down a waste rock channel in front of the portal to eventually discharge into Clear Creek. The Argo Mill is located east of Argo portal. A 1,500-ft long waste rock dump is located east of the mill.

The Argo Tunnel portal is a concrete structure for approximately three feet, anchored into pre-cambrian age granite pegmatite. Access to the tunnel is prevented by the running water and an unlocked metal mesh gate. The tunnel is known to be open for a least 100 feet which can be observed from the portal. Mr. Norman Blake reported that he knew of several individuals who, in the mid-1950's, journeyed approximately 8,000 feet into the tunnel back to a point where the Gem vein intersects the tunnel. The party of individuals reportedly used inner tubes and hip boots in the endeavor. The conditions they encountered included many minor roof falls that were easily traversed and a major obstruction at the 8,000-ft point which prevented their going further.

The tunnel cross-section is 12 feet by 12 feet for the first 13,177 feet, then 9.5 feet by 6 feet to the furthest advance. The more prominent veins cut by the Argo Tunnel and their distances from the portal are as follows:

| Mine | Distance (ft) |
|---|---|
| Gem | 7,860 |
| Sun and Moon | 9,015 |
| Frontenac-Adwuddell | 11,210 |
| Saratoga | 15,080 |
| Old Town | 15,080 |
| Calhoun | 16,506 |
| Mammoth | 17,370 |
| California | 18,362 |
| Kansas-Burroughs | 19,400 |
| Foco | 20,370 |
| Price | 20,980 |
| Dunnell | 21,500 |

Records indicate that not all the mines associated with the veins listed above were directly connected to the Argo Tunnel. The mines known to be connected are as follows:

- Gem, connected approximately 200 feet west of Gem shaft
- Sun and Moon, connected by winze from 12th level
- Saratoga, connected by 1,000-ft lateral at 1,300 feet below No. 2 shaft
- Old Town, connected via a 14,306-ft lateral drift
- California, indirectly connected via a crosscut on the 1,000-ft level to the 900-ft level of the Kansas which is, in turn, connected by a raise driven from the Argo (see below).
- Kansas-Burroughs, connected by a lateral and raise that accidentally reached the flooded Kansas workings in 1942. Four miners were killed and the tunnel was partly filled with old stope material; the Argo Tunnel has not operated since.
- Price, connected by a 200-ft lateral west on the 1,900-ft level
- Gunnell, connected by a winze from the 1,100-ft level

The above mines, in most cases, have several shafts and are interconnected to other workings nearby. For example, the Gem Mine is connected to the Freighter's Friend Mine which, in turn, is connected to the Franklin mine, an operation north of Idaho Springs which is active and currently sinking a shaft. In addition, the Gem is also connected to the Seaton and Tropic mines through the Tropic Tunnel. For the purposes of this discussion of the Argo Tunnel, related mines, their shafts, interconnecting drifts, cross-cuts, raises, and winzes will be identified by the major vein systems that the Argo Tunnel intersected.

The mines connected to the Argo Tunnel listed above have the following remedial alternative design data:

| Mine | No. of Shafts | Stoped Outcrop (ft) | Lowest Collar Elevation |
|---|---|---|---|
| Gem | 15 | 1,400 | 8,575 |
| Sun and Moon | 6 | 1,400 | 9,100 |
| Saratoga | 4 | 3,000 | 8,825 |
| Old Town | 9 | 1,000 | 9,080 |
| California | 8 | 1,500 | 9,400 |
| Kansas-Burroughs | 1 | 2,000 | 9,050 |
| Prize/Robert | 5 | 1,300 | 9,000 |
| Gunnell | 4 | 2,600 | 8,800 |
| Totals | 52 | 19,400 | (8,575 Lowest) |

## 8.2 GEOTECHNICAL RESULTS - TAILINGS AND WASTE ROCK PILES

The results of the geotechnical investigations of the stability of the tailings and waste rock piles adjacent to the mine portals is reviewed in this section. The identification and location of boreholes has previously been shown on plan view maps in Section 8.1.

Samples of materials obtained during the subsurface investigations were subjected to laboratory testing for the purpose of characterizing their engineering properties. The engineering properties determined from the laboratory testing were subsequently used in the slope stability analysis for the existing tailings and waste rock piles. In order to perform the stability analysis and evaluate remedial modifications, the following properties were defined:

- Grain size characterization
- Water content
- Unit weights
- Atterberg Limits
- Angle of internal friction
- Cohesion

The number and types of laboratory tests performed and the locations from which the tested samples were obtained were determined so as to adequately characterize the representative material types at each site. Strength testing included the performance of both consolidated-undrained (CU) and consolidated-drained (CD) direct shear tests with the results being utilized to define total stress and effective stress shear strength properties. All tests were performed in accordance with applicable ASTM specifications and material classifications were completed in accordance with the most recent requirements of ASTM D2487. The laboratory testing was performed by STS, Inc. and Empire Laboratories, Inc.

Establishment of the potential for failure of the waste area and any stabilization alternatives considered requires defining safety factors. The safety factor is an index of a slope's stability with respect to a sudden failure. In most general terms, this may be defined as the ratio of the potential resisting forces to the forces tending to cause movement. Thus, a slope which is on the verge of failure has a safety factor (SF) of 1.0, not zero. Based on accepted engineering practice and considering the assumed homogeneous nature of subsurface materials, an acceptable SF of 1.3 for static loads and a SF of 1.0 for dynamic loads were selected for slope stability evaluation purposes.

### 8.2.1 GREGORY INCLINE

This site is currently occupied by approximately 14,000 cubic yards (CY) of mill tailings from an unknown source underlain by approximately 17,000 CY of mine waste rock, resulting from the driving of the Gregory Incline. The mine waste rock is supported along the local reach of North Clear Creek by timber crib structures that are estimated to be approximately 100 years old. These cribs support stratified waste rock and mill tailings that rise approximately 26 feet above the level of North Clear Creek. The stability

of the crib structure is marginal. Parts of the structure have already failed, dumping waste rock into North Clear Creek. Future slope failures will result in tailings/waste rock entering the stream.

A summary of the laboratory test results is provided in Table B-1. The laboratory test analyses indicate that the mine tailings possess widely varying properties and consist of very loose to medium density silty sands (SM) and silts (ML) and soft to stiff lean clays (CL); the waste rock consists of loose to very dense well graded sands with silt (SW-SM), silty sands (SM), silty gravel (GM), and poorly graded gravel (GP-GM); and the alluvial sand and gravel zone is comprised of medium dense to very density silty gravel (GM) and well graded gravel with silt and sand (GW-GM).

The poor condition of the existing crib wall, the very loose and soft nature of the tailings and the potential contamination which could be caused by a slope stability failure of the waste area resulted in the requirement to assess the waste area stability and consider stabilization alternatives. The objective of performing stability analyses for the Gregory Incline was to assess the stability of the existing tailings/waste rock area.

The heterogeneous nature of the tailings required that a detailed evaluation of the tailing properties be conducted and stability analyses be performed for a range of strength properties representative of the tailings. The discussions which follow address soil properties used for analysis purposes, stability analysis methods, the stability model, and the results of the analyses.

Because of the presence of silts and clays in portions of the tailings as well as the presence of coarse to fine sands and gravels, both total stress and effective stress shear strength properties were used to analyze the stability of the tailings. Because of the free draining nature of the waste rock and the sand and gravel, the shear strength properties can be

TABLE B-1
SUMMARY OF MATERIAL PROPERTIES
GUILLORY INCLINE

| Boring | Sample Type/No | ASTM D2487 Symbol | Material Type/ Sample Interval | WC% | D (PCF) | W (PCF) | LL (%) | PL (%) | PI (%) | % -#200 | Ø DEGRS | C (PSF) | Strength Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | ST/2 | SM | Tailings Silty sand (5'-6') | 9.3 | 108.2 | 118.2 | 18 | 18 | 0 | 38.9 | 31,$Ø_T$ | Ø,$C_T$ | CU |
| 6 | SS/4 | ML | Tailings Sandy silt (10'-12') | 24.7 | — | — | 18 | 16 | 2 | 60.8 | — | — | — |
| 6 | ST/5 SS/6 | CL | Tailings Silty clay (15'-18.5') | 44.0 | 79.0 | 113.8 | 37 | 22 | 15 | 77.2 | 17.4,$Ø_T$ | 300,$C_T$ | CU |
| 6 | SS/7 | SM | Tailings Silty sand (21.5'-22') | 19.4 | — | — | NON PLASTIC | | | 24.1 | — | — | — |
| 6 | SS/8 | SW-SM | Waste Rock Well-graded sand w/silt (25'-27') | 15.9 | — | — | NON PLASTIC | | | 11.6 | — | — | — |
| 8 | SS/7 | GM | Waste Rock Silty gravel (21.6'-22') | 10.1 | — | — | NON PLASTIC | | | 15.5 | — | — | — |
| 9 | SS/3 | SM | Tailings Silty sand (10'-12') | 4.3 | — | — | NON PLASTIC | | | 16.7 | — | — | — |
| 9 | SS/4 | GP-GM | Waste Rock Poorly graded gravel (16'-16.7') | 9.2 | — | — | NON PLASTIC | | | 9.1 | — | — | — |
| 9 | ST/6 | GM | Sand & Gravel Silty gravel (20.4'-22.4') | 8.8 | — | — | 34 | 24 | 10 | 14.7 | — | — | — |
| 9 | ST/7 | SM | Waste Rock Silty sand (25'-26') | 23.0 | 91.8 | 112.9 | NON PLASTIC | | | 19.7 | 31,Ø | Ø,C | CD |

TABLE B-1
SUMMARY OF MATERIAL PROPERTIES
GRIFFIN INCLINE

| Boring | Sample Type/No | ASTM D2487 Symbol | Material Type/ Sample Interval | WC% | D (PCF) | U (PCF) | LL (%) | PL (%) | PI (%) | % -#200 | Φ DEGS | C (PSF) | Strength Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | SS/11 | GW-GM | Sand & Gravel Well-graded gravel (40'-41.7') | 7.8 | — | — | NON PLASTIC | | | 6.6 | — | — | — |

See Table B-1A for explanation of terms.

TABLE B-1A

EXPLANATION OF ABBREVIATIONS

| | |
|---|---|
| WC% | WATER CONTENT, PERCENT. All natural soils contain at least a trace of moisture and soil behavior is affected by the amount of moisture. Water content is thus an important index property. Water content, for the purposes of this report, is expressed on a weight percent basis, water weight divided by the dry soil weight. |
| D | DRY UNIT WEIGHT, POUNDS PER CUBIC FOOT. This is the weight of dry solids in a cubic foot of undisturbed material. The value is used with the density of the dry solid to calculate void ratio and in other soil property index calculations. |
| W | WET UNIT WEIGHT, POUNDS PER CUBIC FOOT. This is the weight of solids plus entrained natural moisture in a cubic foot of undisturbed material. This parameter is used in a slope stability analyses. |
| LL | ATTERBERG LIQUID LIMIT, PERCENT. The Atterberg tests develop moisture-consistency relationships for samples. Consistency denotes the degree of firmness of the soil and is indicated by such terms as soft, firm and hard. As a soil's consistency changes, its engineering properties change also. The Atterberg liquid limit is the percent moisture at which a soil drying from a liquid state of consistency reaches a point where it ceases to behave as a liquid and begins to behave as a plastic. |
| PL | ATTERBERG PLASTIC LIMIT, PERCENT. The Atterberg Plastic limit is the percent moisture at which a soil drying from a plastic state of consistency reaches a point where it ceases to behave as plastic and begins to behave as a semi-solid. |
| PI | PLASTICITY INDEX, PERCENT. This value is the difference between the Atterberg Liquid and Plastic Limits. |
| %-#200 | PERCENT MINUS 200 MESH. This value is determined through grain size distribution tests. A soil's gradation relates directly to overall strength and stability, e.g., shearing resistance and bearing capacity, resistance to erosion or scour and compactibility. Generally, a soil's overall strength diminishes with increasing amounts of minus 200 mesh material. |
| Ø | ANGLE OF INTERNAL FRICTION, DEGREES. This parameter relates to the shear strength of a soil. It is used in a slope stability analysis. A soil's strength is dependent on loading conditions and the angle of internal friction value and/or cohesion. |

TABLE 8-1A (Continued)

EXPLANATION OF ABBREVIATIONS

C — COHESION, POUNDS PER SQUARE FOOT. Cohesion is a soil strength parameter directly related to the amount of clay material present. It is a measure of a form of shearing strength which unlike the angle of internal friction, is somewhat independent of loading conditions. In granular soils, cohesion is usually zero. This parameter is utilized in a slope stability analysis.

TEST

CU — CONSOLIDATED UNDRAINED. The soil sample's direct shear strength is measured under the condition whereby ambient moisture is kept constant throughout the test. The loading condition during the test attempts to approximate final in situ conditions.

CD — CONSOLIDATED DRAINED. The soil sample's direct shear strength is measured under the condition whereby ambient moisture is allowed to escape during the test. The loading condition during the test attempts to approximate final in situ conditions.

$\phi_T$, $C_T$ — Total stress shear strength parameters indicative of short term, post construction soil conditions.

$\phi$, C — Effect stress shear strength parameter indicative of long term soil conditions.

--- — Data was not measured.

SS — Split spoon sampling method was used to gather the sample.

ST — Shelby tube sampling method was used to gather the sample.

utilized for either effective or total stress stability analysis. The shear strength properties incorporated into the stability analysis are summarized in Table 8-1.

Stability analyses for the Gregory Incline were performed by using the following process:

- The field and laboratory test data were evaluated to define appropriate soil properties for each material type.
- Preliminary stability analyses were performed using the above-derived soil properties for known failure surfaces within the site area and the soil properties were adjusted to provide safety factors consistent with the site observations (this process essentially resulted in a slight reduction of strength properties for the tailings).
- Slope stability analysis were performed for the existing waste pile conditions to assess the potential for slope failures.

Stability analyses were performed by using the following techniques:

- Spencer Method (Spencer 1967).
- Taylor's Friction Circle Method (Taylor 1948).

Both hand calculations and computer simulations were used. Hand calculations were performed using Taylor's Friction Circle Method and the T-Slope computer code supplied by TAGA Engineering Software Services was used to perform computer simulated slope stability analyses. Analyses were performed for both assumed circular arc and wedge-shaped failure planes.

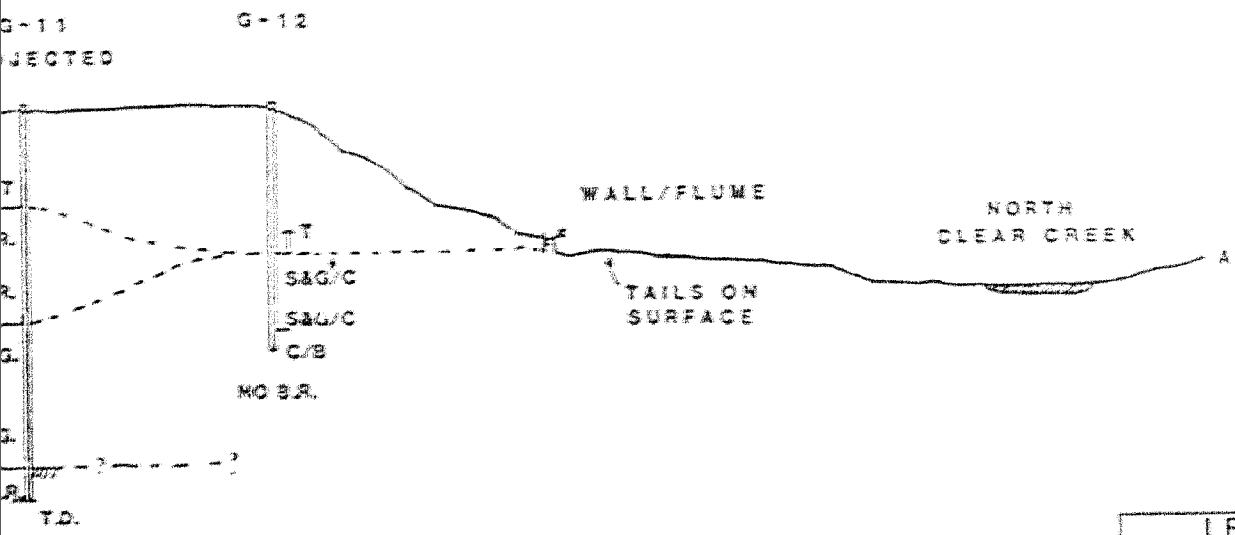
Stability analyses included both effective stress and total stress analyses. The effective stress analyses represent long-term conditions whereas the total stress analyses are representative of short-term and end of construction conditions. Stability analyses were also performed for earthquake loadings by assuming a horizontal ground acceleration of 0.1 g.

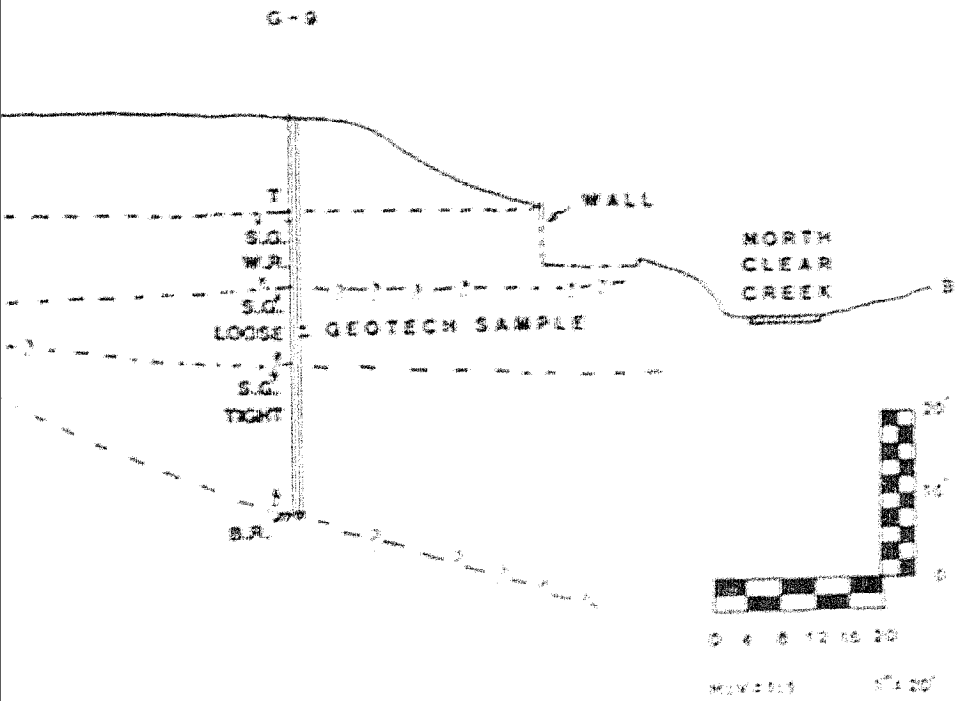
Because of the relatively wide flood plain at the site and the nominal rise in North Clear Creek expected as a result of flooding, rapid drawdown analyses were not considered necessary.

The stability model was defined by initially establishing the critical cross section through the subsurface materials. Figures 8-15, 8-16, 8-17a and 8-17b illustrate Lateral Sections A-B and C at Gregory Incline. Locations of the sections are provided in Figure 8-2. Section C-C', as shown in Figure 8-16, was selected as the critical section based on the thickness of tailings, the overall height of the waste pile and the relatively steep nature of the existing slope (1.7H:1V). A stability analysis was performed for the existing waste pile configuration at Section C-C'. Two circular arc failure planes were evaluated, as shown in Figure 8-16 to define the potential for the failure of the existing waste pile.

To evaluate a modified slope configuration, four circular arc failure planes and two wedge-shaped failure planes were analyzed for a 2.5H:1V slope inclination as shown in Figure 8-18. Two of the circular arc failure planes were assumed to assess the stability of the shallow surficial tailings, one circular arc failure plan was used to evaluate the potential for a toe failure, and one circular arc was used to assess the potential for a deep seated toe failure. One wedge failure surface was assumed to pass completely through tailings materials and one wedge failure surface was assumed to pass near bedrock and to exist near the slope toe.

Results of the preliminary stability analysis performed for the purpose of refining the strength for the subsurface materials showed the SF to be greater than 1.0 with use of the angles of internal friction and cohesion values shown in Table 8-1 and the failure surface from Section B-B' superimposed on Section D-D'. In order to account for the observed site failure or near failure conditions, it was necessary to revise the shear strength properties for the tailings from the laboratory measured values of $\phi_{T} = 17.4$ degrees and $C_{T} = 360$ pounds per square foot (psf) to $\phi_{T} = 17$ degrees and $C_{T} = 500$ psf. No adjustment was made in the waste rock total




## LEGEND

| | |
|---|---|
| T | TAILINGS |
| S-G | SAND & GRAVEL |
| C | COBBLES |
| B | BOULDERS |
| BR | BED ROCK |
| WR | WASTE ROCK |
| E | CDM W L DATA |
| LC | LEVEL OF CREEK BED |
| SS | STREAM SEDIMENTS |
| TD | TOTAL DEPTH |

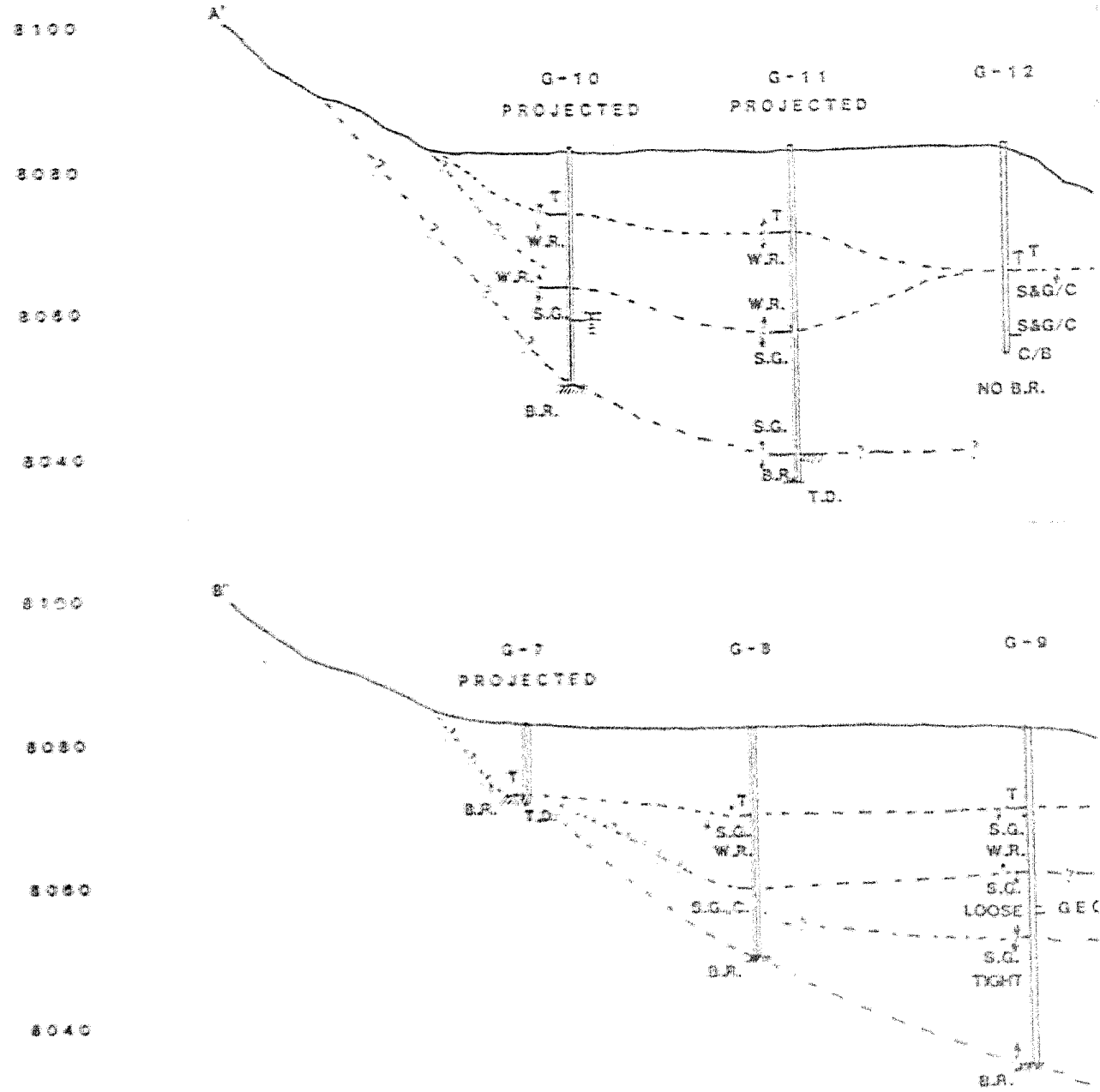
Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

LATERAL SECTIONS
GREGORY INCLINE

CDM

8-15


A'
8100
8080
8060
8040
G-10
PROJECTED
G-11
PROJECTED
G-12
T
W.R.
W.R.
S.G.
B.R.
T
W.R.
W.R.
S.G.
S.G.
B.R.
T.D.
T
S&G/C
S&G/C
C/B
NO B.R.
B'
8100
8080
8060
8040
G-7
PROJECTED
G-8
G-9
T
B.R.
T.D.
T
S.C.
W.R.
S.G.-C.
B.R.
T
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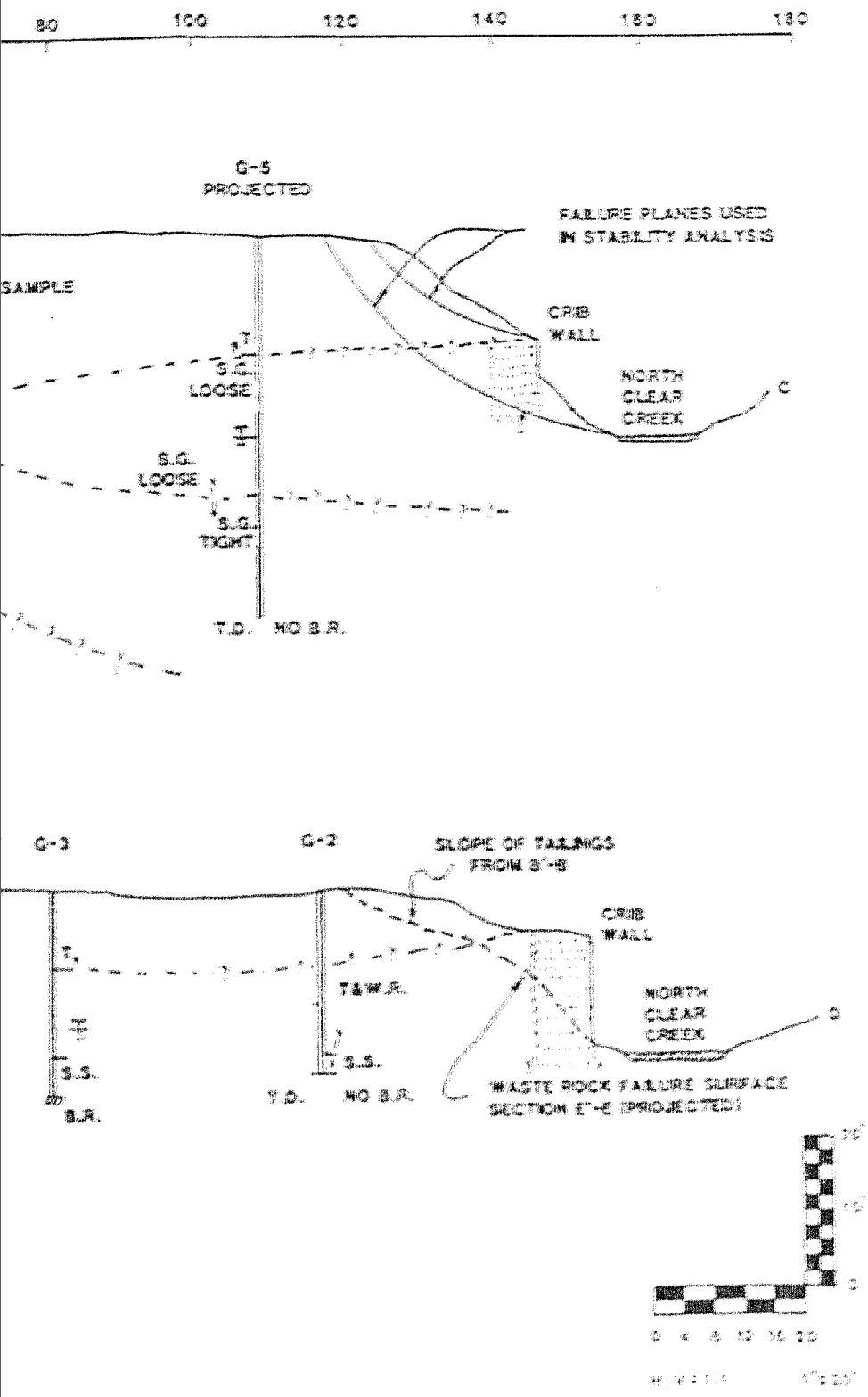
W.R.
S.C.
LOOSE
S.G.
TIGHT
B.R.




## LEGEND

| | |
|---|---|
| T | TAILINGS |
| S-G | SAND & GRAVEL |
| C | COBBLES |
| B | BOULDERS |
| BR | BED ROCK |
| WR | WASTE ROCK |
| Ξ | CDM W L DATA |
| LC | LEVEL OF CREEK BED |
| SS | STREAM SEDIMENTS |
| TD | TOTAL DEPTH |

Source: Dormley Consultants, Inc., 1986

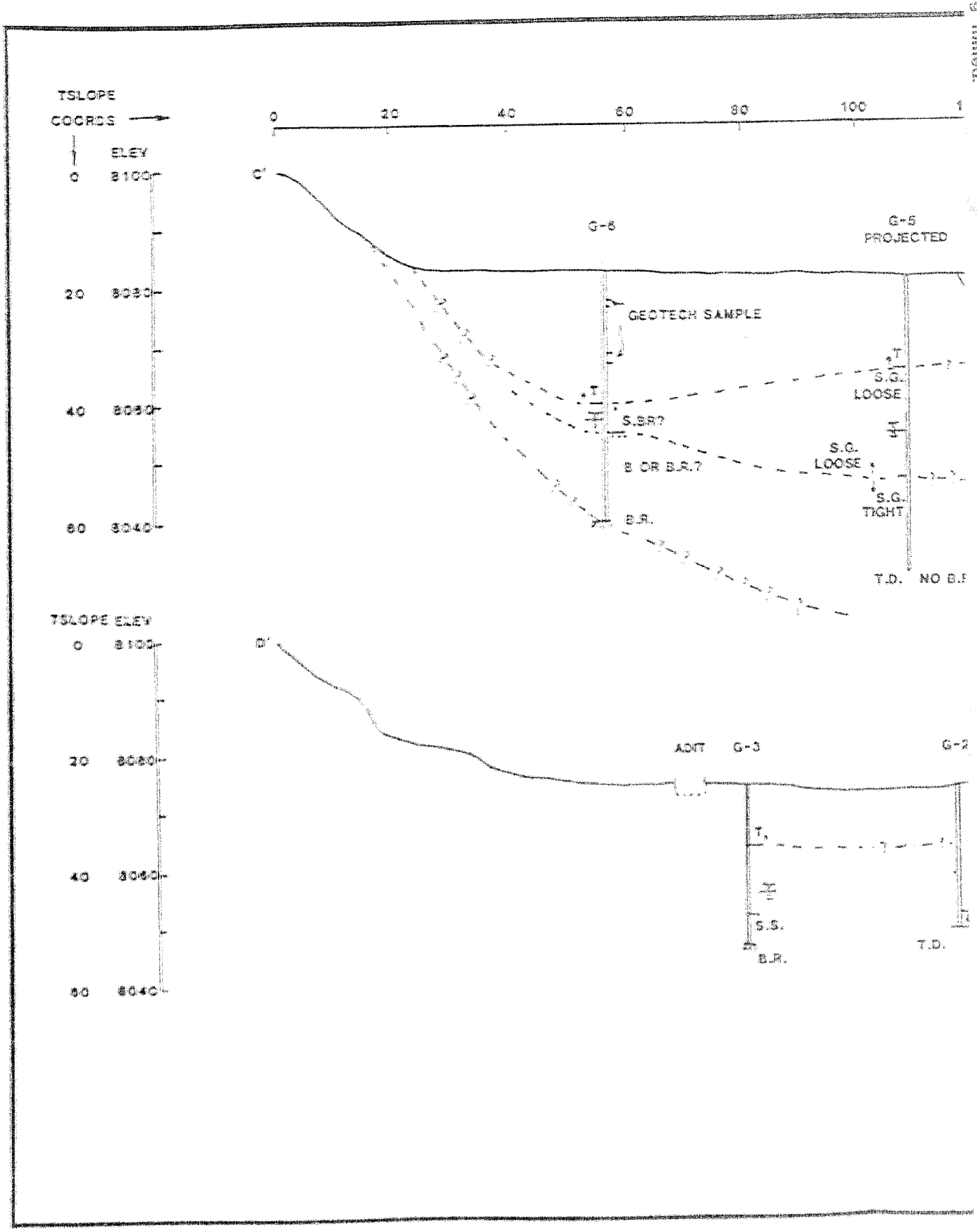
CLEAR CREEK/CENTRAL CITY RI/FS

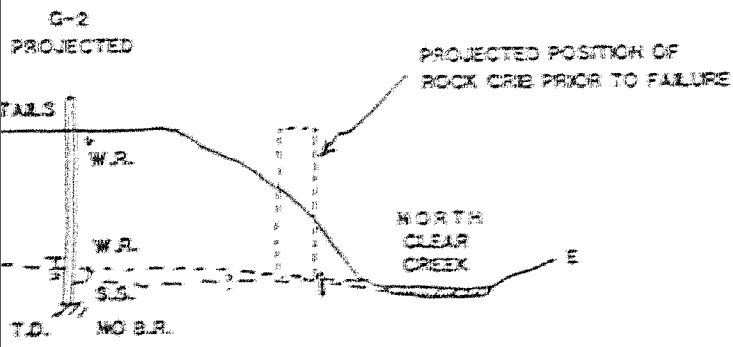
LATERAL SECTIONS
GREGORY INCLINE

CAMP DRESSER & MCKEE INC.

CDM

8-16

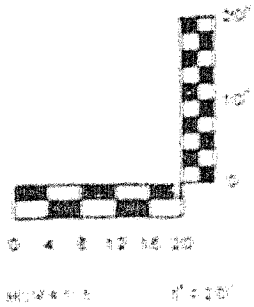

TSLOPE
COORDS
ELEV
0
20
40
60
80
100
C'
G-6
G-5
PROJECTED
GEOTECH SAMPLE
S.G.
LOOSE
S.S.?
B OR B.R.?
S.C.
LOOSE
S.G.
TIGHT
B.R.
T.D.
NO B.R
TSLOPE ELEV
D'
ADIT
G-3
G-2
S.S.
B.R.
T.D.




NO TAILINGS IN THIS SECTION
AS PER INSPECTION OF FIELD PHOTOS.

## LEGEND

| | |
|---|---|
| T | TAILINGS |
| S-G | SAND & GRAVEL |
| C | COBBLES |
| B | BOULDERS |
| BR | BED ROCK |
| WR | WASTE ROCK |
| E | CDM W.L. DATA |
| LC | LEVEL OF CREEK BED |
| SS | STREAM SEDIMENTS |
| TD | TOTAL DEPTH |



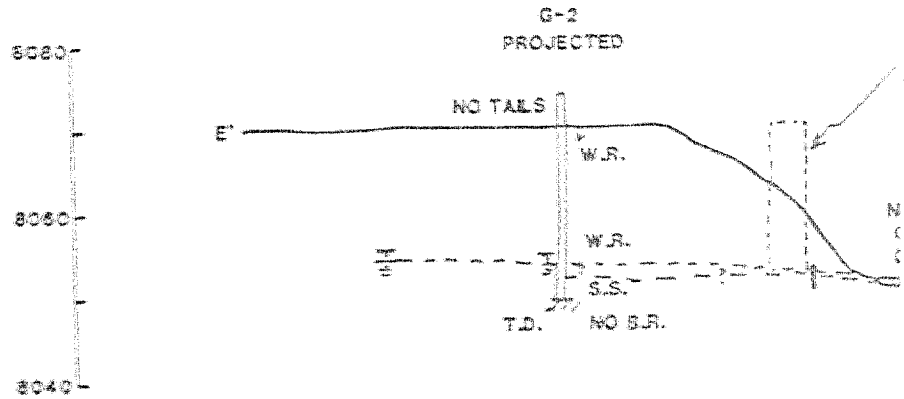

Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

LATERAL SECTIONS
GREGORY INCLINE

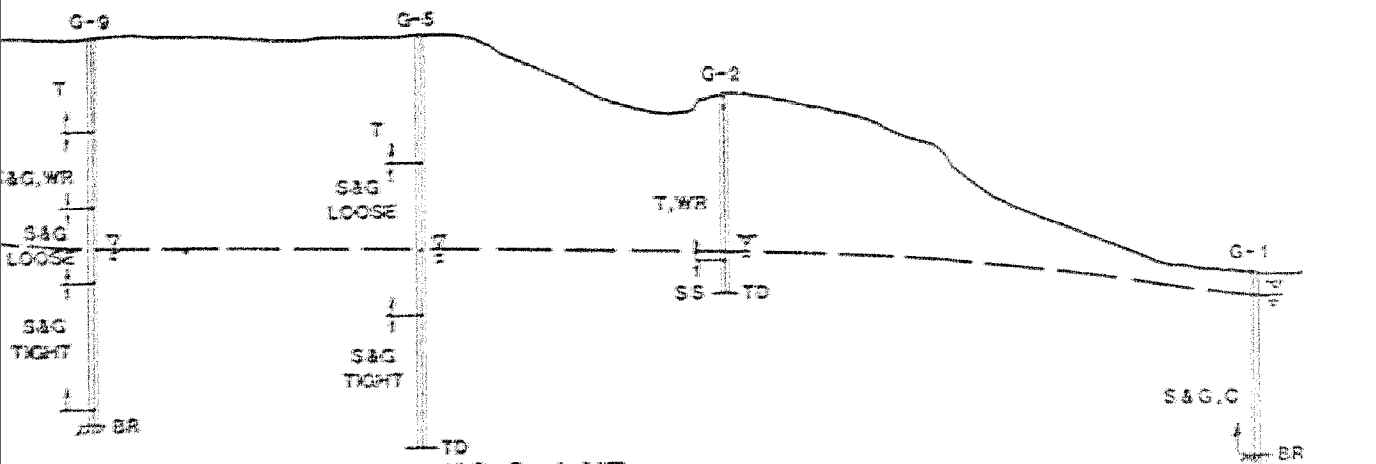
DAMES & MOORE
CDM

8-17b

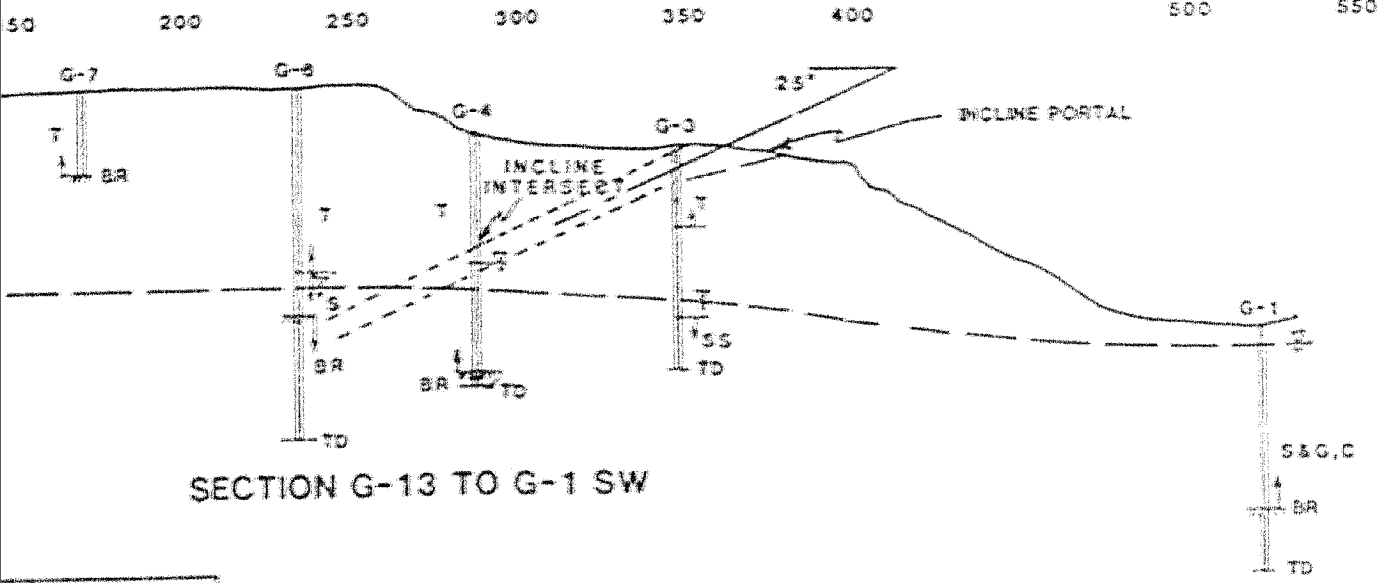



NOTE: NO TAILINGS IN THIS SECTION
AS PER INSPECTION OF FIELD PHOTOS.

| LEG |
|---|
| T TAILIN |
| S-G SAND |
| C COBBI |
| B BOULI |
| BR BED R |
| WR WAST |
| ≡ CDW |
| LC LEVEL CREE |
| SS STREA |
| TD TOTA |




SECTION G-13 TO G-1 NE




SECTION G-13 TO G-1 SW

EGEND

ROCK
TAL DEPTH
REATIC SURFACE
TER TABLE
ILINGS
AND & GRAVEL
ASTE ROCK
EAM SEDIMENTS
AND
OBBLES
OULDERS

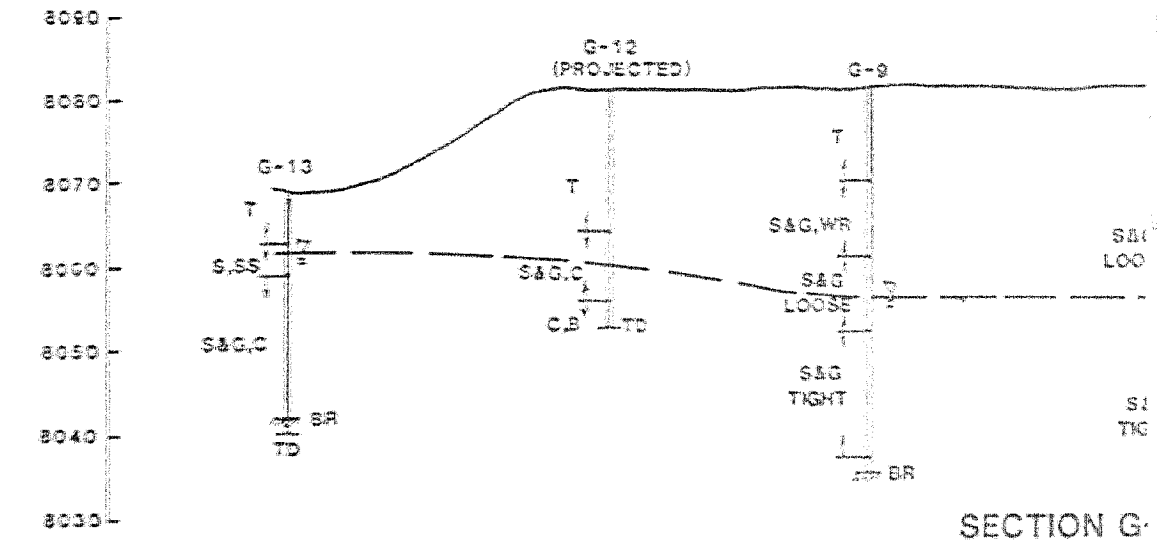
Source: Gormley Consultants, Inc., 1983

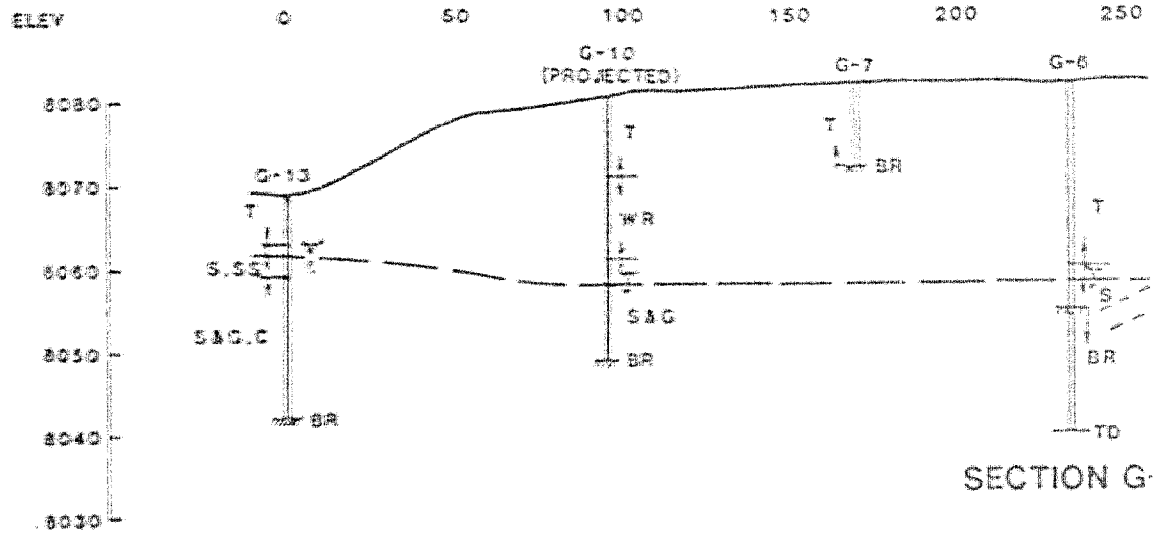
CLEAR CREEK/CENTRAL CITY RI/FS

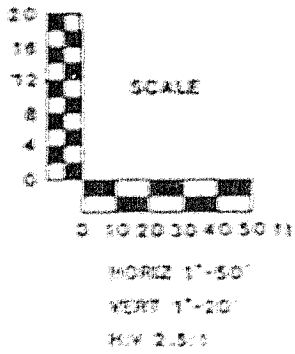
LONGITUDINAL SECTIONS
GREGORY INCLINE

CDM

8-175




## LEGEND

| | |
|---|---|
| BR | BED ROCK |
| TD | TOTAL DEPTH |
| | PHREATIC SURFACE |
| | WATER TABLE |
| T | TAILINGS |
| S&G | SAND & GRAVEL |
| WR | WASTE ROCK |
| SS | STREAM SEDIMENTS |
| S | SAND |
| C | COBBLES |
| B | BOULDERS |

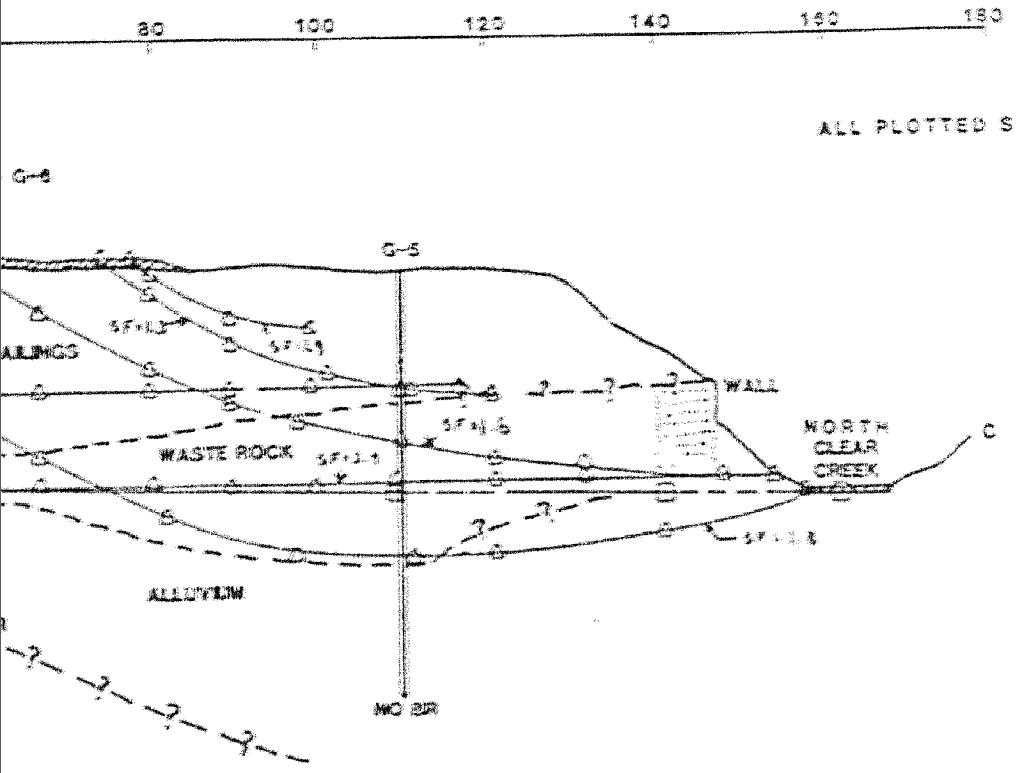
stress shear strength values of $\phi_T$ = 31 degrees and $C_T$ = 0 psf. This assumption is considered to be reasonable because of the coarse grained nature of the waste rock. Strength properties of the sand and gravel zones were assumed to be equivalent to the waste rock strength properties.

Slope stability analysis results for the existing waste pile at Section C-C' indicate that the existing waste pile is marginally stable (Figure 8-18). The minimum static safety factor of 1.3 occurs for the effective stress case and a relatively shallow circular failure surface. The remainder of the assumed failure surfaces produced static safety factors of 1.4 or greater as is indicated in Figure 8.18. These results suggest that a 2.5H:1.0V slope configuration similar to that shown should provide for a stable slope. Analysis results for an assumed earthquake loading of 0.1g indicate a minimum SF of about 1.0. A safety factor of 1.0 for dynamic loading is considered acceptable for this evaluation.

8.2.2 NATIONAL TUNNEL

The waste rock pile associated with the National Tunnel extends 450 feet along the base of the hillside from a point approximately 100 feet west of the portal to a point 350 feet east of the portal. The toe of the waste rock pile is at an elevation of 7,980 feet and the crest of the dump is generally at 8,040 feet, some 10 feet below the elevation of the National Tunnel portal. As depicted on Figure 8-5, the slope of the waste rock pile is generally 1.5H to 1V. The combined volume of mine and mill waste rock is approximately 27,000 cubic yards. The mill waste volume is estimated at approximately 13,000 CY and the waste rock volume at approximately 14,000. Because no borings were drilled through the tailings, the volume estimates are not precise and may actually approach 50,000 CY total volume.

The National Tunnel waste rock dump appears to contain a variety of materials from coarse (6-in. plus) size mine waste rock to a pyritic quartz stamp mill waste rock (minus 1/2-in.). The mine waste rock appears to have




ALL PLOTTED SAFETY FACTORS ARE LONG TERM.

SLOPE STABILITY

| MATERIAL | INPUT DATA $\gamma_d$ (PCF) | $\gamma_w$ (PCF) | LONG TERM $\bar{\phi}$ | $\bar{c}$ (PSF) | SHORT TERM $\phi_u$ | $c_u$ |
|---|---|---|---|---|---|---|
| TAILINGS | 108 | 118 | 17° | 50 | 0° | 500 |
| WASTE ROCK | 91.8 | 112.9 | 31° | 0 | 31° | 0 |
| ALLUVIUM | 114 | 125 | 31° | 0 | 31° | 0 |

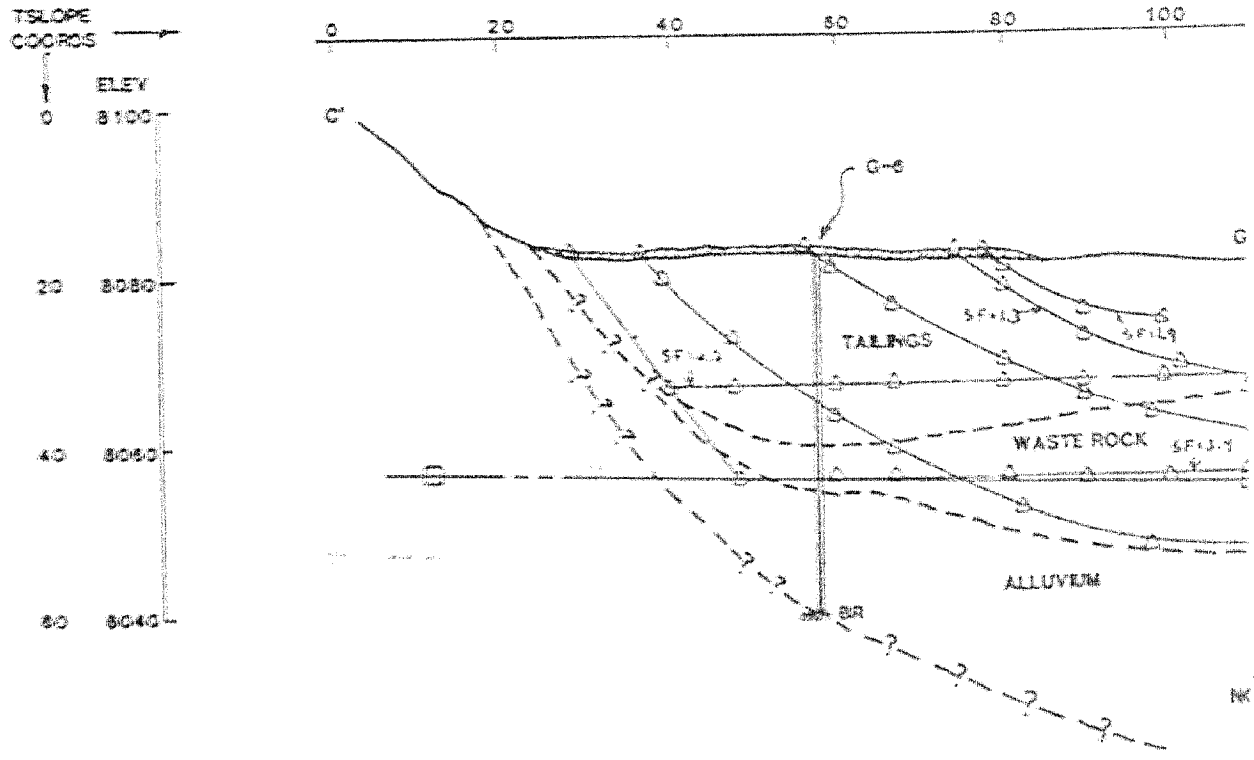
Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

FAILURE PLANES
GREGORY INCLINE

CAMP DRESSER & MCKEE INC.
CDM

8-18




## LEGEND

- WATER TABLE
- POINTS DEFINING FAILURE SURFACE
- TOPSOIL / SOIL CEMENT CAP
- BR BEDROCK

SLOP

| MATERIAL | γd (PCF) |
|---|---|
| TAILINGS | 108 |
| WASTE ROCK | 91.8 |
| ALLUVIUM | 114 |

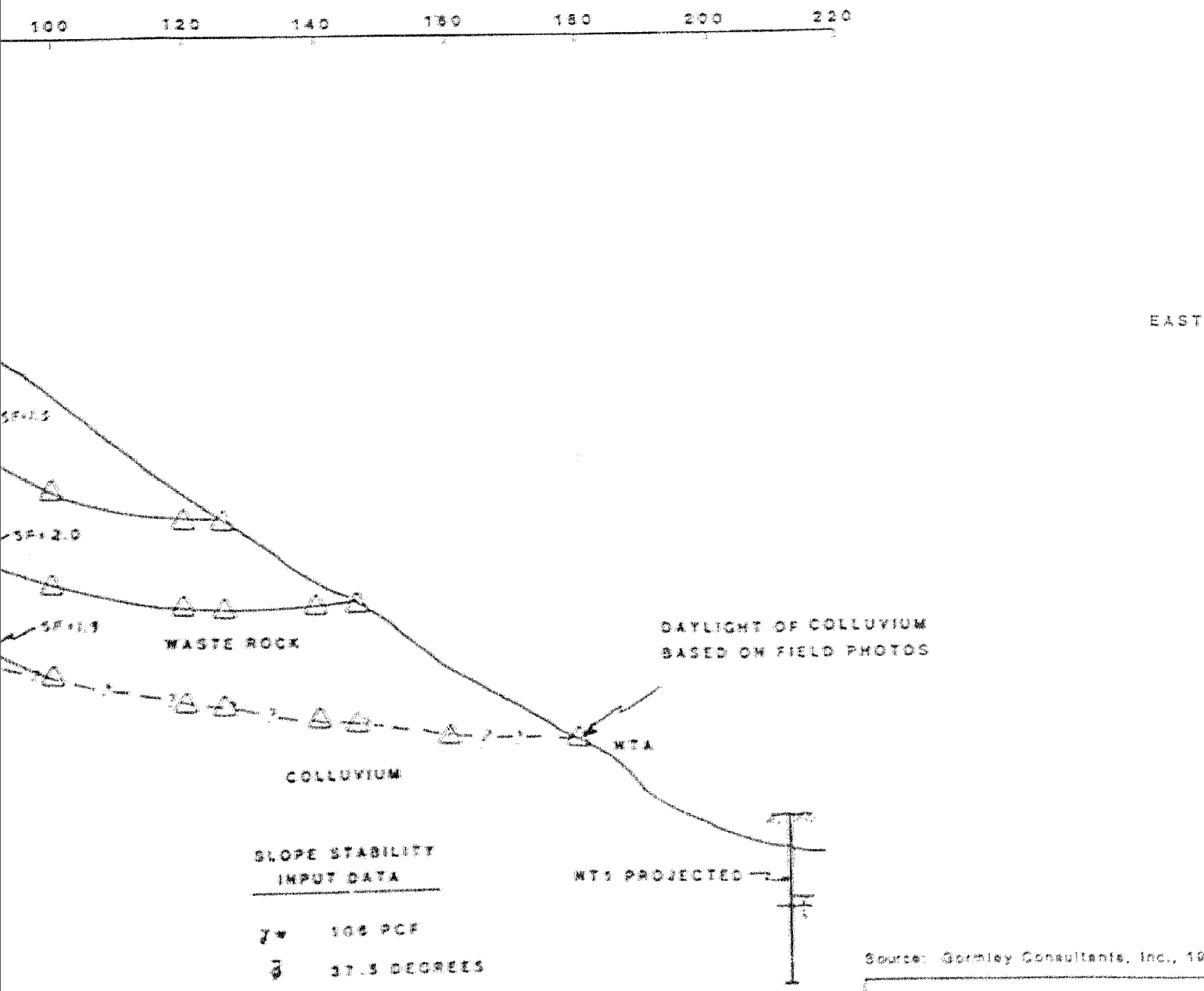
been placed to the east of the portal and the stamp mill waste rock appears to occupy the western portion of the dump. The stamp mill waste rock would be underlain by mine waste rock.

A single boring, designated NT-1, was located in the North Clear Creek floodplain near the toe of the waste rock dump, as shown on Figure 8-5. Figure 8-19 is a lateral section of section NTA (shown on Figure 8-5) and presents a subsurface profile based on the projection of the slope of the hillside above the waste rock pile to the level of the North Clear Creek floodplain. Since the single boring penetrated the phreatic surface, it was completed as a piezometer for the purposes of monitoring ground water levels and obtaining samples. It is likely that both colluvium and alluvium sand and gravel underlie the waste rock and overly bedrock which slopes downward in a northerly direction.

A summary of the laboratory test results is provided in Table 8-1. The laboratory test analyses of "California Sampler" materials indicates that the waste rock possesses a narrow range of properties and consists of loose to medium dense, well graded silty sands (SM) and silty gravel (GM). The angle of internal friction was measured at 37.5° and 49.9°, respectively, for the two waste rock samples and the waste rock showed no cohesion. The borehole materials showed that the colluvial/alluvial sand and gravel zone is comprised of medium dense, poorly graded gravel with silt and sand (GP-GM) and well graded gravel with silt and sand (GW-GM).

The close proximity of structures and the potential contamination which could be caused by a slope stability failure of the waste resulted in the requirement to assess the waste area stability and consider stabilization alternatives. The objectives of performing stability analyses for the National Tunnel waste rock dump were to:

- Assess the stability of the existing waste rock area.
- Evaluate the feasibility of stabilizing the existing waste pile by reshaping the pile, if required, to form a stable embankment.



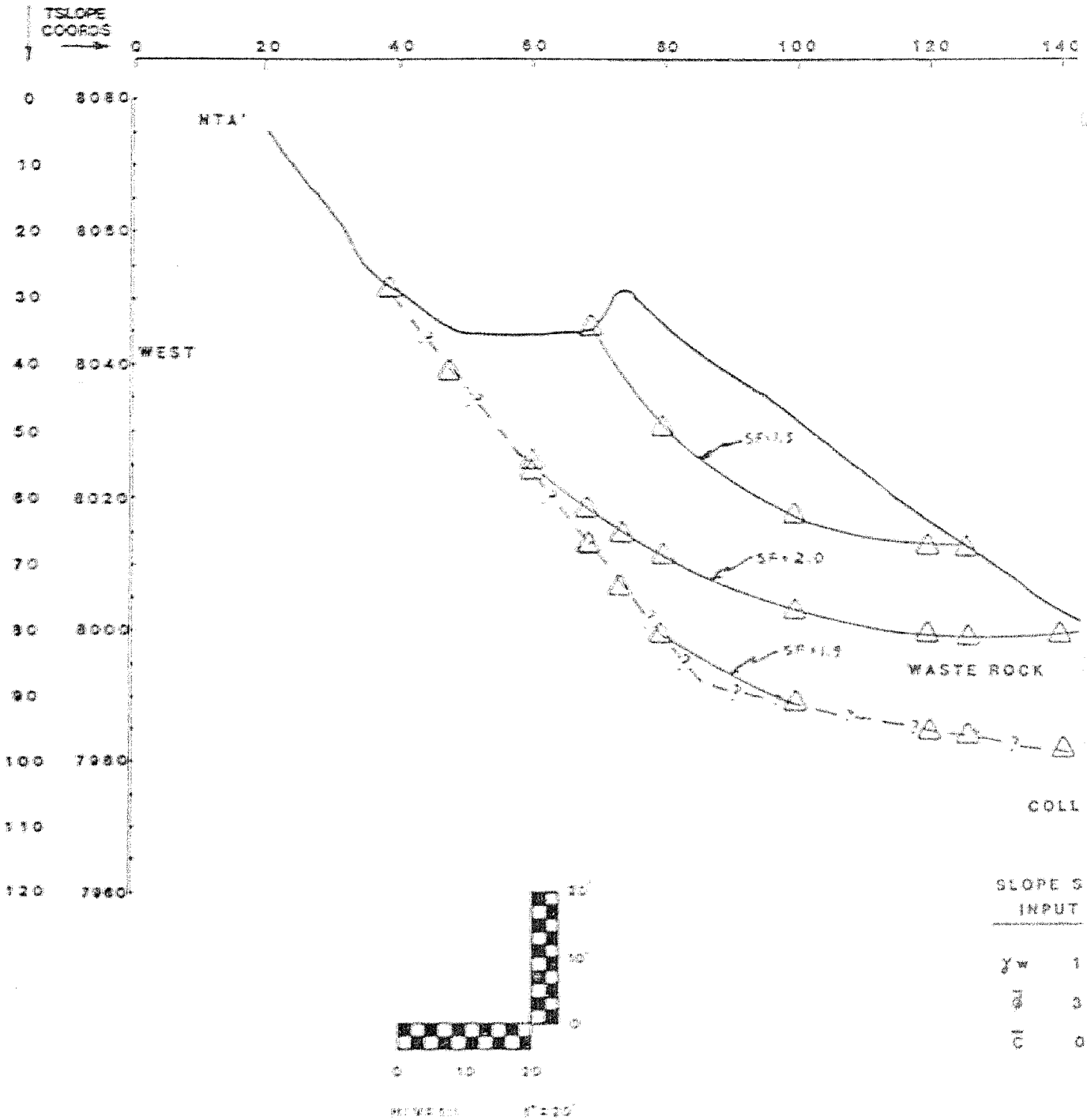

Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

LATERAL SECTION A-A'
NATIONAL TUNNEL

CAMP DRESSER & MCKEE INC.
CDM

8-19


TSLOPE COORDS
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
80
90
100
110
120
8080
8060
8040
8020
8000
7980
7960
NTA'
WEST
SF=1.5
SF=2.0
SF=1.9
WASTE ROCK
COLL
SLOPE S
INPUT
γw 1
φ 3
C 0

The assumed homogeneous nature of the waste rock dump indicated that a limited evaluation be conducted of the dump material properties and stability analyses be performed for a relatively narrow range of representative strength properties. The discussions which follow address soil properties used for analysis purposes, stability analysis methods, the stability model, and the results of the analyses.

The waste rock colluvium and alluvium are composed primarily of sand and gravel and are considered to be relatively free draining. Because of the relatively free draining nature of the soils, effective stress slope stability analyses were considered to be more appropriate than total stress analyses for static loading conditions. Accordingly, only effective stress shear strength properties were measured by laboratory tests for purposes of analyzing the stability of the embankment. For short-term conditions (earthquake loadings), total stress shear strength parameters were assumed to be equal to the effective stress strength parameters because of the coarse nature of the embankment soils. The shear strength properties incorporated with the stability analysis are summarized on Figure 8-19.

The stability analysis for the National Tunnel site was performed by using the following process:

- The field and laboratory test data were evaluated to define appropriate soil properties for each material type.
- Slope stability analyses were performed for the existing waste pile conditions to assess the potential for slope failure. Earthquake loading was also included in the analysis.

The stability analysis was performed by using the Spencer Method (Spencer 1967). Computer simulations were used for analysis purposes; the T-SLOPE computer code supplied by TAGA Engineering Software Services was used to perform computer simulated slope stability analyses. Analyses were performed for both assumed circular arc and wedge-shaped failure planes.

The stability analysis included effective stress analyses to evaluate long-term site conditions. Stability analyses were also performed for earthquake loading by assuming a horizontal ground acceleration of 0.1 g (a design acceleration consistent with the 1985 Uniform Building Code recommendation for Seismic Risk Zone 1, which includes the site). Because of the relatively wide flood plain at the site and the nominal rise in North Clear Creek expected as a result of flooding, rapid drawdown analyses were not considered necessary.

The stability model was defined by initially establishing the critical cross-section through the subsurface materials. Section NTA-NTA', shown on Figures 8-5 and 8-19, was selected as the critical section based on the estimated significant thickness of the tailings, the overall height of the waste pile, the location of the geotechnical samples, and the relatively steep nature of the existing slope (1.5H:1V).

An area behind the shop structure which has apparently been undercut was not evaluated because the cut appears to daylight colluvium. The thickness of the waste rock over colluvium in the cut is small, on the order of a few feet. Thus, the volume of waste rock that would be involved in a failure would be small.

A stability analysis was performed for the existing waste pile configuration at Section NTA-NTA'. As shown on Figure 8-19, two circular arc failure planes and one wedge-shaped failure plane were evaluated to define the potential for the failure of the existing waste pile: the utilized strength factors are given on Figure 8-19.

Results of the effective stress stability analysis showed a minimum safety factor of 1.4 with use of the material properties shown in Table 8-2 and the failure surfaces as shown on Figure 8-19. The analysis indicated a relatively shallow circular failure surface is the most critical. The remainder of the assumed failure surfaces produced static safety factors of 1.8 or greater. These results suggest that the existing slope

TABLE B-2
NATIONAL TUNNEL - SOIL PROPERTIES

| California Sampling | ASTM (D2487) Symbol | Material Type/ Sample Interval | WC% | D (PCF) | W (PCF) | LL (%) | PL (%) | PI (%) | % #200 | Φ DEGS | C (PSF) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (Mill Waste) | | | | | | | | | | | |
| SAMPLE A, Composite #2 Thru #6 | SM | Clayey, gravely, sand (0'-1') | — | — | — | 24.4 | 19.8 | 4.6 | 13.5 | 45.9 | 0 |
| SAMPLE B, Composite #1 & #8 | SM | Clayey, gravely, sand (0'-1') | — | — | — | 24.6 | 24.5 | 0.1 | 22.6 | 37.5 | 0 |
| SAMPLE 1 | SM | Clayey, gravely sand (0'-1') | 17.7 | 92.6 | 109.0 | — | — | — | — | — | — |
| SAMPLE 2 | SM | Clayey, gravely sand (0'-1') | 9.3 | 95.4 | 104.2 | — | — | — | — | — | — |
| SAMPLE 3 | SM | Clayey, gravely sand (0'-1') | 9.0 | 100.5 | 109.5 | — | — | — | — | — | — |
| SAMPLE 4 | SM | Clayey, gravely sand (0'-1') | 8.1 | 97.4 | 105.3 | — | — | — | — | — | — |
| SAMPLE 5 | SM | Clayey, gravely sand (0'-1') | 9.6 | 89.1 | 97.7 | — | — | — | — | — | — |
| SAMPLE 6 | SM | Clayey, gravely sand (0'-1') | 9.6 | 94.0 | 103.0 | — | — | — | — | — | — |
| SAMPLE 7 | SM | Clayey, gravely sand (0'-1') | 14.1 | 89.5 | 102.1 | — | — | — | — | — | — |
| SAMPLE 8 | SM | Clayey, gravely sand (0'-1') | 5.3 | 106.2 | 111.8 | — | — | — | — | — | — |
| Boring NT-1 (Colluvium/Alluvium) | | | | | | | | | | | |
| SAMPLE 4 (SS) | GW-GM | Well-graded gravel w/Silt & sand (10'-12') | 3.4 | — | — | — | — | — | 7.1 | — | — |
| Sample 8 (SS) | GP-GM | Poorly-graded gravel w/silt & sand 20'-21.6' | 5.6 | — | — | — | — | — | 9.7 | — | — |

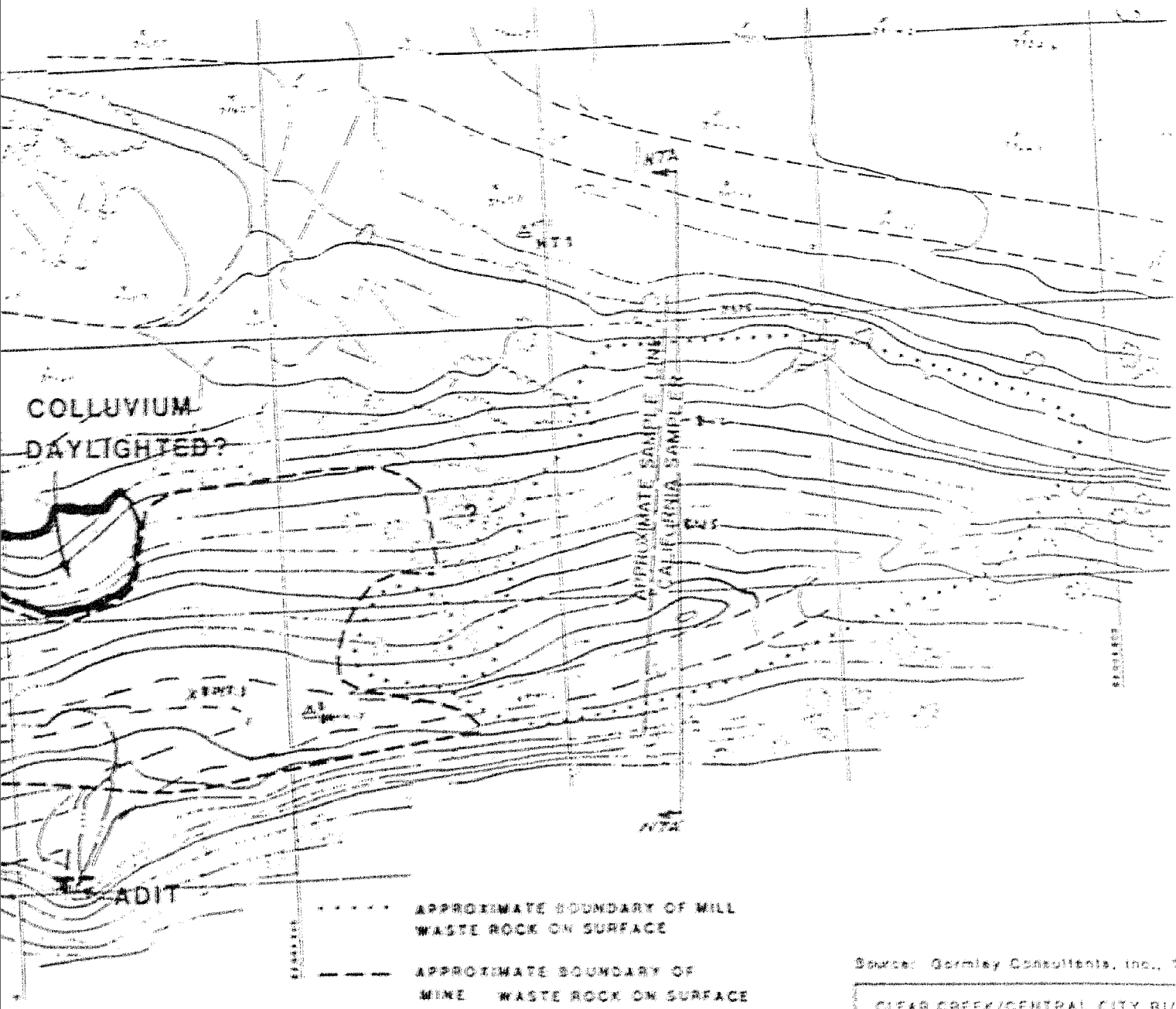
Note: See Table B-1 for an explanation of the abbreviations and the significance of each test.

configuration is quite stable. Analysis results for an assumed earthquake loading of 0.1 g indicate a minimum safety factor of about 1.2 for short-term conditions. This safety factor is considered acceptable for this evaluation. Given the present level of geotechnical data, the existing waste rock slope configuration appears to be stable.

### 8.2.3 QUARTZ HILL TUNNEL

The waste rock pile associated with the Quartz Hill Tunnel is located on the south side of Nevada Gulch from a point immediately in front of the portal to a point about 325 feet east, as shown previously on the Plan View in Figure 8-8. The toe of the waste rock pile is at an elevation of approximately 8,360 feet and the crest of the dump is at 8,590 feet, approximately the same elevation as the Quartz Hill Tunnel portal. The volume of waste rock is approximately 20,000 cubic yards. This value is a very rough estimate and includes only those materials in the immediate vicinity (200 feet) of the portal. None of the material in the parking lots is included. Midway through the site, flow in the intermittent stream in Nevada Gulch enters a 3-ft by 3-ft (approximately) reinforced concrete culvert that intersects a similar structure downstream. This buried culvert has collapsed in one area (Figure 8-8). The merged culvert directs flow beneath the large parking lots south of Central City, which were constructed after World War II with old mill waste rock. The Quartz Hill Tunnel waste rock pile has a flat upper surface where several abandoned structure foundations, possibly from stamp mills, are located. The side slopes of the waste rock dump slope to the north, toward Nevada Gulch, at approximately 1.6H to 1V.

Two borings, designated QH1 and QH2, were located atop the waste rock pile as shown on the Plan View in Figure 8-8. Figure 8-20 presents a lateral section of boring $QH_2$ (A-A') based on the drilling logs and the projection of the slope of the hillside above the waste rock pile to the level of the




Source: Dames & Moore, Inc., 1986

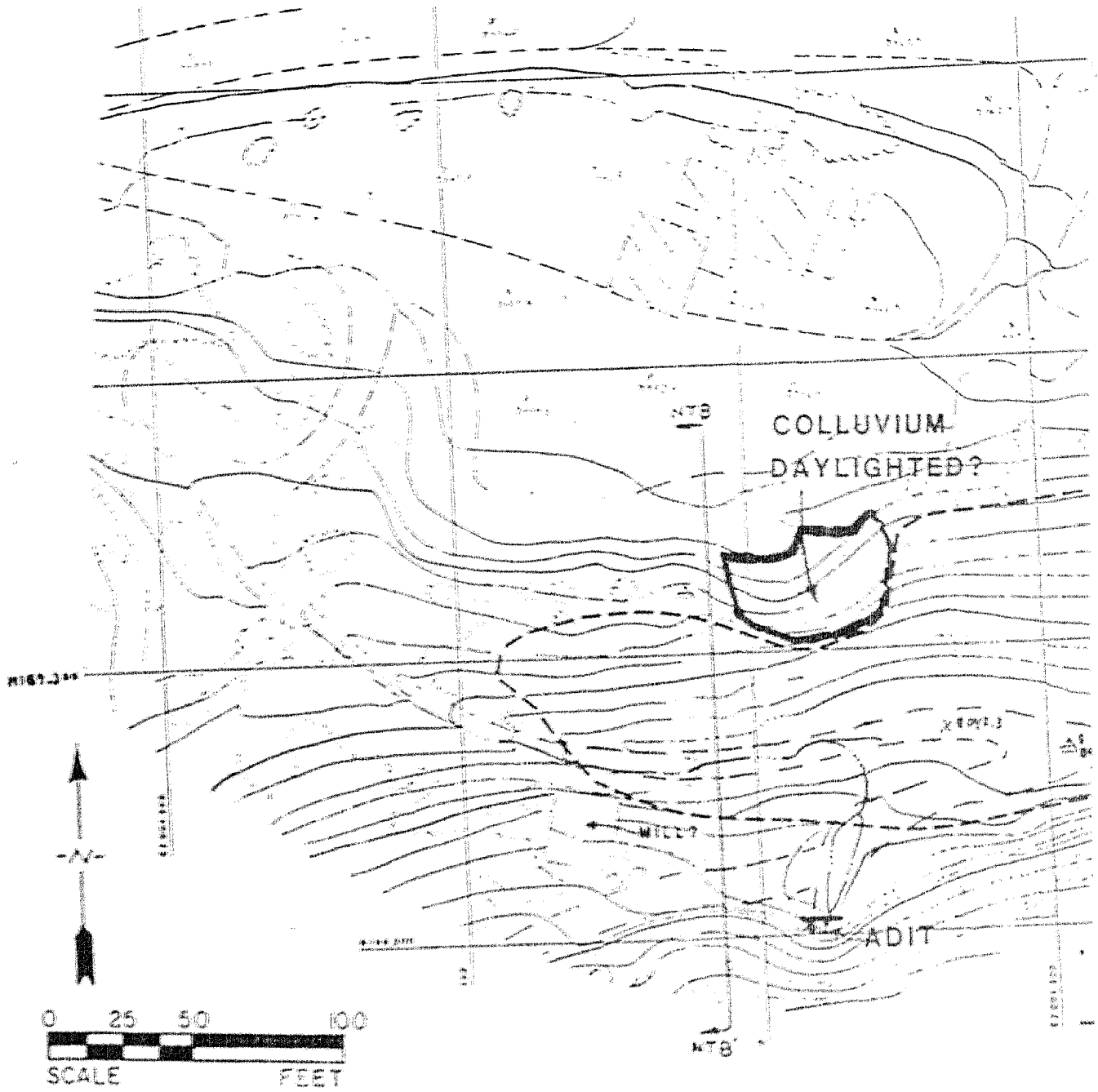
CLEAR CREEK/CENTRAL CITY RI/FS

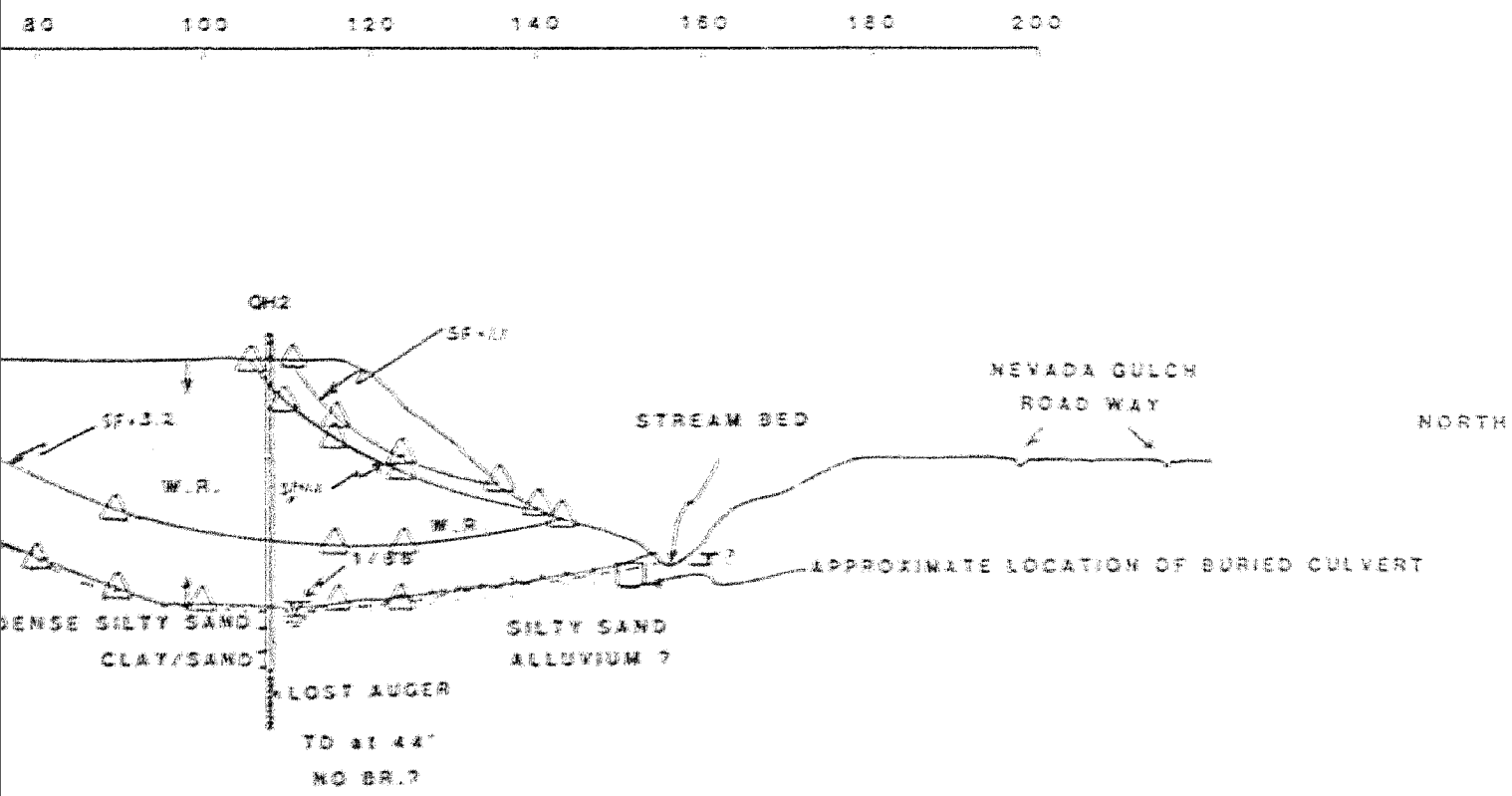
PLAN VIEW
NATIONAL TUNNEL

DAMES & MOORE INC.

CDM

D-5


COLLUVIUM
DAYLIGHTED?
ADIT
-N-
0 25 50 100
SCALE FEET




SLOPE STABILITY
INPUT DATA

| | |
|---|---|
| $\gamma_w$ | 127 PCF |
| $\bar{\phi}$ | 31 DEGREES |
| $\bar{c}$ | 0 PSF |

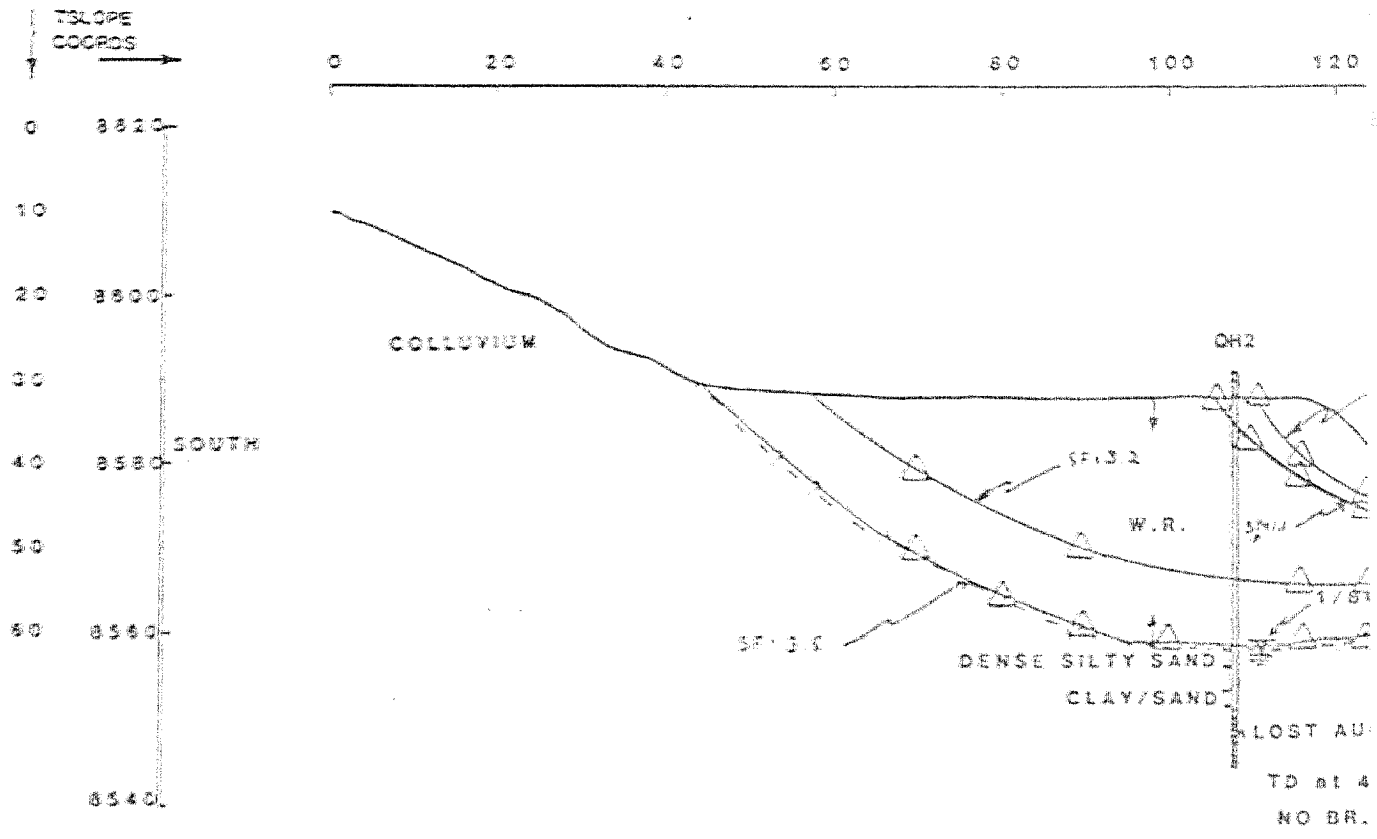
Source: Gorhley Consultants, Inc., 1980

CLEAR CREEK/CENTRAL CITY RI/FS

LATERAL SECTION A-A'
QUARTZ HILL W.R. DUMP

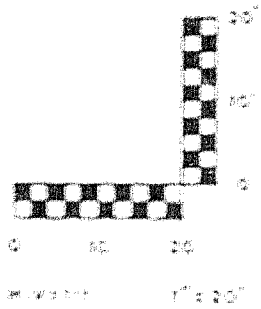
CAMP DRESSER & MCKEE INC.
CDM

8-20




## LEGEND

- T TAILINGS
- S-G SAND & GRAVEL
- C COBBLES
- B BOULDERS
- BR BED ROCK
- WR WASTE ROCK
- W COND W L DATA
- LC LEVEL OF CREEK BED
- SS STREAM SEDIMENTS
- TD TOTAL DEPTH



boring TD and Nevada Gulch. Since both borings penetrated the phreatic surface, they were completed as piezometers for the purposes of monitoring ground water levels and obtaining samples.

Local history indicates that the Quartz Hill waste rock dump lies atop alluvial gravels that may have been placer-mined several times since gold was discovered in the region in 1859.

A summary of the laboratory test results is provided in Table 5-3. The laboratory test analyses indicate that the waste rock possesses a narrow range of properties and consists of brown silty sand with gravel (SM). The alluvial sand and gravel zone is comprised of yellow-brown clayey sand with gravel (SC). The single direct shear test performed gave an angle of internal friction of $31^{\circ}$ and zero cohesion.

The proximity of the waste rock dump to the flow of Nevada Gulch and consideration of the contamination which could be caused by a slope stability failure of the waste area resulted in the requirement to assess the waste area stability and consider stabilization alternatives. The objectives of performing stability analyses for the Quartz Hill Tunnel waste rock dump were to:

- Assess the stability of the existing waste rock area.
- Evaluate the feasibility of stabilizing the existing waste pile by reshaping the pile, if required, to form a stable embankment and to accommodate any channel improvements in Nevada Gulch that may be associated with the discharge remediation.

The apparent homogeneous nature of the waste rock dump indicated that a limited evaluation be conducted of the dump material properties and stability analyses be performed for a relatively narrow range of representative strength properties. The discussions which follow address desired safety factors, soil properties used for analysis purposes, stability analysis methods, the stability model, and the results of the analyses.

TABLE 8-3
QUARTZ HILL - SOIL PROPERTIES

| Boring-Sample # (Type) | ASTM D2487 Symbol | Material Type/ Sample Interval | MC% | D (PCF) | V (PCF) | LL (%) | PL (%) | PI (%) | % -#200 | φ DEGRS | C (PSF) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 - #1 (ST) | — | Clayey, gravely sand (8.5'-10') | 15.6 | 112.6 | 130.2 | — | NON PLASTIC | | — | — | — |
| 1 - #7 (ST) | SC | Silty sand (25'-26') | 17.0 | 112.3 | 124.8 to 127 | 33.4 | 18.9 | 14.5 | 28.8 | 31 | 0 |
| 2 - #2 (SS) | SM | Silty sand (16'-16.8') | 9.7 | — | — | — | NON PLASTIC | | 13.0 | — | — |

Note: See Table 8-1 for an explanation of the abbreviations and the significance of each test.

The waste rock and alluvium are composed primarily of sand and gravel and are considered to be relatively free draining. Because of this characteristic, effective stress slope stability analyses are considered to be more appropriate than total stress analyses for static load conditions. As a result, only effective stress shear strength properties were measured by laboratory tests for the purpose of analyzing the stability of the embankment. For purposes of short-term stability analyses, the total stress shear strength parameters were assumed to be equal to the effective stress shear strength properties. This assumption is deemed valid because of the coarse nature of the subsurface soils. The shear strength properties incorporated with the stability analysis are summarized on Figure 8-20.

The stability analysis for the Quartz Hill Tunnel waste rock dump was performed by using the following process:

- The field and laboratory test data were evaluated to define appropriate soil properties for each material type.
- Slope stability analyses were performed for the existing waste pile conditions to assess the potential for slope failures. Earthquake loading was also included in the analysis.
- Slope stability analyses were performed for a recontoured surface to assess the stability of a slope that would be possibly constructed with channel improvements.

The stability analysis was performed by using the Spencer Method (Spencer 1967). Computer simulations were used for analysis purposes: the T-SLOPE computer code supplied by TAGA Engineering Software Services was used to perform computer simulated slope stability analysis. Analyses were performed for assumed circular arc failure planes.

The stability analysis included effective stress analyses to evaluate long-term site conditions. Stability analyses were also performed for earthquake loadings (short-term loading) by assuming a horizontal ground acceleration of 0.1 g. Because of the relatively narrow flood plain at the

site and the considerable rise in Nevada Gulch expected as a result of flooding, rapid drawdown analyses were also performed.

The stability model was defined by initially establishing the critical cross-section through the subsurface materials. Section A-A', as shown on Figures 8-8 and 8-20, was selected as the critical section based on the significant thickness of the waste rock, the overall height of the waste pile, the location of the geotechnical samples, and the relatively steep nature of the existing slope (1.6H:1V).

A stability analysis was performed for the existing waste pile configuration at Section A-A'. Three circular arc failure planes were evaluated, as shown on Figure 8-20, to define the potential for the failure of the existing waste pile.

Results of the effective stress stability analysis showed a minimum SF of 1.1 with use of the material properties shown in Table 8-3 and the failure surfaces as shown on Figure 8-20. The analysis indicated a relatively shallow circular failure surface along the crest of the slope is the most critical. The remainder of the assumed failure surfaces produced static safety factors of greater than 2.0. These results suggest that a moderate amount of recontouring of the existing slope configuration could yield a final reclaimed slope that is stable. Analysis results for an assumed earthquake loading of 0.1 g on the recontoured (2H:1V) slope indicate a minimum safety factor of about 1.1. This safety factor is considered reasonable for this evaluation.

The analysis of the reclaimed slope for a rapid drawdown condition assumed that the water level in Nevada Gulch rose to the top of the roadway before receding. Because the critical slope failure surface is near the crest of the reclaimed slope, the rapid drawdown analysis did not indicate a reduction in the safety factor.



being filmed.

The stability analysis indicates that a minor amount of recontouring of the side slopes of the Quartz Hill waste rock dump would be required to yield acceptable safety factors.

### 8.2.4 BIG FIVE TUNNEL

The Big Five Tunnel waste rock pile is located near the portal and extends southeast of the portal under I-70 to Clear Creek. It is located on both the north and south sides of Clear Creek and follows the direction of the creek for approximately 600 lineal feet on the north side of the creek and 700 feet on the south side.

No subsurface investigations were conducted at the Big Five site because of limited site access (EPA had not obtained site access permission from the landowner at the time of the drilling program). This cursory study addresses only the waste rock on the north side of the creek as shown on Figure 8-11. The volume of waste rock is approximately 100,000 cubic yards. This is a rough estimate because no borings were drilled into the waste rock. This estimate includes only waste rock on the north side of the creek. The side slopes of the waste rock pile slope to the south toward Clear Creek at typically 1.5H:1V, however, the slope steepens toward the easterly extent of the pile. The toe of the waste rock dump is at an elevation of 7,450 feet and the crest of the dump is at 7,600 feet, approximately the same elevation as the Tunnel portal. The waste rock pile has a flat upper surface which can be reached via an access tunnel beneath Interstate I-70 or, with some grading, from an access to the west.

The proximity of the waste rock dump to the Interstate highway and Clear Creek (at the dump's toe) and consideration of the contamination which could be caused by a slope stability failure of the waste area resulted in the requirement to assess the waste area stability and consider stabilization alternatives.

The objectives of performing stability analyses for the Big Five Tunnel waste rock dump were to:

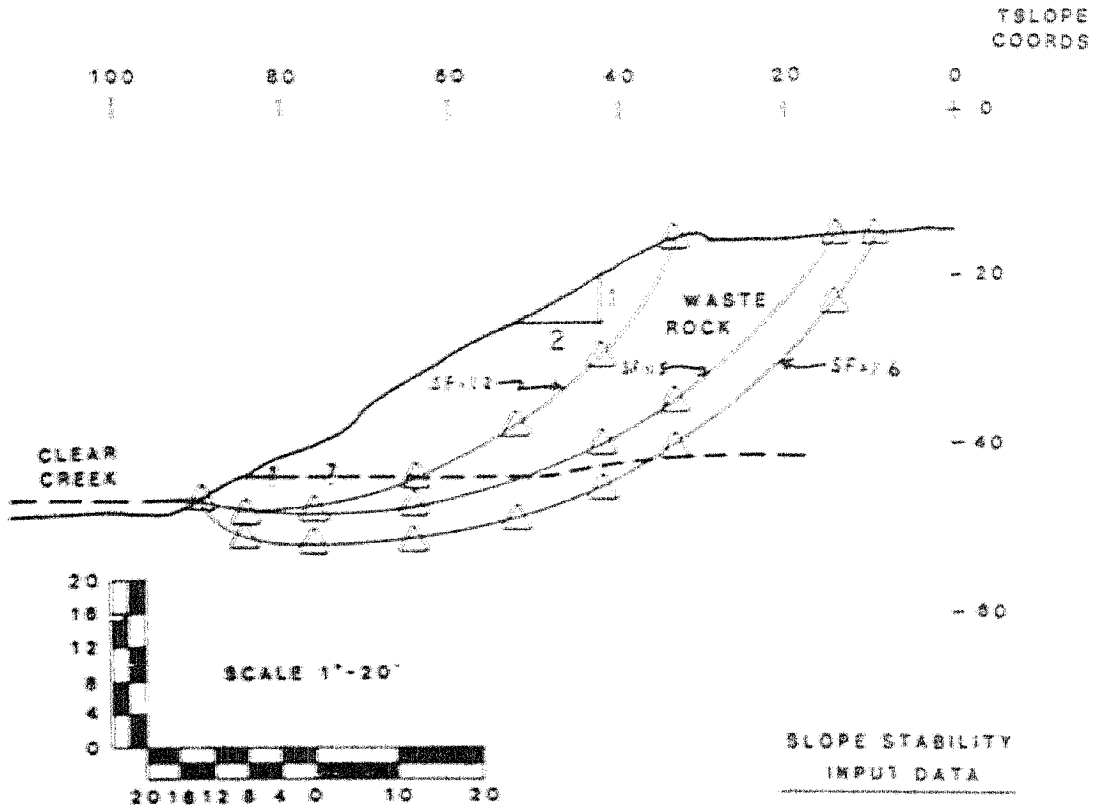
- Assess the stability of the existing waste rock area.
- Evaluate the feasibility of stabilizing the existing waste pile by reshaping the pile, if required, to form a stable embankment.

The assumed homogeneous nature of the waste rock dump and the underlying input data assumptions indicated that a limited evaluation be conducted of the dump material properties and stability strength properties. The discussions which follow address soil properties used for analysis purposes, stability analysis methods, the stability model, and the results of the analyses.

Thirteen of the 14 Argo Tunnel waste rock dump samples analyzed in this study were classified as gravels or sands under the Unified Soil Classification system (Section B.2.5). This preliminary analysis assumes that the Big Five Tunnel waste rock dump would have a similar distribution. Thus, the waste rock and alluvium are considered to be free draining. Effective stress slope stability analyses were considered to be more appropriate than total stress analyses for the Big Five Tunnel waste rock dump because of the assumed relatively free draining nature of the site soils. For short-term conditions (earthquake loads), total stress shear strength parameters were assumed to be equal to the effective stress parameters. The shear strength properties incorporated with the stability analysis are summarized on Figures B-21 and B-22.

The stability analysis for the Big Five Tunnel waste rock dump was performed by using the following process:

- The field and laboratory test data from the Argo Tunnel waste rock dump were assumed to define appropriate soil properties for the material in the Big Five waste rock dump.




SLOPE STABILITY
INPUT DATA

| | |
|---|---|
| $\gamma_w$ | 129.5 PCF |
| $\bar{\phi}$ | 31 DEGREES |
| $\bar{c}$ | 0 PSF |

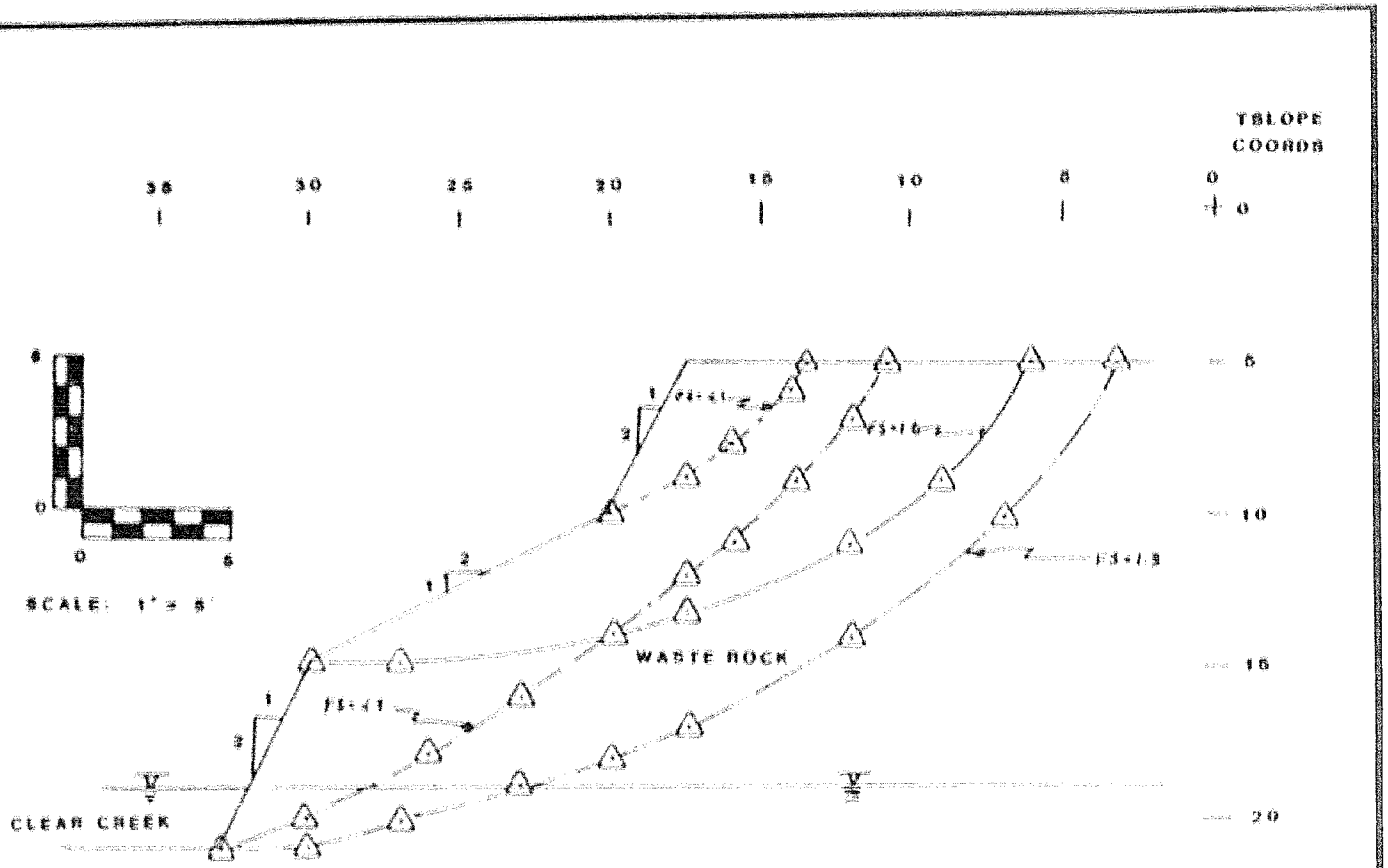
Source: Gormley Consultants, Inc., 1986

CLEAR CREEK/CENTRAL CITY RI/FS

SECTION BFTA
BIG FIVE TUNNEL - TYPICAL

CDM

8-21




Source: Dames & Moore Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY RI/FS

SECTION BFTB

BIG FIVE TUNNEL - WORST CASE

CDM

8-22

- Slope stability analyses were performed for the existing waste pile conditions to assess the potential for slope failure. Earthquake loading and rapid drawdown conditions were also included in the analysis.

The stability analysis was performed by using the Spencer Method (Spencer 1967). Computer simulations were used for analysis purposes; the T-SLOPE computer code supplied by TAGA Engineering Software Services was used to perform computer simulated slope stability analysis. Analyses were performed for assumed circular arc failure planes.

The stability analysis included effective stress analyses to evaluate long-term site conditions. Stability analyses were also performed for earthquake loadings by assuming a horizontal ground acceleration of 0.1 g. Because of the proximity of the site to Clear Creek, which runs at the base of the waste rock dump, a nominal 8-ft rise in Clear Creek was assumed in the analyses of a rapid drawdown condition.

Two stability models were defined by initially establishing the critical cross-section through the subsurface materials. Section 8FTA, as shown on Figures 8-11 and 8-21, was selected as the typical section based on limited site observations, the significant thickness of the waste rock, the overall height of the waste pile, and the steepest slopes (2H:1V) in the proximity of Clear Creek. Section 8FTB, as shown on Figures 8-11 and 8-22, was selected as the worst-case section based on the steep slopes (1H:2V maximum, 1H:1V average), and the observed erosion on the slope face.

Stability analysis was performed for the typical and worst-case pile configuration at Sections 8FTA and 8FTB. A total of seven circular arc failure surfaces were evaluated, as shown on Figures 8-21 and 8-22, to define the potential for the failure of the existing waste pile.

Results of the effective stress stability analysis showed a minimum SF of 1.2 for the typical condition with use of the assumed material properties and failure surfaces as shown on Figure 8-21. The analysis indicated a

shallow circular failure surface across the face of the slope is the most critical. The remainder of the assumed failure surfaces produced static safety factors greater than 1.4.

The rapid drawdown analysis indicated that the SF of the waste rock pile would be virtually unchanged under these conditions because of the assumed well-drained characteristics of the waste rock pile. Earthquake loading of the critical slope resulted in a SF of slightly less than 1.0. These results suggest that no immediate slope stability problem exists for the Big Five Tunnel waste rock dump assuming that the dump materials have characteristics identical to the Argo waste rock dump.

Results of the effective stress stability analysis showed a minimum SF of less than 1.0 for the worst-case condition with use of the assumed material properties and failure surfaces as shown on Figure 8-22. The analysis indicated a shallow to deep circular failure surface across the face of the slope is the most critical. The remainder of the assumed failure surfaces produced static safety factors greater than 1.3. Considering that the slope is currently standing, its condition could be termed as marginally stable. These results suggest that a detailed geotechnical investigation of the Big Five Tunnel waste rock dump be undertaken in order to gather sufficient data to evaluate the stability of the dump more precisely. As part of the Feasibility Study, EPA will do a stability analysis on the Big Five waste rock piles.

### 8.2.5 ARGO TUNNEL

The Argo waste rock dump, a long lineal feature, is located to the east of the portal as shown on Figure 8-11. It is located on the north side of Clear Creek and follows the direction of the creek for approximately 1,500 lineal feet. The side slopes of the waste rock pile slope to the south toward Clear Creek at approximately 1.5H:1V. The toe of the waste rock dump is at an elevation of 7,500 feet and the crest of the dump is at 7,550

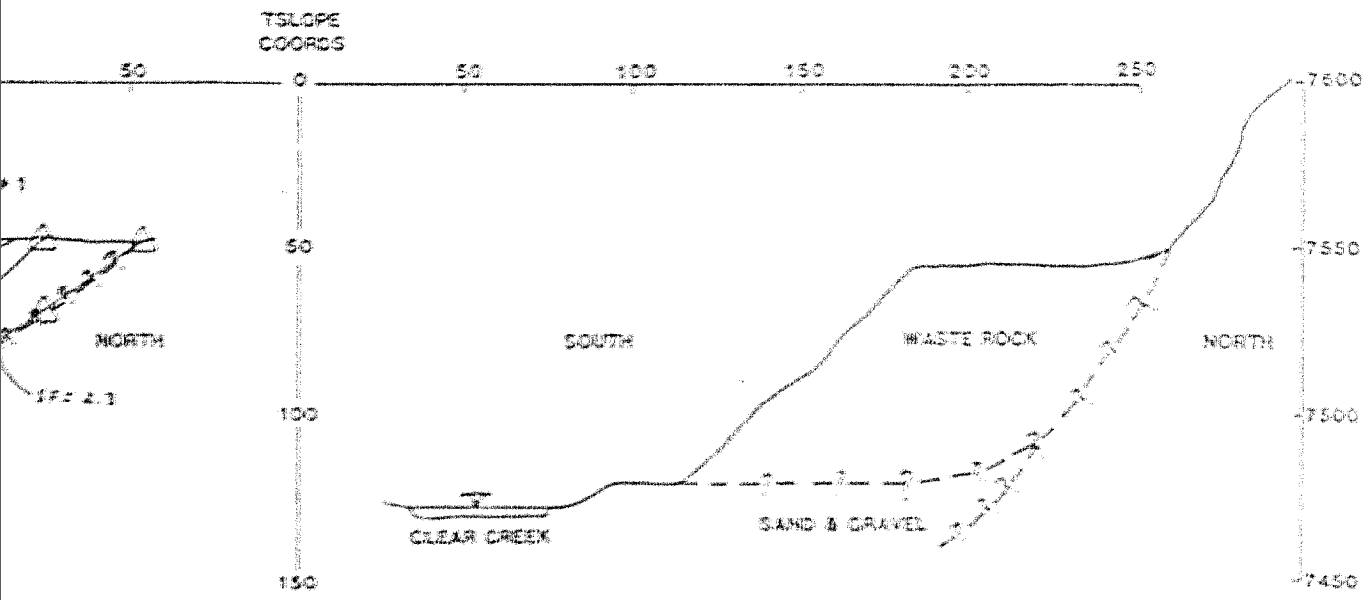
feet, about the same elevation as the Argo Tunnel portal. The waste rock has a flat upper surface which can be reached easily via an access road from the eastern end of the dump.

The dump material is apparently composed of mixed mine waste rock and mill waste rock from the Argo Mill. The mill processes used included stamp mill crushing, a ball mill, tabling froth flotation, amalgamation, and cyanidation. The mill discharge was all -30 mesh in size. The combined volume of mill and mine waste rock is approximately 260,000 cubic yards. This estimate includes only material on the east side of the mill. Approximately 74,000 cubic yards of this volume is below the level of the road.

Three borings, designated Argo Nos. 1 through 3, were located atop and at the toe of the waste rock dump as shown on Figure 8-11. Figure 8-23 presents subsurface profiles of the three borings based on the boring logs and the projection of the slope of the hillside above the waste rock pile to the level of the boring TD's and the Clear Creek flood plain. Since neither of the two borings at the top of the dump penetrated the phreatic surface, they were not completed as piezometers. Three ground water monitoring wells were later installed.

From data available in USGS Professional Paper 94 (1917), it appears that two structures and the grade of the Georgetown branch of the Colorado and Southern Railroad occupied the site prior to the construction of the waste rock dump. It is difficult to say whether the alluvial gravels beneath the dump were placer-mined. Map data from USGS Professional Paper 94 (1917) was used to approximate the pre-dump topography (Section B, Figure 8-23). However, the contour interval of the old map was 50 feet, the approximate current height of the dump.

A summary of the laboratory test results is provided in Table 8-4. The laboratory test analyses indicate that the waste rock possesses a range of properties (almost all containing 68 to 74 percent sand and gravel and




SECTION B
TYPICAL SECTION

SLOPE STABILITY
INPUT DATA

| | |
|---|---|
| $\gamma_w$ | 129.5 PCF |
| $\bar{\phi}$ | 31 DEGREES |
| $\bar{c}$ | 0 PSF |

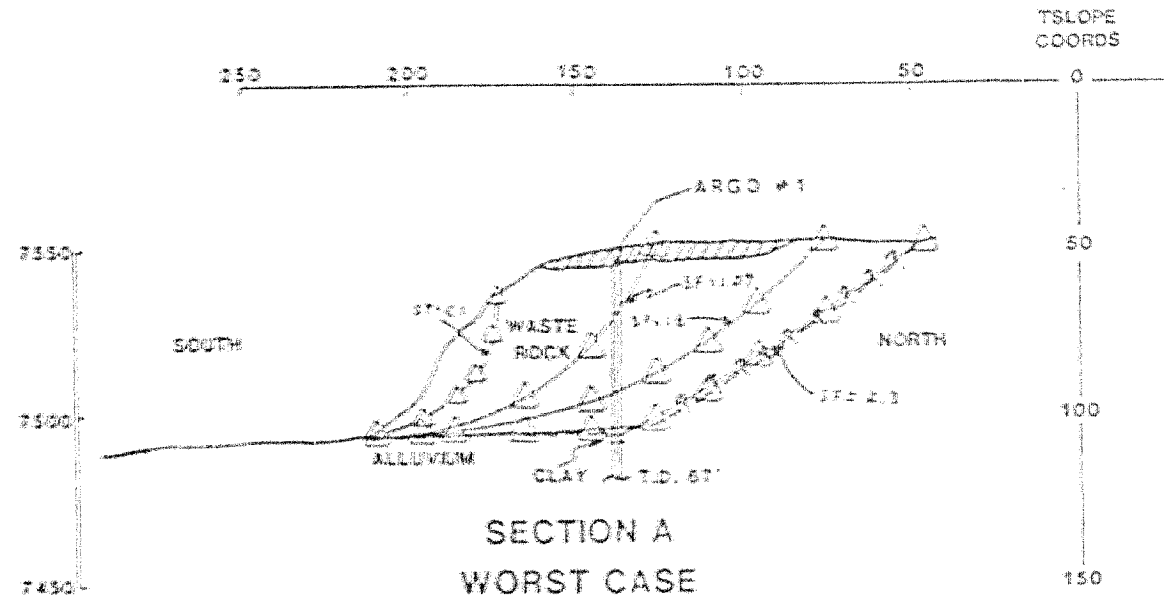
Source: Gormley Consultants, Inc., 1988

CLEAR CREEK/CENTRAL CITY RI/FS

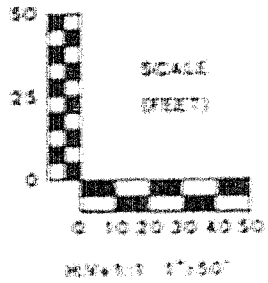
LATERAL SECTIONS
ARGO WASTE ROCK DUMP

CDM

6-23




SECTION A
WORST CASE




SLOPE STABILITY
INPUT DATA

| | |
|---|---|
| $\gamma_w$ | 129.5 PCF |
| $\bar{\phi}$ | 31 DEGREES |
| $\bar{c}$ | 0 PSF |

TABLE B-4

ANCO TUNNEL WASTE ROCK DUMP - SOIL PROPERTIES

| Boring-Sample # (Type) | ASTM D2487 Symbol | Material Type/ Sample Interval | WC% | D (PCF) | W (PCF) | LL (%) | PL (%) | PI (%) | % -#200 | Φ DEGRS | C (PSF) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 - # 5 (SS) | OH | Silty gravel (16'-18') | 11.1 | --- | --- | 36 | 25 | 11 | 30.8 | --- | --- |
| 1- # 7 (SS) | OH | Silty gravel (21'-23') | 7.6 | --- | --- | NON PLASTIC | | --- | 15.6 | --- | --- |
| 1 - # 9 (SS) | SM | Silty sand (26'-28') | 14.8 | --- | --- | 35 | 26 | 9 | 30.1 | --- | --- |
| 1 - #10 (ST) | ML | Sandy silt (30'-31') | 19 | 108.9 | 129.5 | 36.9 | 33.1 | 3.8 | 64.8 | 31 | 0 |
| 1 - #11 (SS) | OH | Silty gravel (31'-33') | 13.8 | --- | --- | 41 | 26 | 15 | 28.6 | --- | --- |
| 1 - #15 (SS) | CL | Clayey sand (40.5'-42.5') | 10 | --- | --- | 27 | 18 | 9 | 30.5 | --- | --- |
| 1 - #16 (ST) | SC | Clayey sand (45'-46') | 11 | 116.1 | 128.9 | 29.1 | 19.7 | 9.4 | 28.9 | 39 | 0 |
| 2 - # 5 (SS) | SM | Silty sand (20'-22') | 12.5 | --- | --- | 36 | 24 | 10 | 26.9 | --- | --- |
| 2 - # 6 (SS) | SC | Clayey sand (25'-27') | 18.1 | --- | --- | 46 | 17 | 29 | 29.0 | --- | --- |
| 2 - # 7 (SS) | SC | Clayey sand (30'-32') | 13.7 | --- | --- | 33 | 21 | 12 | 33.2 | --- | --- |
| 2 - #8&10 (SS) | OH | Silty gravel (40'-47') | 3.7 | --- | --- | NON PLASTIC | | --- | 14.0 | --- | --- |
| 2 - #13 (SS) | GW-GM | Well graded gravel (60'-62') | 4 | --- | --- | NON PLASTIC | | --- | 9.9 | --- | --- |
| 3-# 2 (SS) | GC-GM | Silty, clayey, gravel (5'-7') | 3.8 | --- | --- | 28 | 21 | 7 | 14.1 | --- | --- |
| 3 - # 5 (SS) | GW-GM | Well graded gravel (15'-16.5') | 9.5 | --- | --- | NON PLASTIC | | --- | 5.8 | --- | --- |

Note: See Table B-1 for an explanation of the abbreviations and the significance of each test.

the balance in silt/clay fines) and consists of cemented damp brilliant yellow sand silt, with a zone of peat or coal (waste from mill?), silty sand (SM), clayey sand (CL) and clayey sand with gravel (SC). The alluvial sand and gravel zone is comprised of clayey sand with gravel (SC), with zones of gravel and/or carboniferous material (railroad ballast?), silty gravel (SC), and a well graded gravel with silt and sand (GW-GM). The direct shear tests performed on two samples gave angles of internal friction of $31^{\circ}$ and $39^{\circ}$, respectively, and zero cohesion.

The proximity of the waste rock dump to nearby structures, the undercutting of the dump's toe and consideration of the contamination which could be caused by a slope stability failure of the waste resulted in the requirement to assess waste area stability and consider stabilization alternatives. The objectives of performing stability analyses for the Argo Tunnel waste rock dump were to:

- Assess the stability of the existing waste rock area.
- Evaluate the feasibility of stabilizing the existing waste pile by reshaping the pile, if required, to form a stable embankment.

The apparent homogeneous nature of the waste rock dump indicated that a limited evaluation be conducted of the dump material properties and stability analyses be performed for a relatively narrow range of representative strength properties. The discussions which follow address soil properties used for analysis purposes, stability analysis methods, the stability model, and the results of the analyses.

The stability analysis for the Argo Tunnel waste rock dump was performed by using the following process:

- The field and laboratory test data were evaluated to define appropriate soil properties for each material type.

- Slope suitability analyses were performed for the existing waste pile conditions to assess the potential for slope failures. Earthquake loading was also included in the analysis.

- Slope stability analyses were performed for a recontoured surface to assess long-term slope stability.

The stability analysis was performed by using the Spencer Method (Spencer 1967). Computer simulations were used for analysis purposes; the T-SLOPE computer code supplied by TAGA Engineering Software Services was used to perform computer simulated slope stability analyses. Analyses were performed for assumed circular arc and wedge-shaped failure planes.

The stability analysis included effective stress analyses to evaluate long-term site conditions. Stability analyses were also performed for earthquake loadings by assuming a horizontal ground acceleration of 0.1g. Because of the relatively wide flood plain at the site and the nominal rise in Clear Creek expected as a result of flooding, rapid drawdown analyses were not performed. Since only a minor amount of remedial action appeared to be required to stabilize the undercut condition, analyses of short-term and end of construction conditions, were not performed.

The stability model was defined by initially establishing the critical cross section through the subsurface materials. Section A, as shown on Figure 8-11 and Figure 8-12, was selected as the critical section based on the thickness of the waste rock, the overall height of the waste pile, the location of the toe undercut, and the relatively steep nature of the existing slope (1.5H:1V).

A stability analysis was performed for the existing waste pile configuration at Section A. Two circular arc failure planes and one wedge-shaped failure plane were evaluated, as shown on Figure 8-12, to define the potential for the failure of the existing waste pile.

Results of the effective stress stability analysis showed a minimum SF of 1.07 for the undercut condition with use of the material properties shown

in Table 8-3 and the failure surfaces as shown on Figure 8-23. The analysis indicated a shallow circular failure surface across the face of the slope is the most critical. In an assumed failure event, the waste rock material would certainly impact the structures at the toe of the slope but would probably not reach Clear Creek. The remainder of the assumed failure surfaces produced static safety factors of greater than 1.6.

A more typical cross section through the waste rock dump yielded a minimum SF of 1.2 with the remainder of the assumed failure surfaces producing static safety factors of greater than 1.7. The easterly edge of the dump is close to the banks of Clear Creek and a slope failure would undoubtedly cause some dump material to be deposited in the creek. However, this area is the more stable portion of the dump. These results suggest that a moderate amount of recontouring of the existing undercut slope configuration could yield a final reclaimed slope that is more stable.

### 8.2.6 SUMMARY

Based on accepted engineering practice and considering the assumed homogeneous nature of subsurface materials, an acceptable SF of 1.3 for static loads and a SF of 1.0 for dynamic loads were selected for slope stability evaluation purposes. Estimated SF's and stability conclusions are summarized in Table 8-5.

TABLE 8-5

SAFETY FACTORS

| Tailings/Waste Rock Pile | Safety Factor | | Comments |
|---|---|---|---|
| | Dynamic | Static | |
| Gregory | 1.0 | 1.0-1.1 | Unstable |
| National Tunnel | 1.4 | 1.8 | Stable |
| Quartz Hill | 1.1 | 2.0 | Some recontouring recommended. |
| Big Five | 1.0-1.2 | 1.1-1.4 | Argo data used. Drilling to be done during FS. |
| Argo (Undercut) | 1.07 | 1.6 | Unstable |
| (Other) | 1.2 | 1.7 | Stable (some recontouring recommended) |

# 9.0 AQUATIC ECOLOGY

This section summarizes the available information concerning aquatic ecosystems in Clear Creek and North Clear Creek and discusses their importance and current status. No formal field investigation was undertaken because regional information is available and numerous studies have evaluated the impact of acid mine drainage and elevated metal concentrations on fish populations. In addition, a major aquatic ecology field study has recently been completed for the Yak Tunnel NPL site near Leadville, Colorado which also addresses the impact of acid mine drainage on mountain trout streams.

## 9.1 REGIONAL CONDITIONS

Early settlers and visitors to the Rocky Mountain West found only cutthroat trout (*Salmo clarkii*) in the streams and lakes (Sinns, 1981). Although widespread and common, present evidence indicates that this species had actually developed into several subspecies in different western drainages. As early as 1881, a fish hatchery was established near Denver to raise rainbow (*Salmo gairdnerii*) and brook (*Salvelinus fontinalis*) trout for stocking in nearby mountain streams (Green, 1937). In 1894, brown trout (*Salmo trutta*) were also introduced into Colorado streams.

These native and introduced trout were often an important food source for early settlers and continue to provide considerable recreation for present-day fishermen. The Colorado Division of Wildlife estimates that fishing in Colorado generates approximately 600 million dollars a year to the economy of Colorado (Davies, unpubl.). Mountain trout streams are especially popular, attracting both resident and non-resident fishermen, and are clearly a valuable natural resource for Colorado.

The Clear Creek drainage basin, despite a long history of mining and development activities, continues to support native cutthroat trout as well as introduced populations including rainbow and brook trout (Woodling, 1976). In addition, the State of Colorado has classified Clear Creek as a Class 1 - Cold Water stream. This classification is applied to streams which "do or could protect and maintain a wide variety of cold water biota, including trout and sensitive species". Clearly, however, acid and heavy metal laden drainages have had a damaging effect on the fisheries resources of the basin, particularly in the Clear Creek/Central City region (USDI, 1967, Woodling, 1976). Although numerous factors must be considered in evaluating the suitability of a particular stream for trout (Sinns, 1979), the acid mine drainages described in this RI/FS are clearly a major factor in limiting current trout populations in Clear Creek and North Clear Creek. Because excellent highways make this area readily accessible to recreationists, any damage to the fisheries of these streams is a direct loss to the local tourist/recreation oriented communities.

## 9.2 LOCAL CONDITIONS

Existing conditions pertinent to aquatic life include surface water hydrology, physical habitat, water quality and food availability. These factors and their relevance to the existing fish populations in Clear Creek and North Clear Creek are discussed in the following two sections. It should be noted, however, that an actual quantitative study of the fisheries in Clear Creek or North Clear Creek has never been performed. Creek census and stream survey information from the Division of Wildlife is considered to be strictly qualitative (Gabel, 1986).

### CLEAR CREEK

The fact that the State classified Clear Creek as a Class 1 - Cold Water stream implies that streamflow and other physical habitat factors, are not limiting fish populations (Gabel, 1986). Although the annual streamflow variation in Clear Creek may be great (see Section 6.0) and cause some

problems for trout (Eymes, 1979), the fact that summer base flows (80-300 cfs) are rarely less than 25 percent of the average daily flow (136 cfs) indicates that existing flows provide good trout habitat (Sinns, 1979).

Although Clear Creek's Class 1 status implies that flow, cover and substrate are adequate for trout populations, water quality could still be a limiting factor (Gabel, 1986). When historical and recent water quality data (Section 6.0) are considered together, it is clear that most of the potential aquatic life ARARs for metals (Section 3.5) have been exceeded in the portion of Clear Creek within the current Clear Creek/Central City study area.

Regarding food availability in Clear Creek, no data were found other than a Federal Water Pollution Control Administration (FWPCA) Study (USDI, 1967) which included data on algae and macroinvertebates, and some unpublished data on macroinvertebrates (Woodling, 1975). Attached algae data, illustrated in Figure 9-1, indicate that attached algae in Clear Creek are relatively tolerant of the metals in Clear Creek. According to the study (USDI, 1967), numbers of attached algal cells and the quantity of chlorophyll typically increased at locations where domestic waste was discharged into Clear Creek and Achnanthes was the dominant species.

North Clear Creek, however, was found to have an extremely depressed attached algae population. Limiting factors in the North Clear Creek were thought to be higher metal concentrations, turbidity, and suspended solids. Field observations during the RI indicated that lack of substrate due to extensive precipitation of hydrous metal oxides is also a significant limiting factor. From Figure 9-1, it is evident that North Clear Creek also has a significant impact on attached algae populations in Clear Creek.

Figure 9-2 illustrates Woodling's data on macroinvertebrate species diversity and equitability in Clear Creek. Species diversity indicates relative numbers of species while equitability represents relative numbers

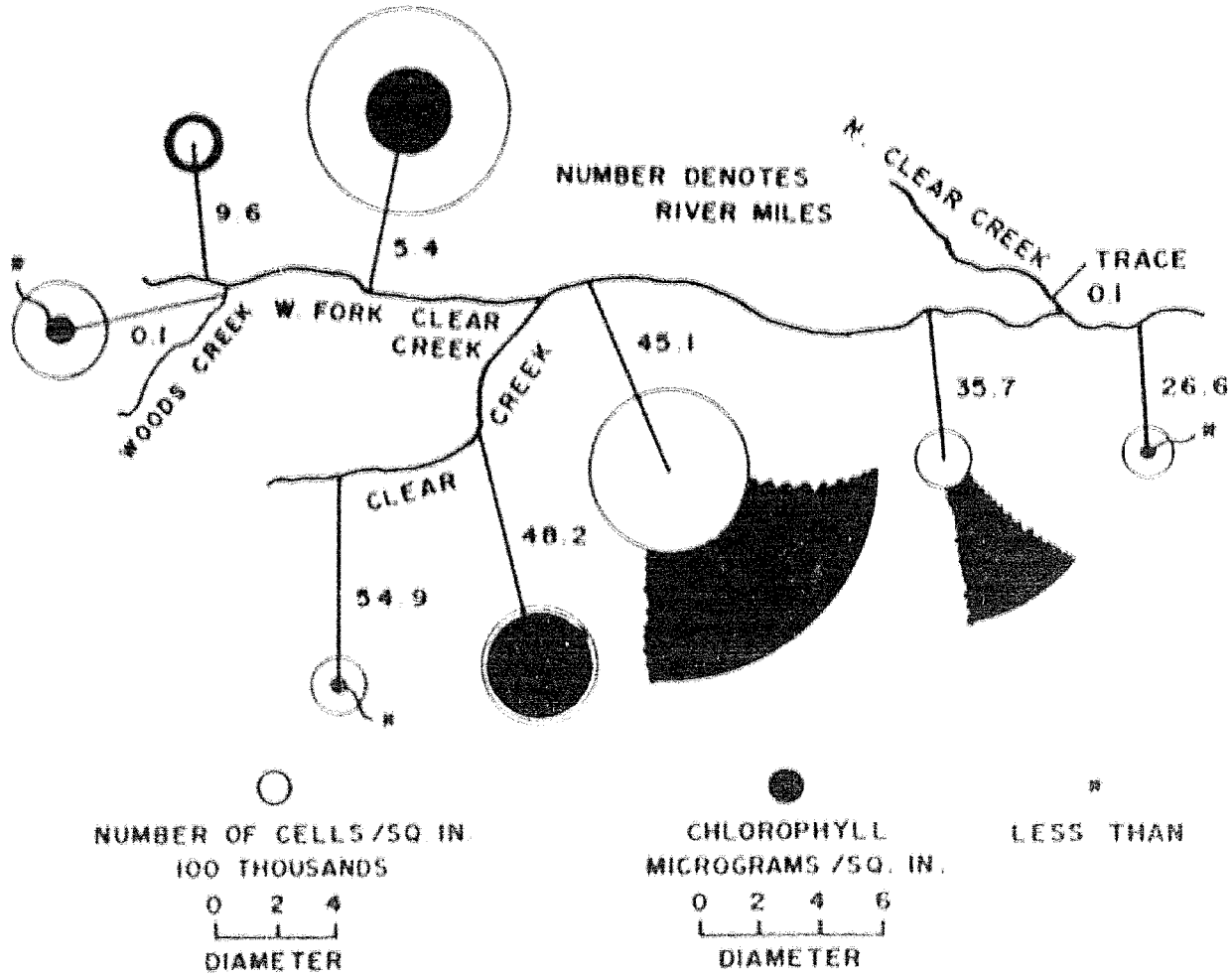
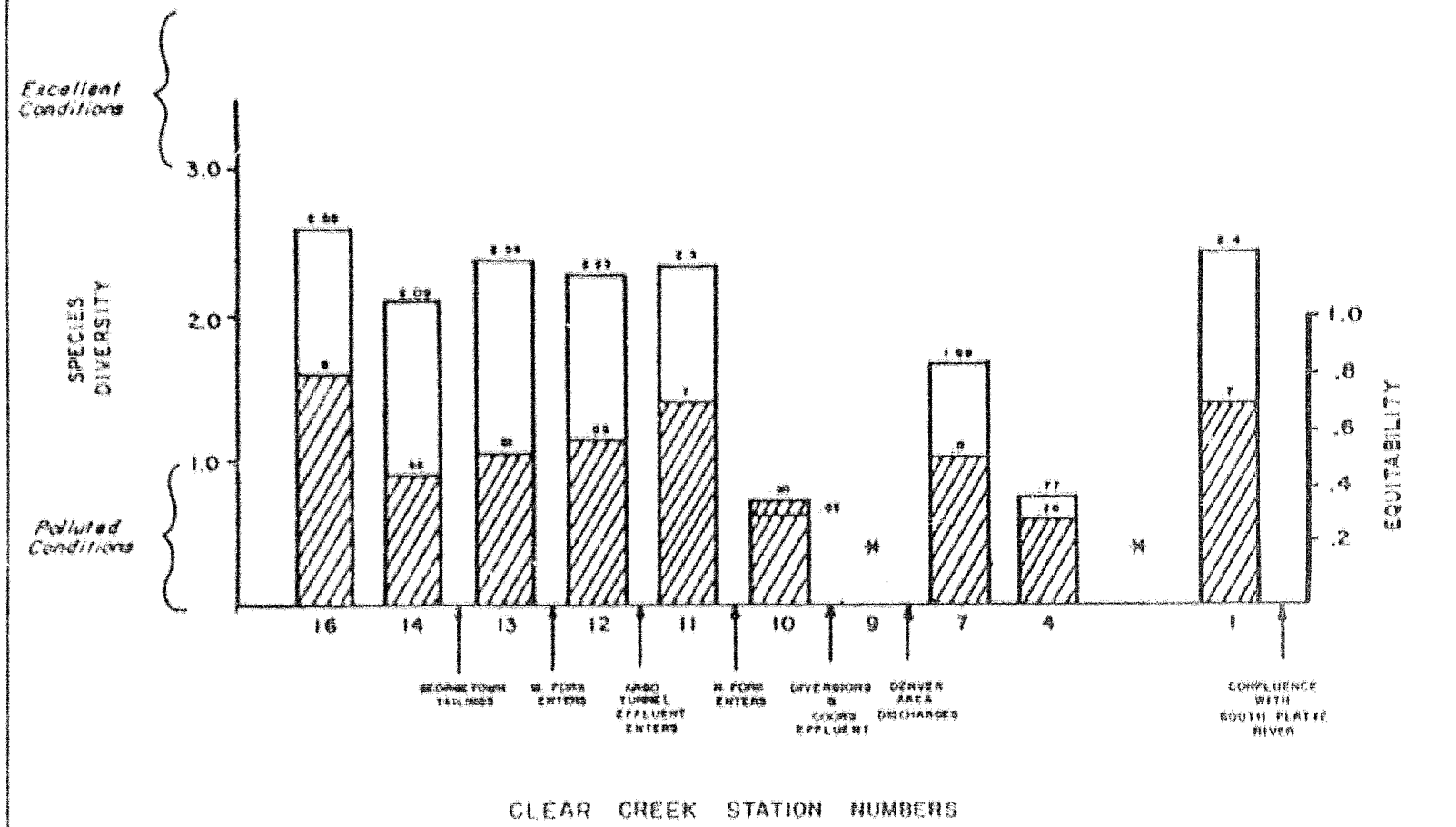



Figure 9-1 Attached Algae, Clear Creek (August 1988)

Source: USDI (1987)

CDM




* (Too Few Organisms Collected to Perform Analysis)

Figure 9-2 Species Diversity & Equitability of Macroinvertebrates
Clear Creek Main Stem (September 1976)

Source: Woodling (1976)

CDM

of individuals in each species. Clearly, macroinvertebrate populations in Clear Creek are adequate prior to the confluence with North Clear Creek. Discharge from North Clear Creek apparently reduces macroinvertebrate populations as well as attached algae populations in Clear Creek.

Fisheries data are also limited. The FWPCA study (USDI, 1967) attempted to correlate fish populations with water toxicity in mining affected basins in general and in Clear Creek specifically. Their summary of all mining-affected basins in Colorado was as follows:

| | Percent | |
|---|---|---|
| | Waters With Threshold Toxicity Value <1 | Waters With Threshold Toxicity Value >1 |
| Sampling Stations | 58 | 42 |
| Fish Captured | 91 | 9 |

It should be noted that at the time of the FWPCA study, most of the metals were regarded as less toxic than they are now known to be.

Figure 9-3 illustrates FWPCA data regarding fish populations and water toxicity in Clear Creek. According to this figure, the number of fish increase and the toxicity threshold becomes less than one between river mile 45 and 50 (See Figure 9-1 for river miles). This is between Lawson and Georgetown. Again, it should be noted that the toxicity threshold would be lower if it were calculated with more recent toxicity data. Of the 11 fish captured in this study, eight were brook trout, one was a rainbow trout, and two were long-nose suckers.

Seven miles upstream from Idaho Springs, Clear Creek is consistently stocked with approximately 8000 rainbow trout per year (DOW unpubl.). Creel census and stream survey information below Idaho Springs, however, indicates that brook trout are caught as frequently as rainbow and that brown trout are also caught (DOW unpubl., Wooding, 1976). A qualitative

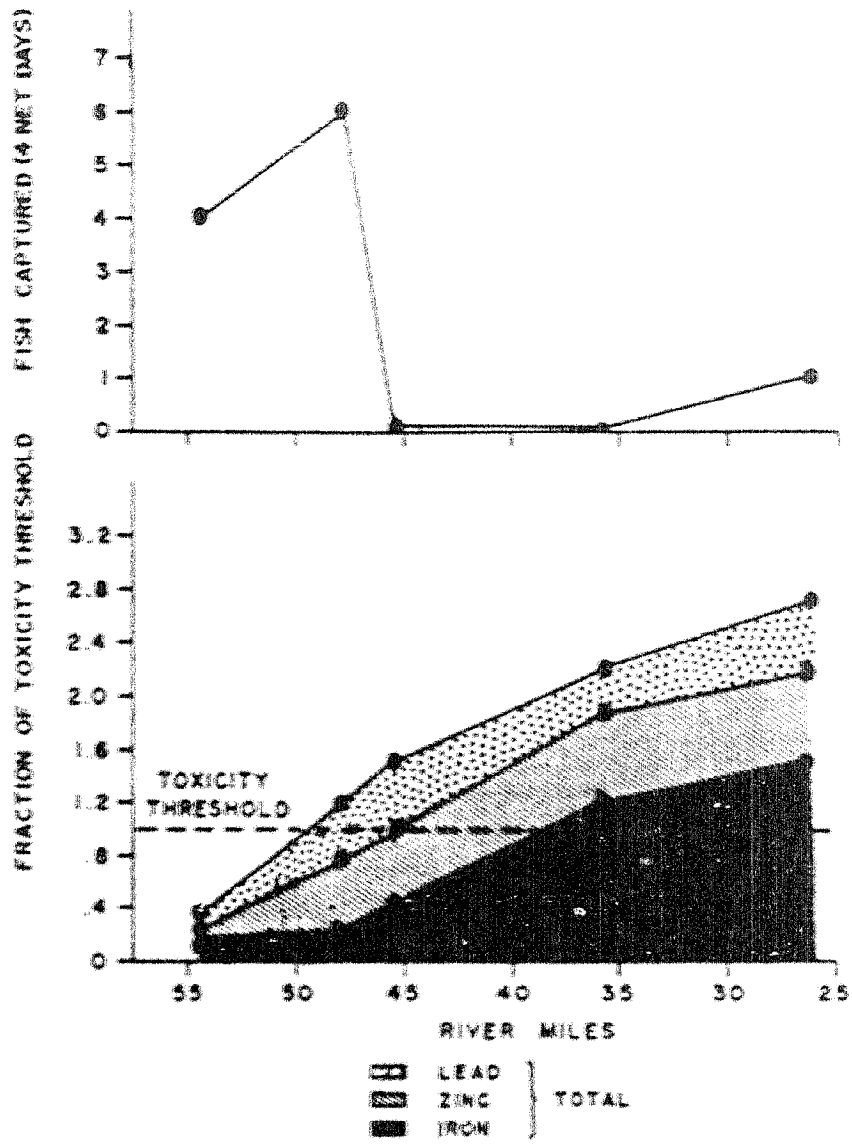



Figure 9-3 Toxicity of Waters & Fish Populations Clear Creek (August 1968)

Source: USDI (1967)

CDM

creel census from 1979-1983 which censused approximately 100 fish per year showed that 50 percent were brook trout, 40 percent were rainbow trout and 10 percent were brown trout.

NORTH CLEAR CREEK

North Clear Creek is classified as a Class 2 - Cold Water stream by the State of Colorado. This classification is applied to streams where "the potential variety of life forms is presently limited by flow and stream bed characteristics." Although stream flows range from 2-50 cfs and are probably limiting at certain times of the year, extensive dredging and mine waste rock deposition from Black Hawk to the confluence with Clear Creek is also a major factor limiting aquatic life.

Water quality is also a major limiting factor in North Clear Creek. All of the proposed ARARs for metals (Section 3.5) have been exceeded in North Clear Creek to a greater extent than in Clear Creek within the current Clear Creek/Central City study area (Section 6.0). In addition, extensive precipitation of hydrous metal oxides was observed on streambed substrates during field observations. This deposition appeared to be sufficiently extensive to prevent utilization of the substrate by algae or macroinvertebrates between Black Hawk and the confluence with Clear Creek. A similar problem has been documented in Deer Creek near Montezuma, Colorado (McKnight and Feder, 1984).

Despite these obvious habitat and water quality problems in North Clear Creek within the site boundary, North Clear Creek has been consistently stocked with approximately 825 rainbow trout per year at locations two to three miles up stream from Black Hawk (DOW unpubl.). In addition, limited creel data in 1979 and 1981 show that both cutthroat and brown trout have been caught in North Clear Creek.

## 9.3 ISSUES OF CONCERN

Although the Clear Creek/Central City site currently supports a trout fishery which could probably be enhanced by water quality remediation efforts, there are several issues regarding water quality and habitat which should be considered in detail.

### WATER QUALITY ISSUES

Water quality issues include the variety of analytical methods currently in use to evaluate and report aquatic metal levels, the fact that trout are known to tolerate metal concentrations higher than the ARARs and the lack of definition as to what constitutes "background" metal concentrations at this site. Some of these issues will be addressed by additional proposed studies (see Section 14.0).

### HABITAT ISSUES

The desirability of including some physical habitat restoration for fisheries along with the currently envisioned water quality remediation needs to be investigated. Physical habitat restoration for fisheries is relatively inexpensive compared to water treatment and could potentially greatly improve the response of the fishery to future remediation efforts.

## 9.4 CONCLUSIONS AND RECOMMENDATIONS

The available information documents the importance of maintaining or enhancing the aquatic ecosystems in Clear Creek and North Clear Creek. Not only are both creeks stocked with rainbow trout, they also maintain small populations of other trout species despite the existing poor water quality. Evidence indicates that improving water quality on both creeks and restoring some habitat on North Clear Creek could result in the re-establishment of a healthy fishery similar to those that occur in Front Range streams unimpacted by mining activities.

In addition, these creeks are both located near popular tourist areas and are easily accessible to large population centers near Denver and along the Front Range. All of these factors contribute to the importance of the aquatic ecosystem at the Clear Creek/Central City site and suggest that aquatic life be considered in the selection of ARARs and remediation strategies.

# 10.0 PUBLIC HEALTH EVALUATION

## 10.1 INTRODUCTION

This public health evaluation (PHE) is designed to evaluate the magnitude and probability of actual or potential harm to public health, welfare, and the environment associated with the actual or threatened release of hazardous substances from the Clear Creek/Central City, Colorado mine drainage sites. It is a site-specific risk assessment performed as part of the Remedial Investigation/Feasibility Study (RI/FS) performed under the Comprehensive Environment Response Compensation and Liability Act (CERCLA) for hazardous waste sites.

This baseline public health evaluation addresses the potential human health and environmental effects associated with the Clear Creek/Central City site under the no-action alternative. The no-action alternative assumes that no remedial (corrective) actions take place and that no restrictions are placed on the future use of the mining sites. Evaluation of the no-action alternative is required under Section 300.68(i)(v) of the National Contingency Plan (NCP) (EPA 1985a). This evaluation is consistent with guidelines from the Office of Emergency and Remedial Response (EPA 1986a) and federal guidelines for risk assessment (EPA 1986b,c,d).

The remainder of this chapter is divided into several sections. Section 10.2 describes the selection of chemicals of concern or indicator chemicals which are a subset of the chemicals detected at the site. The toxicological properties of these indicator chemicals are discussed in Section 10.3. In Section 10.4, the migration pathways of these chemicals from the sites are identified. In Section 10.5, concentrations of the indicator chemicals at potential exposure points are predicted. In Sections 10.6, 10.7 and 10.8, the chemicals are evaluated with respect to their potential impacts on public health, welfare, and the environment.

## 10.2 SELECTION OF CHEMICALS OF CONCERN

The results of environmental sampling undertaken during this remedial investigation (described in detail in Sections 5.0, 6.0 and 7.0 of this report) indicate that a large number of elements and inorganic compounds are present at the Clear Creek/Central City site. In order to focus the PHE on the chemicals that are associated with the greatest potential risk, a subset of these chemicals were selected to be evaluated in this assessment.

The selection of the chemicals of concern was based on the validated data collected during the remedial investigation from the surface water, groundwater, and tailings piles. The major category of contamination is the class of chemical elements released from mining operations. Because elements do not degrade, the major criteria used to select the chemicals of concern were concentration and toxicity. By careful selection, the chemicals of concern provide a basis to evaluate the threat to human health, welfare, and the environment which may be attributed to all chemicals associated with the site.

The selection process used to determine the chemicals of concern was developed by EPA's Office of Emergency and Remedial Response and is presented in the Superfund Public Health Evaluation Manual (EPA 1986a). A few modifications were incorporated into the methodology to resolve conflicts between regulatory guidance and the PHE manual or for materials not found in the manual. For example, the tailings piles were treated as soil because the PHE manual does not address waste as a medium. The selection of chemicals of concern is described in detail in Appendix 10D of this report.

Chemicals of concern were chosen separately for human receptors and aquatic organisms. Arsenic, chromium VI and nickel are present in relatively high concentrations in the mine tailings and have been rated by EPA as Group A human carcinogens by the inhalation pathway. Cadmium is a Group B1

carcinogen by inhalation and is a potent kidney toxin when ingested. Lead and silver were chosen as representative noncarcinogens because they are present in relatively high concentrations in the tailings and are more toxic than the other noncarcinogenic chemicals present. In addition, manganese was added as a chemical of concern at the request of EPA Region VIII.

Chemicals of concern for aquatic life were chosen based on their concentration in water, published criteria values (e.g., AWQC), and supplemental data for chemicals that lacked criteria. Four chemicals, aluminum, copper, zinc and fluoride as well as pH were chosen for detailed evaluation.

In order to be consistent and conservative, all of the chemicals of concern identified will be evaluated for all pathways and receptors in the following analysis. The complete list of chemicals is presented in Table 10-1 along with brief descriptions of the toxicological characteristics of the chemicals. Their toxicological characteristics are described in detail in Appendices 10A and 10B. These compounds represent those which pose the greatest threat to human health, welfare, or the environment.

## 10.3 HAZARD IDENTIFICATION

This section of the report presents a brief description of the key toxicological properties of the chemicals of concern at the Clear Creek/Central City site. In addition, the toxicity values recommended by EPA for use in quantitative risk assessments and any potential Applicable or Relevant and Appropriate Requirements (ARARs) are presented. (See Section 1.0 for a more detailed discussion of potential ARARs.) The toxicological effects of these selected materials in humans and aquatic life are presented in further detail in Appendices 10A and 10B.

TABLE 10-1

CHEMICALS OF CONCERN FOR THE CLEAR CREEK/CENTRAL CITY
PUBLIC HEALTH EVALUATION

| Chemical | Human Health and Aquatic Effects |
|---|---|
| Aluminum | Exposure of fish to aluminum results in the formation of a precipitate that coats the gills and impairs respiration. |
| Arsenic | Inhalation of arsenic is associated with lung cancer in humans; ingestion of arsenic has been linked to skin, bladder, liver, and lung cancer. Arsenic has been found to be embryotoxic, fetotoxic, and teratogenic in several animal species. |
| Cadmium | Cadmium has been shown to be a pulmonary carcinogen. Renal effects are associated with ingestion of cadmium. Cadmium is also a well-documented teratogen. |
| Chromium | Inhalation of chromium (Cr VI) is associated with cancer of the respiratory passages and lungs. High levels of soluble Cr VI and Cr III can produce kidney and liver damage in humans and experimental animals via a variety of exposure routes. |
| Copper | Although copper is an essential trace nutrient, exposure of fish to higher concentrations than necessary can result in osmoregulatory failure. In addition, copper inhibits photosynthesis in algae. |
| Fluoride | Although toxicity data for fluoride are sparse, exposure of trout eggs has resulted in delayed hatching. Fluoride bioaccumulates, particularly in the skeleton and gills. |
| Lead | Exposure to lead can result in anemia and nervous system alterations (brain damage, encephalopathy and subtle learning disabilities). |
| Manganese | Exposure to high levels of manganese has been reported to cause pneumonitis in humans. Chronic exposure to manganese is associated with progressive neurological disease. |
| Nickel | Inhalation of nickel and nickel compounds is associated with nasal cavity and lung cancers in humans. Nickel salts are known to produce allergic contact dermatitis. |

TABLE 10-1 (Continued)

CHEMICALS OF CONCERN FOR THE CLEAR CREEK/CENTRAL CITY
PUBLIC HEALTH EVALUATION

| Chemical | Human Health and Aquatic Effects |
|---|---|
| Silver | Acute exposure to silver results in gastrointestinal and bronchial irritation in humans and experimental animals. Argyria (a discoloration of the skin and mucous membranes) occurs in humans following chronic exposure to silver. |
| Zinc | Although zinc is an essential trace nutrient, exposure of fish to high concentrations causes edema and necrosis of the liver and necrosis of the gills. |
| pH | Low pHs adversely effect aquatic organisms both directly and indirectly, by increasing the solubility of certain metals. At pHs below 6.5, reproductive effects are seen. Below pH 3.5, lethality occurs. |

Source: Appendices 10A and 10B

### 10.3.1 ALUMINUM

#### Human Health Effects

Aluminum is generally not considered to be very toxic to humans. Injection of aluminum into the cerebrospinal fluid of animals has been shown to produce neurological changes that are histologically similar to the neurological changes seen in people with Alzheimer's disease, although some ultrastructural differences are present (EPA 1985b). EPA has not established health criteria for aluminum.

#### Toxicity to Aquatic Life

Exposure of fish to aluminum results in the formation of a precipitate that coats gill filaments and impairs respiration (Driscoll et al. 1980). Other toxic effects include slight demyelination in the brain, necrosis of the liver, and inflammatory glomerular nephrosis in kidney tissue. EPA (1986e) has proposed a continuous concentration criterion of 150 ug/liter and a 1-hour average concentration criterion of 750 ug/liter not to be exceeded more than once every 3 years. In acute assays, the most sensitive vertebrate species is the brook trout Salvelinus fontinalis, with a 96-hour $LC_{50}$ of 3600 ug/liter (Decker and Menendez 1974); the $EC_{50}$ for the green alga Selenastrum capricornutum was 460 ug/liter (Call 1984). The lowest maximum acceptable toxicant concentration was 1388 ug/liter for the cladoceran Daphnia magna (Kimball manuscript). No measured bioconcentration factors are available, but Chapman et al. (1968) estimated a bioconcentration factor of 10 for edible portions of freshwater fish.

### 10.3.2 ARSENIC

#### Human Health Effects

Arsenic is associated with an increased incidence of lung, liver, bladder, and skin cancer in individuals exposed via drinking water (Tseng et al.

1968, Chen et al. 1986) and with an increased incidence of lung cancer in occupationally exposed workers (Brown and Chu 1982). EPA's Carcinogen Assessment Group (CAG) calculated a cancer potency factor for exposure via ingestion of 15 $(mg/kg/day)^{-1}$ based on the Tseng et al. (1968) study, and calculated a "unit risk" for inhalation exposure of $1.36 \times 10^{-2}$ $(ug/m^3)^{-1}$ (equivalent to a cancer potency factor of 50 $(mg/kg/day)^{-1}$) based on several occupational studies. EPA has classified arsenic in Group A--Human Carcinogen, based on the weight of the evidence for carcinogenicity (EPA 1984a). EPA Office of Drinking Water has promulgated a Primary Drinking Water Standard (Maximum Contaminant Level (MCL)) of 50 ug/liter for arsenic and has also presented this value as a proposed Maximum Contaminant Level Goal (MCLG).

Toxicity to Aquatic Life

Toxicities of arsenic to freshwater aquatic organisms are similar for both the trivalent and pentavalent forms. Although the exact mechanisms of arsenic toxicity are not known, the main pathological effect appears to be enzyme inhibition. EPA (1984b) has established a continuous concentration criterion of 190 ug/liter for arsenic (III) and a 1-hour average concentration criterion of 360 ug/liter not to be exceeded more than once every 3 years. No criteria for arsenic (V) have been established because of insufficient data (EPA 1984b). In acute assays, invertebrates were much more sensitive than vertebrates; an $EC_{50}$ of 840 ug/liter was reported for Bosmina longirostris, and a maximum acceptable toxicant concentration of 914 ug/liter was reported for Daphnia magna. Arsenic bioaccumulates in lower forms of aquatic life more readily than in vertebrates with whole-body bioconcentration factors are 3 to 17 for the snails Stagnicola emarginata and Helisoma campanulatum, respectively (Spehar et al. 1980).

### 10.3.3 CADMIUM

Human Health Effects

Cadmium caused an increased incidence of lung tumors in mice exposed via inhalation (Takemaka et al. 1983) and has been associated with an increased incidence of cancer in occupationally exposed workers (Thun et al. 1985). Cadmium has not been shown to be carcinogenic when administered orally. Exposure via either route can lead to an accumulation of cadmium in the kidneys with subsequent dysfunction (EPA 1985c). EPA CAG calculated a "unit risk" for inhalation exposure of $1.8 \times 10^{-3}$ $(ug/m^3)^{-1}$ (equivalent to a cancer potency factor of $6.1 (mg/kg/day)^{-1}$) based on the Thun et al. (1985) study (EPA 1985c). EPA (1980a) promulgated an MCL of 10 ug/liter (equivalent to an exposure of 20 ug/day) for cadmium in drinking water based on the "generally accepted" estimate of 200 ug/g cadmium in the renal cortex as the critical concentration and Friberg et al.'s (1974) estimate that 250-350 ug/day would produce this level after 50 years of exposure. EPA has proposed an MCLG of 5 ug/liter for cadmium. EPA has classified cadmium in Group B1--Probable Human Carcinogen (by inhalation), based on the weight of the evidence for carcinogenicity (EPA 1985c).

Toxicity to Aquatic Life

Cadmium is a cumulative poison to aquatic organisms because there is almost no excretion of this metal. Studies reporting cadmium toxicity to aquatic organisms demonstrate an inverse relationship between cadmium toxicity and water hardness. EPA (1984c) recommended a 4-day average concentration criterion for cadmium not to exceed the value given by $e^{(0.7852[\ln(hardness)]-3.490)}$ and a 1-hour concentration criterion not to exceed the value given by $e^{(1.128[\ln(hardness)]-3.828)}$ more than once every 3 years. For example, at a water hardness of 50 mg/liter the 4-day and 1-hour criteria would be 0.66 and 1.8 ug/liter respectively. In both acute and chronic assays, the most sensitive species is *Daphnia magna* with a 48-hour $EC_{50}$ of 9.9 ug/liter and a maximum acceptable toxicant

concentration of 0.15 µg/liter. Whole body bioconcentration factors (BCFs) for cadmium range from 33 for rainbow trout to 2,213 for the mosquito fish (*Gambusia affinis*).

### 10.3.4 CHROMIUM

#### Human Health Effects

The toxicity of chromium is dependent to a great degree on the chemical species. Certain chromium (VI) compounds are considered to be carcinogenic by inhalation (but not by ingestion) and chromium (III) compounds are not considered to be very toxic. EPA CAG (EPA 1984d) determined a cancer potency factor for lifetime inhalation exposure to chromium (VI) of 41 $(mg/kg/day)^{-1}$ based on occupational studies (Mancuso 1975). This is equivalent to a unit risk of $1.2 \times 10^{-2}$ $(\mu g/m^3)^{-1}$ assuming a 70-kg person inhales 20 $m^3$ air/day. EPA has classified chromium (VI) in Group A--Human Carcinogen (by inhalation), based on the weight of the evidence for carcinogenicity (EPA 1984d). EPA promulgated an MCL of 50 µg/liter for chromium (VI) but has recently proposed an MCLG of 120 µg/liter for total chromium.

#### Toxicity to Aquatic Life

For freshwater aquatic organisms, chromium (VI) appears to be more toxic than chromium (III). Freshwater fish generally appear to be more tolerant of chromium than invertebrates. Slowed growth, increased locomotor activity, and enzyme inhibition have been reported following chronic exposure. EPA (1984e) has established a continuous concentration criterion for chromium (VI) of 11 mg/liter not to be exceeded more than once every 3 years. In acute assays, the most sensitive species is the scud (*Gammarus pseudolimnaeum*) with a 48-hour $EC_{50}$ of 67 µg/liter. In chronic tests, the most sensitive species was the rainbow trout (*Salmo gairdneri*) with a maximum acceptable toxicant concentration of 71 µg/liter (Sauter et al.

1976). Chromium is not highly bioconcentrated: Calamari (1981) has calculated a whole body bioconcentration factor of 3.4 for rainbow trout based on uptake and depuration.

### 10.3.5 COPPER

#### Human Health Effects

Copper is not a potent toxic agent to humans (EPA 1980b, 1984f). The current EPA secondary drinking water standard is 1 mg/liter, based on copper's organoleptic properties rather than on its toxicity (EPA 1980b). The EPA Office of Drinking Water has proposed an MCLG for copper of 1.3 mg/liter based on the occurrence of gastrointestinal effects in man (EPA 1985b, 1984f). EPA has determined oral and inhalation RfDs of $3.7 \times 10^{-2}$ and $1 \times 10^{-2}$ mg/kg/day, respectively.

#### Toxicity to Aquatic Life

The primary mechanism of copper toxicity in aquatic organisms is osmoregulatory disruption and failure (Rand and Petrocelli 1985). Copper toxicity decreases with increasing water hardness. EPA (1985f) recommended that the 4-day average concentration of copper (in ug/liter) should not exceed the value given by $e^{(0.8545[\ln(\text{hardness})]-1.465)}$, and the 1-hour average concentration should not exceed the value given by $e^{(0.942[\ln(\text{hardness})]-1.464)}$. For example, at a water hardness of 50 mg/liter, the 4-day and 1-hour criteria would be 6.5 and 9.2 ug/liter, respectively. In acute assays, the most sensitive species is Daphnia magna with an $EC_{50}$ of 6.5 ug/liter (Chapman et al. manuscript). However, an $EC_{50}$ of 1 ug/liter based on growth reduction is reported for the green alga Chlorella sp. (Steeman-Nielsen and Wium-Anderson 1970). The lowest maximum acceptable toxicant concentration was 3.873 ug/liter for the brook trout (Sauter et al. 1976). Continued ingestion of copper in excess of nutritional requirements leads to accumulation, especially in the liver



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(Rand and Petrocelli 1985). A muscle bioconcentration factor of 1.0 was reported for the bluegill *Lepomis macrochirus* exposed for 560 days (Benoit 1975).

10.3.6 FLUORIDE

Human Health Effects

Fluoride in drinking water is effective in preventing dental caries at levels around 1 mg/liter. At levels above 2 mg/liter, fluoride can cause moderate to severe dental fluorosis ranging from brown stains on the teeth to pitting of the enamel and a corroded appearance of the teeth. At levels above 4 mg/liter, fluoride can cause skeletal fluorosis, ranging from slight osteosclerosis (increased bone density) to a severe crippling fluorosis (EPA 1985d). EPA has established an MCL of 4 mg/liter to protect against the effects of skeletal fluorosis and has also established a secondary drinking water standard of 2 mg/liter to protect against the cosmetic effects of dental fluorosis (EPA 1985e).

oxicity to Aquatic Life

luoride is not a potent toxic agent to freshwater aquatic species, wever, data are extremely limited. Studies using rainbow trout indicate at water hardness may have an antagonistic effect on fluoride toxicity. 4-week $LC_{50}$ of 8,500 ug/liter was reported in soft water; in hard water centrations up to 25,000 ug/liter resulted in no increased mortality rbert and Shurben 1964). EPA has not established criteria for fluoride d on protection of aquatic life. In acute assays, the most sensitive ies is the rainbow trout with a 48-hour $LC_{50}$ of 2,700 ug/liter. nic data are insufficient to calculate a maximum acceptable toxicant entration. Reproductive effects, including premature hatching and ded development, were reported in frog eggs kept in well water ining 1,000 ug/liter fluoride (Cameron 1940) and delayed hatching was ted in trout eggs exposed to 1,500 ug/liter fluoride (Ellis et al.

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(Rand and Petrocelli 1985). A muscle bioconcentration factor of 1.0 was reported for the bluegill Lepomis macrochirus exposed for 660 days (Benoit 1975).

10.3.6 FLUORIDE

Human Health Effects

Fluoride in drinking water is effective in preventing dental caries at levels around 1 mg/liter. At levels above 2 mg/liter, fluoride can cause moderate to severe dental fluorosis ranging from brown stains on the teeth to pitting of the enamel and a corroded appearance of the teeth. At levels above 4 mg/liter, fluoride can cause skeletal fluorosis, ranging from slight osteosclerosis (increased bone density) to a severe crippling fluorosis (EPA 1985d). EPA has established an MCL of 4 mg/liter to protect against the effects of skeletal fluorosis and has also established a secondary drinking water standard of 2 mg/liter to protect against the cosmetic effects of dental fluorosis (EPA 1985e).

Toxicity to Aquatic Life

Fluoride is not a potent toxic agent to freshwater aquatic species, however, data are extremely limited. Studies using rainbow trout indicate that water hardness may have an antagonistic effect on fluoride toxicity. A 1-week $LC_{50}$ of 8,500 ug/liter was reported in soft water; in hard water concentrations up to 75,000 ug/liter resulted in no increased mortality (Herbert and Shurben 1964). EPA has not established criteria for fluoride based on protection of aquatic life. In acute assays, the most sensitive species is the rainbow trout with a 48-hour $LC_{50}$ of 2,700 ug/liter. Chronic data are insufficient to calculate a maximum acceptable toxicant concentration. Reproductive effects, including premature hatching and retarded development, were reported in frog eggs kept in well water containing 1,000 ug/liter fluoride (Cameron 1940) and delayed hatching was reported in trout eggs exposed to 1,500 ug/liter fluoride (Ellis et al.

1948). Bioaccumulation of significant amounts of fluoride have been reported in aquatic organisms, primarily in the skeleton and gills (NRCC 1977). A bioconcentration factor of 1.3 is reported in trout fillets (Groth 1975).

### 10.3.7 LEAD

#### Human Health Effects

Lead has been shown to cause adverse neurological effects in humans, and particularly in young children and fetuses, even when exposed to relatively low levels. The Centers for Disease Control (CDC) currently define "lead toxicity" in a child as a blood lead level greater than 25 µg/dl and an erythrocyte protoporphyrin level greater than 35 µg/dl (CDC 1985). EPA has established an ambient air quality standard for lead of 1.5 $\mu g/m^3$ and an MCL for drinking water of 50 µg/liter. Both of these standards are currently undergoing review by EPA (1984g) and EPA Office of Drinking Water has proposed an MCLG of 20 µg/liter for lead.

#### Toxicity to Aquatic Life

The primary mechanism of acute toxicity of lead to freshwater organisms is unknown. A dietary deficiency of calcium increases the storage of lead in tissues, probably due to redistribution of lead from storage in bone (Rand and Petrocelli 1985). Lead toxicity decreases with increasing water hardness. EPA (1985f) has established a 4-day average concentration criterion for lead not to exceed the value given by $e^{(1.266[\ln(hardness)]-4.661)}$, and a 1-hour average concentration criterion not to exceed the value given by $e^{(1.266[\ln(hardness)]-1.416)}$ more than once every 3 years. For example, at a water hardness of 50 mg/liter $CaCO_3$, the 4-day and 1-hr criteria would be 1.3 and 34 µg/liter, respectively. In acute assays, invertebrate species are more sensitive than vertebrate species. A 48-hour $EC_{50}$ of 124 µg/liter is reported for the seed at a water hardness of 46 mg/liter $CaCO_3$ (Spehar et al. 1978a,b). The lowest

maximum acceptable toxicant concentration from chronic studies is 19 ug/liter for rainbow trout at a water hardness of 103 mg/liter $CaCO_3$ (Davies et al. 1976). A whole-body bioconcentration factor of 45 was reported using a natural small lake population of bluegills (Atchison et al. 1977).

### 10.1.8 MANGANESE

#### Human Health Effects

Chronic occupational exposure to manganese-containing dust has been associated with neurological effects similar to Parkinson's disease (EPA 1984h,i). Although the workers were apparently exposed by inhalation, there is some evidence that much of the inhaled manganese is subsequently coughed up and ingested. One case study of a family that ingested contaminated drinking water and then exhibited symptoms of manganese poisoning also suggests that manganese is toxic when ingested. Chronic exposure to manganese also affects the hematopoietic system. EPA calculated RfDs of 0.22 mg/kg/day and $1.2 \times 10^{-4}$ mg/kg/day for oral and inhalation exposure to manganese and has also established a secondary drinking water standard of 50 ug/liter based on organoleptic effects (EPA 1986f).

#### Toxicity to Aquatic Life

Manganese is a micronutrient for both plants and animals and is not considered to be highly toxic to freshwater organisms. EPA has not established criteria for manganese based on protection of aquatic life: McKee and Wolf (1963) reported that 1,000 ug/liter manganese was not toxic to fish and other aquatic organisms, although Birge et al. (1981) reported a 4-day early-life stage $EC_{10}$ of 958 ug/liter in rainbow trout. In acute assays, the most sensitive organism was a killifish (*Fundulus* sp.), with a lethal concentration of 12,000 ug/liter manganese as manganese chloride.

Data for other freshwater fish indicate that this value may be low; other acute values range from 500,000 µg/liter to 4,850,000 µg/liter.

10.3.9 NICKEL

Human Health Effects

Occupational exposure in the nickel refinery industry has been associated with an increased incidence of cancers of the nasal cavity and lung. It is generally felt that some specific forms of nickel are responsible for this carcinogenicity, but it is difficult to determine which specific compounds are carcinogenic. Nickel is not considered to be carcinogenic by the oral route of exposure. EPA's Carcinogen Assessment Group calculated a cancer potency factor of 1.15 $(mg/kg/day)^{-1}$ for nickel based on epidemiological studies of nickel refinery workers (EPA 1983). Nickel can be classified in Group A--Human Carcinogen, based on the weight of evidence for carcinogenicity (EPA 1986b). EPA calculated an RfD of 0.01 mg/kg/day for oral exposure to nickel (EPA 1986d).

Toxicity to Aquatic Life

Adverse effects in aquatic organisms associated with nickel exposure include alteration of cell membranes, formation of precipitates on gills, hematological effects and reproductive impairment (Birge et al. 1981, EPA 1986b). Toxicity of nickel to freshwater organisms decreases with increasing water hardness. EPA (1986i) has proposed a 4-day average concentration criterion not to exceed the value given by $e^{(0.8460[\ln(hardness)]-1.1645)}$ and a 1-hour average concentration criterion not to exceed the value given by $e^{(0.8460[\ln(hardness)]+3.3612)}$ more than once every 3 years. For example, at a water hardness of 50 mg/liter $CaCO_3$, the 4-day and 1-hour criteria would be 88 and 790 µg/liter, respectively. Nickel does not appear to be highly bioconcentrated in edible tissue of fish. Calamari et al. (1981) calculated a bioconcentration factor of 1.1 for rainbow trout muscle tissue based on uptake and depuration.

## 10.3.10 SILVER

### Human Health Effects

The primary effect of chronic exposure to silver is argyria, a permanent bluish, metallic discoloration of the skin and mucous membranes (EPA 1985g). EPA established an MCL of 50 ug/liter to protect against this effect (EPA 1985g). EPA is considering revising this standard and has proposed a guidance level of 90 ug/liter for silver in water. This value corresponds to an oral RfD of 0.003 mg/kg/day (EPA 1986f).

### Toxicity to Aquatic Life

Silver is one of the most toxic metals to aquatic organisms, and was particularly toxic to development stages of rainbow trout (Birge et al. 1981). Water hardness has an antagonistic effect on acute toxicity of silver. EPA (1980c) has established a criterion for silver not to exceed the value given by $e^{(1.72[\ln(\text{hardness})]-6.52)}$ at any time. For example, at a water hardness of 50 mg/liter, the acute criterion would be 1.2 ug/liter. Data indicate that chronic toxicity to freshwater aquatic life may occur at concentrations as low as 0.12 ug/liter. Although no measured bioconcentration factors were available for silver, Chapman et al. (1968) have estimated a BCF of 3,080 for edible portions of freshwater fish.

## 10.3.11 ZINC

### Human Health Effects

Zinc is not highly toxic to humans and is, in fact, an essential element (EPA 1984j). Zinc salts of strong acids are astringent and corrosive. An oral reference dose of 0.21 mg/kg/day was derived by EPA (1984j) based on the occurrence of anemia and reduced blood copper in some patients

receiving therapeutic doses of approximately 150 mg/day zinc for extended periods of time. An inhalation RfD of 0.01 mg/kg/day has also been estimated for zinc (EPA 1986f).

Toxicity to Aquatic Life

Zinc is an essential trace nutrient important to cell growth and differentiation. Exposure to sublethal concentrations of zinc causes extensive edema and necrosis of liver tissue. Death results from gill necrosis and hypoxia. Zinc toxicity is dependent on water hardness. EPA (1986j) has proposed that the one-hour average concentration for total recoverable zinc should not exceed the value given by $e^{(0.8195\{\ln(hardness)\}+0.7871)}$ ug/liter, and the 4-day average should not exceed the value given by $e^{(0.8195\{\ln(hardness)\}+0.6881)}$. For example, at a water hardness of 50 mg/liter, the 1-hour and 4-day criteria would be 54 and 49 ug/liter, respectively. The most sensitive vertebrate species in acute assays is the rainbow trout with a 96-hour $LC_{50}$ of 90 ug/liter (Carton 1972); however, a 7-day $EC_{50}$ of 30 ug/liter based on growth inhibition was reported for the green alga Selenastrum capricornutum (Bartlett et al. 1974). In chronic studies a maximum acceptable toxicant concentration of 47 ug/liter was reported for both Daphnia magna and flagfish Jordanella floridae (Biesinger and Christensen 1972, Spehar 1978b). A whole body bioconcentration factor of 432 was reported for the flagfish following 100 days of exposure (Spehar et al. 1978b).

10.1.12 pH

Human Health Effects

The pH at which effects, either irritation or severe burning, are observed varies depending on the properties of the acid. Hydrochloric acid causes severe damage at a pH of 1 and has essentially no effect at a pH of 3. On the other hand, certain buffered solutions cause discomfort at a pH of 4.5. Corrosive burns may result from skin or eye contact with strong acids or

from ingesting them. The eye is sensitive to the corrosive effects of acid. The extent of eye damage is a function of several factors including the pH of the solution, the heat of hydration, and the capacity of the anion to combine with protein of the corneal tissue. The damage noted in the first few hours after contact is a measure of the long-term effects that may be expected. Acid burns in the eye may heal completely or may result in complete opacity.

Toxicity of Aquatic Life

EPA has suggested that a pH range of 6.5 to 9.0 will provide adequate protection for freshwater fish and in vertebrates (EPA 1986k). At a pH between 5.0 and 6.5, adverse reproductive effects are seen in a wide variety of species, including fathead minnows, salmonids and bass. Below pH 3.5, acute lethality occurs (CRS 1984). In the presence of certain cations such as calcium dioxide, stress can become significant in acidified hard water (CRS 1984).

## 10.4 PATHWAY ANALYSIS

A complete environmental exposure pathway is composed of four necessary elements: (1) a source and mechanism of chemical release to the environment, (2) an environmental transport medium (e.g., air, groundwater) for the released chemical, (3) a point of potential contact with the contaminated medium (the exposure point), and (4) an exposure route at the contact point. Potential pathways of exposure to contaminants released from the Clear Creek/Central City site are presented in Table 10-2. Only pathways that are considered to be potentially complete are included in this table. For each exposure pathway identified, the probability of significant exposure is qualitatively evaluated, based on best professional judgment, with reference only to the frequency and duration of exposure and not to the toxic potential or the concentration of the chemicals.

TABLE 10-2

POTENTIAL PATHWAYS OF EXPOSURE TO CONTAMINANTS ORIGINATING FROM CLEAR CREEK/CENTRAL CITY SITE

| Exposure Medium | Release Mechanism | Exposed Population | Exposure Point | Potential Exposure Route |
|---|---|---|---|---|
| Surface Water | Surface Runoff Groundwater Discharge | Aquatic life | North Clear Creek; Clear Creek | Direct contact; ingestion |
| | | Wetland community | Marsh at National Tunnel | Direct contact; ingestion |
| | | Communities using surface water downstream from sites | Homes in Golden | Ingestion |
| | | Swimmers | Clear Creek | Direct contact; incidental ingestion |
| | | Tourists visiting historical sites | Ponded water at portals of Argo and Big Five mine | Direct contact |
| | | Livestock/Irrigated crops | Permitted diversions | Direct contact; uptake; ingestion |
| | Bioaccumulation of metals | Individuals consuming fish | North Clear Creek; Clear Creek | Ingestion |
| Groundwater | Percolation through mine tailings; percolation of of tunnel discharges | Individuals using groundwater for drinking water | Alluvial wells near North Clear Creek and Clear Creek | Ingestion |
| Air | Wind entrainment of dust from tailings piles | Individuals at or near site | Gregory and Argo Tailings Piles | Inhalation |
| | Dust generation from human activities (e.g., motorcycle riding) | Individuals at or near site | Gregory Tailings Piles | Inhalation |
| Soil Tailings | Contaminated surface soil and tailings | Tourists and children walking or playing in tailings piles | Gregory and Argo Tailings Piles | Direct contact; incidental ingestion |

In the following sections, each exposure pathway is discussed and the rationale for selecting the exposure points is explained. In Section 10.5, the concentrations at each exposure point will be quantified and the dose to potential receptors will be estimated.

### 10.4.1 SURFACE WATER

Several of the exposure pathways presented in Table 10-1 involve surface water as the exposure medium. The potential receptors include both aquatic communities and human populations. The aquatic communities in both Clear Creek and North Clear Creek have been affected by the mining activities in the area (see Section 9.0). In addition to the aquatic communities in the streams, one wetland area was identified in the study area and will be included in the assessment. This wetland is adjacent to North Clear Creek and intercepts discharge from National Tunnel.

Individuals may be exposed to chemicals in surface water, either directly by ingesting or contacting water, or indirectly, by ingesting fish that have bioaccumulated chemicals. The first drinking water intake from surface water downstream from the mine discharges is at the City of Golden, 12.5 miles downstream from the junction of Clear Creek and North Clear Creek. About 15,000 people are served by the City of Golden water system. Peak water demands in the past have ranged from 6 to 9 million gallons/day (see Section 2.5 of this report). Both dermal contact and incidental ingestion of water are likely to occur when swimming. Swimming is known to occur in Clear Creek upstream from the junction with North Clear Creek.

The Argo and Gregory sites are the biggest tourist attractions of the mine sites evaluated in this PRE. Visiting tourists to the mines may dabble their hands in ponded water or mine discharge. The discharge from the Argo tunnel is easily accessible to visitors because the footpath to the portal used by tourists runs parallel to the discharge stream. Although the Big Five mine is not a well-known tourist spot, the pond may attract visitors.

This pathway is not of concern for chronic exposure, because regular, long term contact is not expected. However, acute skin irritation may occur if the discharge is sufficiently acidic.

There are several permitted diversions of Clear Creek and North Clear Creek water. Originally, these diversions were permitted for agricultural uses such as irrigating crops and watering livestock. Available information indicates that such uses are currently very limited. For example, deep aquifer wells are generally used to water livestock. Water from diversionary canals appears to be used primarily for industrial and municipal purposes (e.g., watering parkland) and may be treated before use. Although use of Clear Creek and North Clear Creek water for agricultural purposes may result in exposures to crops and livestock, the lack of information about these uses precludes the consideration of agricultural pathways in this report.

10.4.2 GROUNDWATER

As discussed in Section 7.0, high concentrations of metals are present in the alluvial ground water wells installed on or near all five sites. The extent of these elevated levels cannot presently be determined because the upgradient wells also contained elevated concentrations. The extent and nature of this ground water contamination will be the subject of additional investigations (see Section 14.0).

Contamination of the alluvial aquifer may also occur if water percolates through mine tailings, or if mine discharge percolates through the soil, leaching metals from the tailings or soil. As discussed in Section 7.0, water from the Argo tunnel will most likely discharge directly into adjacent surface water, with little opportunity to percolate through the soil into the groundwater. Discharge from the National Tunnel flows in a well-defined channel to the wetland that is adjacent to North Clear Creek and probably contributes minimally to groundwater contamination. Discharge from the Big Five and Quartz Hill mines however, flows slowly (and is

ponded at the Big Five mine) and hence may contribute to the release of metals to the groundwater near these sites. At the Gregory Incline site, ground water moves through the tailings and discharges as a seep on the crib wall.

There is little information on the use of alluvial groundwater in the Clear Creek drainage basin for drinking water. Most of the drinking-water wells appear to be screened in the uncontaminated bedrock below the alluvial aquifer, but there are at least two wells in the drainage basin that are screened in the alluvial aquifer (see Section 7.0). Exposure to chemicals in the alluvial groundwater will be assessed for two hypothetical wells, one in the North Clear Creek subbasin and one in the mainstem of Clear Creek subbasin.

10.4.3 AIR

Exposure to metals in tailings or soil can potentially occur through inhalation of dust by people at or near the sites. Two mechanisms for dust generation will be considered: 1) dust resulting from wind entrainment of tailings or soil particles; and 2) dust generated from human activities (in particular, riding of dirt bikes on the tailings piles and generation of wind by a helicopter using the heliport). The Gregory tailings pile are readily accessible and in some areas are quite compacted or have a surface crust. Dirt-bike riding is known to occur at the Gregory tailings piles, where the helicopter pad is also located. The Argo tailings are also readily accessible but are less compacted and more friable than the Gregory tailings. The Argo tailings are not used extensively by dirt-bike riders due to their steepness. Currently, however, waste rock at Argo is being removed for use in constructing roads. The activity, including operation of dump trucks and front-end loaders, will increase dust emissions from this area. In addition, there are tailings and waste rock piles associated with other areas of the Clear Creek/Central City site; however, there are insufficient sampling data available to quantitatively evaluate risk due to dust emissions from these sources.

### 10.4.4 SOIL/TAILINGS

In addition to inhalation, exposure to metals in soil or tailings can also occur by direct dermal contact with these materials and by incidental ingestion. Tourists visiting the mines may contact the tailings, although the potential for significant exposure is low. Older children living in the area, particularly those from ages 6 to 16 who have less parental supervision than younger children, may play or ride dirt bikes at the tailings piles. The potential for this type of exposure would be greater in the summer months when school is out and summer clothing expose more skin. The Argo waste rock pile and the Gregory tailings pile will be used to evaluate this exposure pathway.

## 10.5 EXPOSURE ASSESSMENT

### 10.5.1 METHODOLOGY

In this section, data collected during the remedial investigation are used to estimate the extent and duration of human exposure in the absence of further remediation. For each pathway described in Section 10.4, exposure scenarios are constructed and geometric mean and maximum exposure point concentrations are presented. Catastrophic cases are also evaluated for scenarios for which it is appropriate and when sufficient data are available. The exposure point concentrations are compared with federal or state standards (applicable or relevant and appropriate requirements, or ARARs) that exist for the chemicals in a particular medium (e.g., water or air). In addition, daily intake values for chronic exposure (CDIs) are estimated for average and maximum plausible cases. In general, geometric mean concentrations are used to calculate the average intake estimates, and maximum concentrations will be used to calculate intake for the maximum plausible cases. These concentrations are provided in Table 10-3. As in previous sections, if values were reported as less than the detection limit, the value of the detection limit was used in calculating the mean concentration. This is a conservative approach resulting in maximum

TABLE 10-3
EXPOSURE POINT CONCENTRATIONS FOR AQUATIC AND WILDLIFE COMMUNITIES

Water Concentrations (ug/liter)[a,b]

| Chemical | Clear Creek Geometric Mean | Clear Creek Maximum | North Clear Creek Geometric Mean | North Clear Creek Maximum | Marsh Below the National Tunnel Geometric Mean | Marsh Below the National Tunnel Maximum | Clear Creek Below Confluence Geometric Mean | Clear Creek Below Confluence Maximum |
|---|---|---|---|---|---|---|---|---|
| Aluminum | 855 | 1160 | 637 | 946 | 496 | 788 | 378 | 633 |
| Arsenic | 4.36 | 10.0 | ND | ND | 9.28 | 10.0 | 3.94 | 10.0 |
| Cadmium | 3.20 | 7.00 | 5.48 | 14.0 | 5.16 | 6.7 | 2.51 | 5.00 |
| Chromium | ND | ND | 4.85 | 8.00 | 5.54 | 7.10 | 4.76 | 8.00 |
| Copper | 121 | 285 | 69 | 166 | 196 | 284 | 40.7 | 51.0 |
| Fluoride | 670 | 920 | 160 | 220 | 550 | 400 | 575 | 770 |
| Lead | 8.10 | 15.0 | 8.75 | 15.0 | 17.1 | 50.0 | 4.95 | 8.00 |
| Manganese | 1530 | 6220 | 1660 | 4660 | 11900 | 17200 | 1250 | 2300 |
| Nickel | 6.67 | 20.0 | 21.8 | 36.0 | 121 | 217 | 9.85 | 20.0 |
| Silver | 0.670 | 5.00 | 0.67 | 5.00 | 0.610 | 4.00 | 0.669 | 5.00 |
| Zinc | 733 | 2210 | 863 | 1870 | 4390 | 6700 | 485 | 793 |
| pH | 7.2 | 7.2 | 5.7 | 5.7 | 3.7 | 3.4 | 6.8 | 7.1 |

a. Sampling stations used to calculate exposure point concentrations were SW-21, SW-5, SW-7 and SW-2 for Clear Creek, North Clear Creek, the Marsh Below National Tunnel and Clear Creek below Confluence, respectively (see Figures 4-9 and 4-10)

b. Water concentrations are total metal, except for fluoride, which is dissolved.

ND = Not Detected. Detection limits for chromium ranged from 4.8 - 8.0 ug/liter. Detection limits for arsenic ranged from 7.9 - 10.0 ug/liter.

concentrations. Some of the geometric mean values reported in Table 10-3 are slightly different than those reported in Appendix 6F, Statistical Summaries for Surface Water Data. This is due to some changes during final quality control checks. The changes were typically small in mean values only and do not effect the conclusions of this section.

Different exposure assumptions may also be used in estimating intakes for the average and maximum plausible cases. In Section 10.6, the CDI values are used in conjunction with their corresponding potency factors for chemicals that are potential carcinogens or to reference doses (RfDs) for chemicals that exhibit noncarcinogenic effects. Chronic daily intakes are calculated for the exposure period, assumed to be a lifetime for all exposure pathways except for swimming and direct contact to the tailings piles. When assessing carcinogenic risk in Section 10.6, the exposures from these two pathways will be prorated over a lifetime. In Section 10.7, the surface water exposure point concentrations will be used to evaluate the risks to aquatic communities.

### 10.5.2 SURFACE WATER EXPOSURE PATHWAYS

In this section, exposure point concentrations and chronic daily intakes are presented for surface water exposure pathways. In general, total concentrations were used in the calculations because these were considered to be more relevant for the exposure pathways considered. Only dissolved concentrations were available for fluoride. Geometric means were calculated using detected concentrations and the sample detection limit for undetected concentrations. If a particular chemical was not detected in any of the samples at a given location, it was not considered in the corresponding pathway.

<u>Aquatic and Wetland Organisms</u>

The surface water concentrations used in this assessment for the exposure of aquatic and wetland communities are shown in Table 10-3. Exposure point

concentrations are presented for North Clear Creek, the mainstem of Clear Creek, and the wetland below the National tunnel. Surface water samples taken at stations SW-21 and SW-5 (see Figures 4-9 and 4-10) were used to calculate the exposure point concentrations for Clear Creek and North Clear Creek, respectively. These stations were chosen because they are below the major discharges to the two branches of Clear Creek yet above their confluence. Total metal concentrations rather than dissolved concentrations were used because particulate and complexed metal forms are readily available to many aquatic animals, and most aquatic toxicity data are based on total metal concentrations (Black 1985). In addition, EPA has recommended that total recoverable metal concentrations be compared to the Ambient Water Quality Criteria until protocols for measuring the "acid-soluble" fractions of metals have been approved (EPA 1985f, 1986i,j). The "total" metal concentrations used in this evaluation were measured by Contract Laboratory Program procedures. The procedures and results are similar to "total-recoverable" values (see Appendix 10E for a detailed discussion).

Drinking Water

The City of Golden diverts water from Clear Creek to be used for drinking water. Because limited samples of Golden drinking water were taken, exposure to metals via this pathway cannot be quantitatively assessed. However, using knowledge of water treatment processes, some qualitative statements can be made which can then be compared with the raw and treated water sampling results. Initially, water from Clear Creek is diverted through an intake structure into a settling basin to allow natural particulates to settle out of solution. Following this initial settling, various chemicals, such as potassium permanganate ($KMnO_4$), iron sulfate ($FeSO_4$), and alum or lime, are added to oxidize and/or precipitate the remaining heavy metals. (A discussion will follow regarding the effectiveness of these chemicals on the removal of the chemicals of concern). Next, the water is diverted to a clarifier where the

precipitates settle out of solution. The final treatment step involves the addition of carbon to the clarifier discharge which is filtered and chlorinated prior to distribution.

The ability of the water treatment chemicals to remove the inorganic chemicals of concern depends on many factors including the treatment method, pH, oxidation state of the element, and turbidity. The various inorganics present in the Clear Creek water may undergo different types of reactions during the removal process. In addition, some of the inorganics will be removed more effectively by certain types of treatments than others. It is assumed that the City of Golden adds chemicals in adequate proportions to effectively remove the undesirable inorganic components. Results currently available from the City of Golden indicate that treatment is adequate. The following discussion is not specific for the City of Golden treatment plant and is intended to provide general information on the chemicals used for treatment with respect to the inorganics present.

Arsenic is generally present in water in either the +3 or the +5 oxidation state. Iron sulfate and alum are generally used as coagulants to precipitate arsenic. The effectiveness of these coagulants depend upon the initial oxidation state of arsenic. Sorg and Logsdon (1978) summarized the results of several investigations on water treatment technologies and reported that iron sulfate was the most effective additive for removing arsenic and that it removed arsenic (V) more efficiently than arsenic (III). Lime was found to be more effective at removing arsenic (V), than arsenic (III), although removal of arsenic (III) increased with increasing pH. Activated carbon was not effective at removing arsenic.

Cadmium removal from water treated with iron sulfate or alum was found to be pH dependent, decreasing as pH increased from 7 to 9-10 (Sorg and Logsdon 1978). Iron sulfate was more effective at removing cadmium than alum. Under the conditions studied, alum removed no more than 80% of the cadmium present; at pH 9, iron sulfate removed about 100%. Lime removed virtually all of the cadmium present in the pH 8.5-11.3 range. Although

activated carbon was effective in removing cadmium from water, the doses that were required to be effective would be too large to be economically used for this purpose at treatment plants.

Chromium (VI) was not removed by iron sulfate or alum. Iron (II) was found to reduce chromium (VI) to chromium (III) which could then be precipitated from solution as chromium hydroxide. However, the pH needed for reduction is not comparable with the pH of water generally found in water treatment plants (Faust and Aly 1983). Lime and activated carbon also did not effectively remove chromium (VI). An anion exchanger, however, was found to be effective at removing chromium (VI) (Faust and Aly 1983).

Copper has not been widely studied in terms of water treatment technology. Copper can be sorbed onto hydrous oxides of manganese and iron in the pH ranges of 0.5-3.0 and 4.3-6.5, respectively. The use of manganese oxides will not be a particularly effective water treatment (Faust and Aly 1983). However, in a study using a mixture of metals in the presence of metal-fulvic acid complexes and alum, alum was found to remove the copper complex (Truitt and Weber 1979).

Fluoride is generally added during the water treatment process rather than removed. Most treatment processes are not effective in removing fluoride (Sorg 1978, Faust and Aly 1983). Very large amounts of alum were found to remove only small amounts of fluoride. Lime was found to remove fluoride by coprecipitation with magnesium hydroxide. Activated carbon could remove fluoride but only at a pH of less than 3 (Sorg 1978, Faust and Aly 1983). Faust and Aly (1983) reported that activated alumina was an excellent remover of fluoride, and alumina is slightly specific for fluoride.

Lead was effectively removed from water by alum and iron sulfate in the pH range of 6 to 8. Lime was found to be more effective than alum or iron sulfate at lower pHs. Although activated carbon can remove some lead, large amounts must be added and this method is not as cost effective as alum or iron sulfate (Sorg and Logsdon 1978).

Silver is not effectively removed from water by conventional treatment technologies. In the pH range of 6 to 8, neither alum nor iron sulfate effectively removed silver. Lime was only moderately effective. The ability of activated carbon to remove silver increased with increasing silver concentrations. This could ultimately become cost prohibitive.

Based upon the above analysis, it is expected that the treatment processes used by the City of Golden will remove or significantly reduce the inorganic ions discussed above. It is likely that the treatment processes will also effectively reduce concentrations of other metals such as aluminum, manganese, nickel, and zinc. Aluminum and manganese are expected to precipitate out as the oxides. Zinc is likely to precipitate as the hydroxide or be sorbed onto iron and manganese oxides and thereby removed from the water (Faust and Aly 1983). Nickel is also expected to sorb to manganese and iron oxides (Montgomery 1985).

The City of Golden Water Treatment Plant samples raw and tap water and analyzes it for water quality parameters. Raw water data for the chemicals of concern were available for July 18, 1985 and October 29, 1985 and are summarized in Table 10-4. These data were used because the dates correspond to sampling episodes during the RI. As observed, the data collected at SW002 (Clear Creek below North Clear Creek) compares very well with the data collected by the City of Golden. The data indicate that only minor dilution occurs between SW002 and the City of Golden. In addition, for several elements, a comparison of raw and tap water is provided in Table 10-4. These data indicate that substantial reductions (a minimum of 10%) in aluminum and manganese concentrations occur with treatment.

Swimming

The exposure point concentrations and daily intakes for individuals swimming in Clear Creek are shown in Table 10-5. The exposure point

TABLE 10-4

CITY OF GOLDEN SAMPLES
(all samples in mg/liter)

| Parameter | SV002 07/18/85 | Golden Raw Water 07/18/85 | Golden Raw Water 10/29/85 | Golden Raw Water mean 1986 | Golden Tap Water mean 1986 |
|---|---|---|---|---|---|
| Aluminum | 0.371 | 0.296 | - | 0.462[a] | 0.0466[a] |
| Arsenic | <0.003 | <0.005 | - | - | - |
| Cadmium | <0.001 | 0.0014 | 0.0027 | - | - |
| Chromium | <0.004 | <0.001 | <0.006 | BDL[b] | BDL[b] |
| Fluoride | 0.43 | - | 0.797[c] | - | - |
| Lead | 0.008 | 0.008 | - | 0.0012[d] | 0.0012[d] |
| Manganese | 0.555 | 0.460 | - | 1.27[a,e] | 0.016[a,e] |
| Silver | 0.0001 | 0.0005 | <0.0008 | 0.0002[f] | 0.0001[f] |
| pH | 7.5 | 7.855 | 7.838 | - | - |

[a]Sampled June 2-4, 1986
[b]Sampled April 23, 1986
[c]Sampled January 20, 1986
[d]Sampled April 24-25, 1986
[e]Sampled February 3-5, 1986
[f]Sampled April 7, 1986

BDL = below detection limit
"-" = Not Measured

TABLE 10-5
EXPOSURE POINT CONCENTRATIONS AND CHRONIC DAILY INTAKES FOR THE SWIMMING EXPOSURE PATHWAY

| Chemical | Exposure Point Concentration (ug/liter) Geometric Mean | Maximum | Chronic Daily Intakes (mg/kg/day) Average Case | Maximum Plausible Case |
|---|---|---|---|---|
| Aluminum | 655 | 1380 | 4.2E-04 | 6.8E-04 |
| Arsenic | 4.36 | 10.0 | 2.2E-06 | 4.9E-06 |
| Cadmium | 3.20 | 7.00 | 1.6E-06 | 3.5E-06 |
| Chromium | ND | ND | NQ | NQ |
| Copper | 121 | 285 | 6.0E-05 | 1.4E-04 |
| Fluoride | 670 | 920 | 3.3E-04 | 4.5E-04 |
| Lead | 6.10 | 15.0 | 3.0E-06 | 7.4E-06 |
| Manganese | 1510 | 6220 | 7.5E-04 | 3.1E-03 |
| Nickel | 6.67 | 20.0 | 3.3E-06 | 9.9E-06 |
| Silver | 0.670 | 5.00 | 3.3E-07 | 2.5E-06 |
| Zinc | 731 | 2710 | 3.6E-04 | 1.3E-03 |
| pH | 7.2 | 7.2 | NQ | NQ |

a. Data from Sampling Stations SW 21 were used to calculate exposure point concentrations (see Figure 10-1).

b. The Assumptions used to estimate chronic daily intakes were presented in Table 10-4.

ND = Not detected, detection limit for chromium ranged from 4.0 - 8.0 ug/liter.
NQ = Not quantified

concentrations were calculated from total metal concentrations taken from sampling station SW-21, which is downstream from the discharges to Clear Creek.

Swimmers can be exposed to metals in the water by dermal contact and also by incidental ingestion of water while swimming. The chronic daily intakes (CDIs) for this exposure pathway were estimated using the following equation:

$$CDI_S = (DI_D + DI_I) \times F/BW$$

where

$CDI_S$ = chronic daily intake for swimming (mg/kg/day);

$DI_D$ = intake from dermal contact (mg/event);

$DI_I$ = intake from incidental ingestion (mg/event);

F = frequency of event (events/365 days); and

BW = average body weight over exposure period (kg).

The above equation was used to estimate exposure for an average case and a maximum plausible case. For the average case, a child was assumed to swim 36 times a year (3 times a week during a 12-week period in the summer) for a 10-year period (from ages 6-16). The child was assumed to weigh an average of 40 kg during this period. For the maximum plausible case, a 70-kg adult was assumed to swim 36 times a year over a 20-year period.

The intake from incidental ingestion ($DI_I$) was calculated by assuming that 0.2 liters of water (one-tenth the daily water intake for adults) is incidentally swallowed during each swimming event. The metal ingestion intake for each event was calculated by multiplying the concentration of metal in the water (in mg/liter) by the water intake of 0.2 liters water per event. The dermal absorption of ions in water is generally considered to be very low. Most values of the flux of ions across the skin were measured in hot mineral baths (Schaefer et al. 1982). In these baths, the

high temperature of the water plus the high concentration of ions facilitate movement of ions through the skin. Still, the fluxes measured were very low. In the case of Clear Creek, the low temperature of the water plus the low concentration of ions (as compared with a mineral bath) will reduce absorption even further. Hence, the dermal intake dose ($DI_D$) will be assumed to be zero in this assessment.

The assumptions for the most probable and maximum plausible cases are summarized in Table 10-6.

Direct Contact With Discharge

In this scenario, the acute exposure of visitors to the mines to the chemicals of concern by dipping their hands in the discharge water is evaluated. The Argo mine, in particular, is a prominent tourist attraction, and the discharge is readily accessible to visitors walking along the footpath. Of the contaminants, only pH is likely to be of concern for acute dermal exposures. The geometric mean and minimum pHs of the Argo tunnel discharge are 2.9 and 2.8, respectively. For the Big Five tunnel discharge, geometric mean and minimum pHs are 3.1 and 3.0 respectively. Because this exposure pathway is being evaluated only for acute effects, no CDIs were calculated.

Consumption of Fish

The exposure to individuals who consume fish caught from Clear Creek or North Clear Creek is estimated in this section. Both streams are stocked with rainbow trout, and limited creel data indicate that brown and cutthroat trout are also caught (see Section 9.0 for a more detailed description of aquatic life in these streams).

Concentrations of metals, arsenic, and fluoride in fish were calculated by applying bioconcentration factors (BCFs) to concentrations of the elements in the stream. The bioconcentration factors used in the calculations are

Table 10-5

ASSUMPTIONS USED TO CALCULATE CHRONIC DAILY INTAKES
FOR SWIMMING EXPOSURE SCENARIO

| | Most Probable Case | Maximum Plausible Case |
|---|---|---|
| Frequency of contact | 36 times/year | 36 times/year |
| Years of exposure | 10 | 20 |
| Average body weight during exposure period | 40 kg | 70 kg |
| Water incidentally ingested per event | 0.2 liter/event | 0.2 liter/event |
| Dermal intake | negligible | negligible |

shown in Table 10-7. Measured bioconcentration factors based on residues in muscle (i.e., edible) tissue were used when they were available. For most of the other chemicals, bioconcentration factors based on whole-body residues were used, and it was assumed that the distribution of chemicals in the fish was homogeneous. In general, the highest bioconcentration factors identified in the literature for a freshwater fish species were used. No measured bioconcentration factors were available for silver, aluminum, or manganese; therefore, the BCFs estimated by Chapman et al. (1968) were used.

Several limitations of the use of bioconcentration factors should be noted. The bioconcentration of chemicals by fish can vary with the species of fish. Thus, application of BCFs from experiments using bluegills may not accurately reflect the residues of chemicals found in trout. In addition, bioconcentration is probably dependent on the form of the chemical in the water. Very little is known, however, of the influence that chemical speciation has on bioconcentration. Further, some information suggests that fish that have become tolerant to high metal concentrations accumulate higher concentrations of chemicals than fish that are not tolerant (Dixon and Sprague 1981a). Thus, use of BCFs measured in the laboratory may not accurately estimate bioconcentration under some field conditions.

Finally, by using a BCF, it is implicitly assumed that the predominant mechanism for the accumulation of chemicals by fish is by absorption through the gills from the water and not through the food web. There is little quantitative information regarding accumulation of chemicals from food in addition to water. Although lead may biomagnify in invertebrate food webs, it has not yet been shown to biomagnify in vertebrate food webs (EPA 1984k). Arsenic in oysters was reported to accumulate mostly from phytoplankton rather than water (Zaroogian and Hoffman 1982), although a similar experiment has not been conducted using freshwater organisms. Veith et al. (1980) have suggested that chemicals with BCFs less than about 500 are unlikely to accumulate through the food web. Of the chemicals of concern, only silver has a BCF greater than 500 and that BCF is associated

TABLE 10-7

BIOCONCENTRATION FACTORS (BCF) USED TO CALCULATE CONCENTRATIONS OF CHEMICALS IN FISH

| Chemical | BCF | Basis | Source |
|---|---|---|---|
| Aluminum | 10 | Estimated for edible portions of freshwater fish | Chapman et al. 1968 |
| Arsenic | 4 | 28-day whole body bioconcentration by bluegills | Barrows et al. 1980 |
| Cadmium | 151 | 34-day muscle bioconcentration by brook trout | Benoit et al. 1976 |
| Chromium (VI) | 3.4 | Bioconcentration in muscle of rainbow trout, calculated for equilibrium based on uptake and depuration | Calamari et al. 1982 |
| Copper | 290[4] | 30-day bioconcentration by fathead minnow larvae | Lind et al. manuscript |
| Fluoride | 1.3 | Concentration in trout fillets | Smith 1975 |
| Lead | 45 | Whole body bioconcentration by blue gills | Atchison et al. 1977 |
| Manganese | 35 | Estimated for edible portions of freshwater fish | Chapman et al. 1968 |
| Nickel | 1.1 | Bioconcentration in muscle of rainbow trout, calculated for equilibrium based on uptake and depuration | Calamari et al. 1982 |
| Silver | 1,030 | Estimated for edible portions of freshwater fish | Chapman et al. 1968 |
| Zinc | 402 | 800-day whole body bioconcentration by fingerfish | Spehar et al. 1978b |

4 This value may overestimate bioconcentration. Benoit (1975b) reports a bioconcentration factor of 0 in the muscle of bluegills exposed for 560 days.

with a great deal of uncertainty. For the purposes of this assessment, it will be assumed that the water is the major source of chemicals in fish.

CDIs for this exposure pathway were calculated for individuals who rely on the fish in streams for a large part of their diet. For the average case, it was assumed that a person eats an average of 12 g fish per each day caught from either Clear Creek or North Clear Creek. This value is based on the mean daily intake of freshwater trout reported by EPA (1984l), and agrees closely with values compiled by Pao et al. (1982) from USDA survey data. For the maximum case, a daily intake of 100 g fish each day was used. This value corresponds to the 90th percentile fish consumption for the subpopulation of people that eat fish regularly (defined as at least once every three days) (Pao et al. 1982). The use of these numbers is considered to present conservative but not unrealistic estimates of fish intake. It should be noted, however, that neither Clear Creek nor North Clear Creek may support enough edible fish to account for these intakes, particularly the maximum case. The CDIs for this exposure pathway as well as the estimated concentrations in fish are presented in Table 10-8.

### 10.5.3 GROUNDWATER EXPOSURE PATHWAY

In this section, the exposure to chemicals from drinking groundwater will be evaluated. Exposures were estimated for two hypothetical alluvial groundwater wells, one in the Clear Creek subbasin and the other in the North Clear Creek subbasin. Groundwater samples taken at the Argo and Big Five sites were used to calculate exposure point concentrations for the Clear Creek subbasin well. Groundwater samples taken at the Gregory, National, and Quartz Hill sites were used to calculate exposure point concentrations for the North Clear Creek subbasin well. More detail on the exact locations of the wells can be found in Section 7.0. The geometric mean and maximum concentrations for the two wells are presented in Table 10-9. Chronic daily intakes were calculated assuming that a 70-kg person drinks 2 liters of water from the well every day over a lifetime (EPA 1986a). These chronic daily intakes are also presented in Table 10-9.

TABLE 10-8
INGESTION OF FISH FROM NORTH CLEAR CREEK AND CLEAR CREEK

| | Fish Concentrations (mg/kg)[a] | | | | Chronic Daily Intake (mg/kg/day)[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | Clear Creek | | North Clear Creek | | Clear Creek | | North Clear Creek | |
| Chemical | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Aluminum | 8.6E+00 | 1.4E+01 | 6.4E+00 | 9.5E+00 | 1.5E-03 | 2.0E-02 | 1.1E-03 | 1.4E-02 |
| Arsenic | 1.7E-02 | 4.0E-02 | NQ | NQ | 3.0E-06 | 5.7E-05 | NQ | NQ |
| Cadmium | 4.8E-01 | 1.1E+00 | 8.3E-01 | 2.1E+00 | 8.3E-05 | 1.5E-03 | 1.4E-04 | 3.0E-03 |
| Chromium | NQ | NQ | 1.6E-02 | 2.7E-02 | NQ | NQ | 2.8E-06 | 3.9E-05 |
| Copper | 3.5E+01 | 8.3E+01 | 2.0E+01 | 4.8E+01 | 6.0E-03 | 1.2E-01 | 3.4E-03 | 6.9E-02 |
| Fluoride | 8.7E-01 | 1.2E+00 | 2.1E-01 | 2.9E-01 | 1.5E-04 | 1.7E-03 | 3.6E-05 | 4.1E-04 |
| Lead | 2.7E-01 | 6.8E-01 | 3.9E-01 | 6.8E-01 | 4.7E-05 | 9.6E-04 | 6.8E-05 | 9.6E-04 |
| Manganese | 3.8E+01 | 1.6E+02 | 4.2E+01 | 1.2E+02 | 6.6E-03 | 2.2E-01 | 7.2E-03 | 1.7E-01 |
| Nickel | 7.3E-03 | 2.2E-02 | 2.4E-02 | 4.0E-02 | 1.3E-06 | 3.1E-05 | 4.1E-06 | 5.7E-05 |
| Silver | 2.1E+00 | 1.5E+01 | 2.1E+00 | 1.5E+01 | 3.5E-04 | 2.2E-02 | 3.5E-04 | 2.2E-02 |
| Zinc | 3.2E+02 | 1.2E+03 | 3.6E+02 | 8.1E+02 | 5.4E-02 | 1.7E+00 | 6.2E-02 | 1.2E+00 |

a. The concentrations in fish were calculated by multiplying concentrations of chemicals in North Clear Creek and Clear Creek presented in Table 10-3 by the bioconcentration factors presented in Table 10-7.

b. Chronic daily intakes were calculated by assuming that a 70 kg person eats 12 g or 100 g fish daily for the most probable and maximum plausible cases, respectively. Water concentrations are total metal, except for fluoride, which is dissolved.

NQ - Not Quantified

TABLE 10-9
EXPOSURE POINT CONCENTRATIONS AND CHRONIC DAILY INTAKES FOR THE GROUNDWATER EXPOSURE PATHWAY

| | Exposure Point Concentrations (mg/liter) | | | | Chronic Daily Intake (mg/kg/day) | | | |
|---|---|---|---|---|---|---|---|---|
| | Clear Creek Subbasin | | North Clear Creek Subbasin | | Clear Creek Subbasin | | North Clear Creek Subbasin | |
| Chemical | Geometric Mean | Maximum | Geometric Mean | Maximum | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Aluminum | 1.2E+01 | 1.1E+02 | 4.9E+00 | 2.2E+02 | 3.5E-01 | 3.1E+00 | 1.4E-01 | 6.2E+00 |
| Arsenic | 2.3E-02 | 1.2E-01 | 1.7E-02 | 1.2E+00 | 6.5E-04 | 3.4E-03 | 4.8E-04 | 3.4E-02 |
| Cadmium | 3.5E-02 | 1.8E-01 | 2.9E-02 | 6.4E-01 | 1.0E-03 | 5.3E-03 | 8.3E-04 | 1.8E-02 |
| Chromium | 1.6E-02 | 1.0E-01 | 2.9E-02 | 2.0E+00 | 5.1E-04 | 2.9E-03 | 8.3E-04 | 5.7E-02 |
| Copper | 8.4E-01 | 8.9E+00 | 5.5E-01 | 8.4E+01 | 2.4E-02 | 2.5E-01 | 1.6E-02 | 2.4E+00 |
| Fluoride | 1.3E+00 | 3.4E+00 | 8.6E-01 | 2.5E+00 | 4.3E-02 | 9.7E-02 | 2.5E-02 | 7.1E-02 |
| Lead | 3.4E-02 | 5.3E-01 | 2.0E-02 | 2.9E-01 | 9.7E-04 | 1.5E-02 | 5.8E-04 | 8.3E-03 |
| Manganese | 2.5E+01 | 8.3E+01 | 3.2E+01 | 1.5E+02 | 7.1E-01 | 2.4E+00 | 9.1E-01 | 4.4E+00 |
| Nickel | 1.5E-01 | 3.8E-01 | 2.5E-01 | 9.9E-01 | 4.2E-03 | 1.1E-02 | 7.0E-03 | 2.8E-02 |
| Silver | 1.3E-03 | 5.0E-03 | 2.3E-03 | 3.4E-02 | 3.6E-05 | 1.4E-04 | 6.7E-05 | 9.7E-04 |
| Zinc | 6.4E+00 | 4.0E+01 | 1.0E+01 | 1.2E+02 | 1.8E-01 | 1.1E+00 | 3.0E-01 | 3.3E+00 |
| pH | 4.2 | | 4.0 | | ND | ND | ND | ND |

a. Exposure point concentrations for the Clear Creek Subbasin were calculated using groundwater samples taken near the Argo and Big Five tunnels.

b. Exposure point concentrations for the North Clear Creek Subbasin were calculated using groundwater samples taken near the Gregory Incline, National tunnel and Quartz Mill tunnel.

c. Chronic daily intakes were calculated assuming a 70 kg person drinks 2 liters of water per day.

### 10.5.4 AIR EXPOSURE PATHWAYS

Respirable airborne particulate matter with an aerodynamic diameter less than or equal to 10 um, referred to as $PM_{10}$, can contribute to inhalation exposure if contaminated (Cowherd et al. 1984). The method used to estimate exposure to airborne particulate matter involves use of emission factors and the output of an air dispersion model. Contaminant emission rates are determined from the emission factors, the source extent, and the mass fraction of the contaminants in the tailings. Air concentrations in the breathing zone of receptors are then calculated, based on the emission rates. Finally, chronic daily intakes are calculated incorporating assumptions on the episodic nature of the emissions. It should be noted that aluminum is a primary component of the minerals that are present in the tailings, and as such is largely unavailable. Hence the daily intake calculated for inhalation of aluminum in dust will greatly overestimate the intake that is biologically available.

Fugitive dust emissions can arise through two sources (Khan and Singh 1986):

- Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.); and
- Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind at speeds which exceed a threshold velocity.

For the baseline assessment, fugitive dust from the first source may be attributed to episodic activity, such as individuals riding trail bikes or the medical evacuation helicopter landing on tailings piles and will be discussed in the last part of this section. Consideration of this source of dust is likely to become more significant during the feasibility study if alternatives involving the use of heavy equipment on the tailings are proposed. Fugitive dust from entrainment by wind is also episodic in nature, occurring primarily when wind speed exceeds a critical threshold

value. Regardless of the source, once dust is emitted, it may be transported to an exposure point where it may contact potential receptors.

Local weather conditions can greatly influence the amount of dust generated from both of the above sources. The nearest meteorological station to the Clear Creek/Central City site is located at the Stapleton Airport outside of Denver. The annual mean wind speed at the airport is 3.9 meters per second with a maximum of 25 meters per second. The wind direction is primarily from the south year-round (NOAA 1978). Several differences, however, should be noted between weather characteristics at the Denver airport and those at the site area. Although summer and fall wind speeds are similar, average and maximum wind speeds at Idaho Springs are significantly higher from December to April[1]. In addition, the wind directions from December to April in Idaho Springs are predominantly from the west and southwest.

Entrainment of Dust Particles by Wind

After ore processing, the tailings are usually discarded into a water pond where moisture mitigates significant wind erosion. When the pond becomes full (such as at the Gregory tailings pile), the tailings dry and become more susceptible to wind erosion. Countering this effect is a certain amount of cementation of small particles which occurs through wetting and drying. The Bureau of Mines has sponsored research to characterize wind threshold speeds required to erode substantial amounts of dust from inactive tailings ponds (Bohn and Johnson 1983). This research simulated natural conditions as it was performed in-situ on the tailings surface using a wind tunnel and a real-time cascade impactor.

Bureau of Mines investigators found that the threshold wind velocities ranged from 15 to 26 mph. The amount of erosion depended strongly on tailings silt content and, to a lesser extent, on precipitation. EPA

1. Nolan Doesken, Colorado Climatological Center, Fort Collins, Colorado: personal communication, December, 1986

(1985b) has developed an emission factor equation for wind erosion of storage piles which is based on a wind speed threshold of 12 mph.

$$E_w = 1.9 \left(\frac{s}{1.5}\right)\left(\frac{365-p}{235}\right)\left(\frac{f}{15}\right)$$

where

$E_w$ = emission factor of dust from wind entrainment (kg/day/hectare);

s = silt content (%);

p = number of days with at least 0.01 in of precipitation per year; and

f = percentage of time that the wind speed exceeds 12 mph.

The similarity in wind threshold values along with the direct proportionality to silt content and lack of precipitation suggest that this equation is compatible with the research results of Bohn and Johnson (1983). Hence it was used in the baseline assessment at the Clear Creek/Central City site. This approach, however, estimates total particulate emission rates. Respirable particulate matter is roughly 75% of total particulate matter (Schaum 1984b). The particulate emission rates were converted to chemical emission rates associated with the respirable fraction of dust emitted from Gregory and Argo tailings piles using the following equation:

$$E_{10w} = a\, E_w F_c$$

where

$E_{10w}$ = average emission rate of respirable metals (kg/day/hectare);

a = mass fraction of chemical;

$E_w$ = emission fact of dust from wind entrainment (kg/day/hectare); and

$F_c$ = respirable fraction of dust emissions (0.75)

The chemical emission rates determined above predict the rate at which chemicals on dust are released. Once the dust is generated, it is transported to the breathing zone of people on the site and downwind to off-site receptors. No models are currently available to estimate the concentration of chemicals in the breathing zone of people on site. A Gaussian dispersion model can be used to estimate off-site air concentrations. For the purposes of this assessment, air concentrations will be calculated for a hypothetical receptor 100 m downwind of the Gregory tailings pile and Argo waste rock/tailings pile. The results of this model will also be used to consider exposure to on-site receptors.

Because both of the piles at the Argo and Gregory sites are much longer than they are wide, the piles will be considered to be a line source of dust. The following equation was used to calculate air concentrations 100 m downwind of the site (adopted from Turner 1970):

$$C_{air} = \frac{2\, R_{10v}\, W\, CF}{\sqrt{2\pi}\, \sigma_z u}$$

where

$C_{air}$ = concentration of chemical in air ($g/m^3$);

$R_{10v}$ = chemical emission rate (kg/day/hectare);

$W$ = width of tailings pile (m);

$CF$ = conversion factor (10,000 $m^2$/hectare, 100 g/kg, 1 day/$8.64 \times 10^4$ sec);

$\sigma_z$ = vertical dispersion coefficient, based on distance of receptor and atmospheric stability class (m); and

$u$ = windspeed (m/sec).

The input parameters are summarized in Table 10-10. Because wind entrainment of dust is only expected to occur at wind speeds greater than 12 mph (5.4 m/s), this wind speed was used in the model. An atmospheric stability class of D was used to estimate $\sigma_z$ based on recommendations

TABLE 10-10

INPUT PARAMETERS TO ENTRAINMENT BY WIND EXPOSURE EQUATIONS

| | |
|---|---|
| Silt content (s) | 44% for Gregory tailings Pile, 22% for Argo Waste rock pile |
| Percentage of time that wind exceeds 12 mph (f) | 16% |
| Respirable fraction of dust emissions ($F_r$) | 0.75 (Schaum 1984b) |
| Wind speed (u) | 5.4 m/s |
| Width of tailings pile (W) | 33 m for Gregory tailings pile 33 m for Argo tailings pile |
| Dispersion coefficient ($\sigma_z$) | 4.8 m (Turner 1970) |
| Breathing rate (BR) | 20 $m^3$/day |
| Frequency of exposure ($F_e$) | 0.16 |
| Body weight (BW) | 70 kg |
| Number of days with less than 1 mm of rainfall (p) | 96 days (NOAA 1984) |

presented in the Draft Superfund Exposure Assessment Manual (Versar 1986). The same parameters were used for both the average and maximum plausible cases. Geometric mean concentrations of chemicals in the tailings piles were used to calculate the average case air concentrations, whereas maximum concentrations were used for the maximum plausible case.

Air concentrations were converted to chronic daily intakes by the following formula:

$$CDI_v = \frac{C_{air} \times BR \times F_e \times CF}{BW}$$

where

$CDI_v$ = chronic daily intake by inhalation of dust from wind entrainment (mg/kg/day);

$C_{air}$ = concentration of chemical in air ($g/m^3$);

BR = breathing rate ($m^3$/day);

$F_e$ = frequency of exposure;

CF = conversion factor (1,000 mg/g); and

BW = body weight (kg).

It was assumed that a 70-kg person living near the site for an entire lifetime breathes 20 $m^3$ air each day. It was further assumed that these air concentrations will occur only when wind speeds exceed 12 mph, or about 16% of the time according to data from Stapleton Airport (NOAA 1978). All of the input parameters for this scenario are presented in Table 10-10. Exposure point concentrations and CDIs are presented in Table 10-11.

Dust Generated during Dirt Bike Riding

In this exposure scenario, it was assumed that dirt-bike riding on unpaved tailings at the Gregory incline generates dust emissions. For this

TABLE 10-11
CONCENTRATION IN AIR AND CHRONIC DAILY INTAKES FROM WIND ENTRAINMENT OF DUST [a]

| | Off Site Concentration in Air (g/m3) | | | | Chronic Daily Intakes (mg/kg/day) | | | |
|---|---|---|---|---|---|---|---|---|
| | Gregory | | Argo | | Gregory | | Argo | |
| Chemical | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Aluminum | 3.5E-08 | 1.1E-07 | 1.2E-07 | 2.0E-07 | 1.6E-06 | 5.2E-06 | 5.7E-06 | 9.0E-06 |
| Arsenic | 2.2E-09 | 9.0E-09 | 8.1E-09 | 1.1E-08 | 1.0E-07 | 4.1E-07 | 2.8E-07 | 4.8E-07 |
| Cadmium | 3.4E-10 | 6.4E-10 | 1.8E-10 | 2.9E-10 | 1.5E-08 | 2.9E-08 | 8.4E-09 | 1.3E-08 |
| Chromium | 9.7E-10 | 1.1E-09 | 8.7E-10 | 1.7E-09 | 4.4E-08 | 1.5E-07 | 3.1E-08 | 7.8E-08 |
| Copper | 4.9E-08 | 5.7E-08 | 5.0E-09 | 1.6E-08 | 2.2E-07 | 2.6E-06 | 2.3E-07 | 7.3E-07 |
| Fluoride | NQ | NQ | NQ | NQ | NQ | NQ | NQ | NQ |
| Lead | 5.6E-08 | 2.0E-08 | 3.6E-08 | 5.5E-08 | 7.4E-07 | 1.2E-06 | 1.5E-06 | 2.5E-06 |
| Manganese | 1.3E-09 | 4.8E-09 | 5.6E-09 | 7.7E-09 | 5.4E-08 | 2.2E-07 | 2.6E-07 | 3.5E-07 |
| Nickel | 5.6E-10 | 8.1E-10 | 2.4E-10 | 3.3E-10 | 2.6E-09 | 3.7E-08 | 1.1E-08 | 1.5E-08 |
| Silver | 1.3E-09 | 2.5E-09 | 5.5E-10 | 7.0E-10 | 5.8E-08 | 1.1E-07 | 2.9E-08 | 3.6E-08 |
| Zinc | 3.7E-09 | 9.5E-10 | 8.3E-09 | 9.2E-09 | 1.7E-07 | 4.2E-08 | 3.8E-07 | 4.2E-07 |

(a) The formulas and assumptions used to calculate concentrations and chronic daily intakes are described in the text.

NQ = Not Quantified

scenario, it was also assumed that five youths would ride bikes at the Gregory tailings pile on the average 3 days a week during the summer (12 weeks) and 2 days a week during late spring and early fall (an additional 12 weeks). During each riding session, it was assumed that each youth would ride the distance of the circumference of the tailings pile 20 times at an average speed of 25 mph.

The emission rate equation for vehicle traffic presented by Cowherd et al. (1984) was used to determine the emission rate for this exposure scenario. The $PM_{10}$ emission factor for both maximum plausible and average cases for vehicle traffic over the surface materials was calculated by the following equation:

$$e_{10v} = (0.85)\left(\frac{s}{10}\right)\left(\frac{S}{24}\right)^{0.8}\left(\frac{W}{3}\right)^{0.3}\left(\frac{w}{6}\right)^{1.2}\left(\frac{365-p}{365}\right)$$

where

$e_{10v}$ = $PM_{10}$ emission factor per vehicle-kilometer of travel (VKT) ($\frac{kg}{VKT}$);

s = silt content of soils (%);

S = mean vehicle speed (km/hour);

W = mean vehicle weight (Mg);

w = mean number of wheels; and

p = number of days with at least 0.254 mm (.01 inches) of precipitation per year.

The $PM_{10}$ emission rate for emission due to vehicle traffic, $E_{10v}$, is estimated by multiplying the $PM_{10}$ emission factor by the number of vehicle-kilometers travelled each day:

$$E_{10v} = e_{10v} T_v CF$$

where

$E_{10v}$ = $PM_{10}$ emissions due to vehicle traffic (kg/sec);

$e_{10v}$ = $PM_{10}$ emission factor due to vehicle traffic (kg/VKT);

$T_v$ = round trips per day x vehicles per round trip x distance per vehicle (km/day); and

CF = conversion factor (1 day/8.64x$10^4$ sec).

Based on the scenario described above, $T_v$ was calculated as 0.350 km (the circumferrence of the Gregory tailings pile) multiplied by 20 trips and 5 youths per trip. Thus, $T_v$ is equal to 35 km/day. The particulate emission rates were then converted to contaminant emission rates using the equation

$$R_{10v} = aE_{10v}$$

where

$R_{10v}$ = average emission rate of metals on particulates less than 10 um (kg/sec);

a = mass fraction of metals in the tailings; and

$E_{10v}$ = $PM_{10}$ due to vehicle traffic (kg/sec).

The concentrations of chemicals in the breathing zones of receptors 100 m downwind of the tailings pile were calculated using a Gaussian dispersion model for a line source similar to the one described under the wind entrainment of dust section.

$$C_{air} = \frac{2\ R_{10v}\ CF}{\sqrt{2\pi}\ \sigma_z u L}$$

where

Cair = concentration of chemical in air ($g/m^3$);

$R_{10v}$ = chemical emission rate (kg/sec);

$\sigma_z$ = vertical dispersion coefficient, based on distance of the receptor and atmosphere stability class (m);

u = wind speed (m/sec);

CF = conversion factor (1,000 g/kg); and

L = length of tailings pile (m).

For the average case, the wind speed was assumed to be 3.66 m/sec (the average wind speed at the Stapleton Airport) with an atmospheric stability class of D. For the maximum plausible case, a wind speed of 1 m/sec and an atmospheric stability class of F were assumed. These meteorological characteristics were chosen based on recommendations presented in the Draft Superfund Exposure Assessment Manual (Versar 1986).

Air concentrations were converted to chronic daily intakes by the following formula:

$$CDI_v = \frac{(C_{air})(BR)(Fe)(CF)}{BW}$$

where

$CDI_v$ = chronic daily intake by inhalation of dust generated by vehicles (mg/kg/day);

$C_{air}$ = concentration of chemical in air ($g/mg^3$);

BR = breathing rate;

Fe = frequency of exposure;

CF = conversion factor (1,000 mg/g); and

BW = body weight (kg).

It was assumed that a 70-kg person breathes 20 $m^3$ of air each day. The frequency of exposure, based on the scenario described at the beginning of this section would be 60 times a year or 0.16. All of the input parameters for this scenario are presented in Table 10-11. Exposure point concentrations and CDIs are presented in Table 10-12.

TABLE 10-12

INPUT PARAMETERS TO VEHICLE DUST GENERATION EXPOSURE EQUATIONS

| | |
|---|---|
| Silt content (s) | 44% |
| Average vehicle speed (S) | 40 km/hr |
| Average vehicle weight (W) | $9.1 \times 10^{-2}$ ($Mg$) |
| Numbers of wheels/vehicle (w) | 2 wheels |
| Number of days with less than 1 mm rainfall (p) | 96 days (NOAA 1984) |
| Length of tailings pile (L) | 141 m |
| Dispersion coefficient ($\sigma_z$) | 4.8 m for average case, 2.1 m for maximum plausible case |
| Wind speed (u) | 3.67 m/sec for average case; 1 m/sec for maximum plausible case |
| Total distance travelled per day ($T_v$) | 35 km/day |

Table 10-13

CONCENTRATIONS IN AIR AND CHRONIC DAILY INTAKES FROM GENERATION OF DUST BY DIRT BIKES [a]

| Chemical | Gregory Off Site Concentration in Air (g/m³) | | Chronic Daily Intake (mg/kg/day) | |
|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Aluminum | 2.4E-08 | 5.9E-07 | 1.1E-06 | 2.7E-05 |
| Arsenic | 1.5E-09 | 4.6E-08 | 6.8E-08 | 2.1E-06 |
| Cadmium | 2.3E-10 | 3.3E-09 | 1.0E-08 | 1.5E-07 |
| Chromium | 6.5E-10 | 1.7E-08 | 3.0E-08 | 7.6E-07 |
| Copper | 3.3E-09 | 2.9E-07 | 1.5E-07 | 1.3E-05 |
| Fluoride | NS | NS | NQ | NQ |
| Lead | 1.1E-08 | 1.3E-07 | 5.0E-07 | 6.1E-06 |
| Manganese | 7.9E-10 | 2.4E-08 | 3.6E-08 | 1.1E-06 |
| Nickel | 3.8E-10 | 4.2E-09 | 1.7E-08 | 1.9E-07 |
| Silver | 8.5E-10 | 1.3E-08 | 3.9E-08 | 5.9E-07 |
| Zinc | 2.5E-09 | 4.2E-09 | 1.3E-07 | 2.1E-07 |

a. The formulas and assumptions used to calculate concentrations and chronic daily intakes are described in the text.

NS = Not sampled

NQ = Not quantified

Boeing filmed

## 10.5.5 SOIL/TAILINGS EXPOSURE PATHWAY

In this section, the direct exposure to metals in soils or tailings will be evaluated. The population considered to have the highest potential for exposed is older children, ages 6 to 16, who play or ride dirt bikes on the tailings piles. Although tourists may also contact soil or tailings during visits to the sites, the frequency of contact would be much lower for this population than for older children.

Exposure point concentrations were calculated for both the Gregory and Argo tailings piles because the potential for exposure is greatest at these two locations. Geometric mean and maximum concentrations of the indicator chemicals are presented in Table 10-14.

Chronic daily intakes for the exposure periods (ages 6-16) were calculated by assuming that the predominant route of exposure is through incidental ingestion of soil. It should be noted that much variation in incidental ingestion can arise depending on personal activities and habits. For example, eating, drinking, or smoking on the tailings piles would tend to increase exposure by this pathway. Although dermal exposure to the soil also will occur, the bioavailability of metals through the skin from soil is so low that it will not be quantified. The following formula was used to calculate chronic daily intakes:

$$CDI_I = C_T\left(\frac{F}{Y}\right)\left(\frac{I_1}{BW_1} + \frac{I_2}{BW_2}\right)$$

where

$CDI_I$ = chronic daily intake by incidental ingestion over the exposure period (mg/kg/day);

$C_T$ = concentration of metal in tailings (mg/kg);

$F$ = frequency of exposure (days/365 days);

$I_1$ = ingestion of soil by youths aged 6-11 (kg/day);

TABLE 10-14
EXPOSURE POINT CONCENTRATIONS AND CHRONIC DAILY INTAKES FOR DIRECT CONTACT WITH AND INCIDENTAL INGESTION OF SOIL/TAILINGS

| | Exposure Point Concentrations (mg/kg) | | | | Chronic Daily Intake (mg/kg/day)[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Gregory | | Argo | | Gregory | | Argo | |
| Chemical | Geometric Mean | Maximum | Geometric Mean | Maximum | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Aluminum | 606 | 1960 | 4120 | 6560 | 1.1E-04 | 2.8E-03 | 7.5E-04 | 9.3E-03 |
| Arsenic | 38.30 | 154.00 | 204 | 352 | 7.0E-06 | 2.2E-04 | 3.7E-05 | 5.0E-04 |
| Cadmium | 5.79 | 11.00 | 6.12 | 9.7 | 1.1E-06 | 1.6E-05 | 1.1E-06 | 1.4E-05 |
| Chromium | 16.7 | 56.00 | 22.4 | 57 | 3.1E-06 | 7.9E-05 | 4.1E-06 | 8.1E-05 |
| Copper | 84 | 960.0 | 165 | 534 | 1.5E-05 | 1.4E-03 | 3.0E-05 | 7.6E-04 |
| Fluoride | NS | NS | NS | NS | NO | NO | NO | NO |
| Lead | 278 | 445.0 | 1120 | 1820 | 5.1E-05 | 6.3E-04 | 2.0E-04 | 2.6E-03 |
| Manganese | 20.3 | 82 | 186 | 256 | 3.7E-06 | 1.2E-04 | 3.4E-05 | 3.6E-04 |
| Nickel | 9.63 | 14.0 | 7.97 | 11 | 1.8E-06 | 2.0E-05 | 1.5E-06 | 1.6E-05 |
| Silver | 21.7 | 43.00 | 21.5 | 26 | 4.0E-06 | 6.1E-05 | 3.9E-06 | 3.7E-05 |
| Zinc | 63 | 157 | 276 | 308 | 1.2E-05 | 2.2E-04 | 5.0E-05 | 4.4E-04 |

a. Chronic daily intakes were calculated for the exposure period of 10 years using the assumptions described in the text.

NS = Not sampled

NO = Not quantified

$I_2$ = ingestion of soil by youths aged 11-16 (kg/day);

$BW_1$ = averaged body weight of youths aged 6-11 (kg); and

$BW_2$ = averaged body weight of youths aged 11-16 (kg).

Based on consideration of a number of studies evaluating soil ingestion rates, average and maximum plausible soil ingestion values were estimated. (See Appendix 10C for development of soil ingestion values.) For children 6 to 11 years of age, an average consumption of 50 mg/day of soil and a maximum plausible consumption of 250 mg/day of soil were assumed. Youths 11 to 16 years of age were also estimated to consume 50 mg/day, but a maximum plausible case was estimated at 100 mg/day, since mouthing tendencies would have decreased somewhat by these ages. The frequency of exposure was assumed to be 50/365 days for the most probable case and 100/365 days for the maximum plausible case for the entire exposure period. These rough estimates were obtained by assuming that during the summer months (July and August), children would play 3 to 7 days a week on the tailings piles, whereas during the spring and fall (May, June, September, and October) the frequency would be 1 or 2 times a week. It was assumed that 6 to 11 year-olds weigh an average of 30 kg and that those over 11 weigh an average of 50 kg. The predicted intakes were averaged over the 10-year exposure period and are presented in Table 10-14. It should be noted that aluminum is a primary component of the minerals that are present in the tailings, and as such is largely unavailable. Hence, the daily intake presented here for aluminum greatly overestimates the intake that is biologically available.

## 10.6 HEALTH RISK ASSESSMENT

In this section, information on the potential levels of exposure to contaminants (presented in section 10.5) is combined with information on the toxicity of the contaminants (presented in section 10.3) in order to determine the health risks to individuals living near the Clear Creek/Central City area. For carcinogenic contaminants, the excess risk of

developing cancer over a lifetime due to exposure to the contaminant under the given scenario is determined by multiplying the chronic daily intake (CDI) values estimated for the average and maximum plausible cases by the cancer potency factor for the carcinogen. If more than one carcinogen is present, risks associated with the individual contaminants are combined to determine the total cancer risk as suggested in the EPA guidelines for Health Risk Assessment of Chemical Mixtures (EPA 1986c).

For noncarcinogenic contaminants, the CDI is divided by the health criterion value [the reference dose (RfD), formerly referred to as the allowable daily intake (ADI)]. If the CDI:RfD ratio is greater than one (i.e., if the daily intake exceeds the EPA health criterion), the contaminant may pose a health hazard to individuals exposed under the given scenario. As for carcinogens, the CDI:RfD ratios are summed to determine if combined exposure may pose a health concern (EPA 1986c).

It should be recognized that a number of assumptions were used in deriving both the CDI and the chemical-specific cancer potency factor or reference dose, and therefore there is some uncertainty in the resulting risk value. In both the exposure and hazard assessments, an attempt was made to err on the side of safety (i.e., to overestimate exposure and hazard) in order to ensure that the resulting risk assessment is conservative (i.e., unlikely to underestimate the true risk). A further discussion of the uncertainties in risk assessment is presented in Section 10.8.

Applicable or relevant and appropriate requirements (ARARs) have been developed for most of the contaminants present in drinking water in the Clear Creek/Central City area (see Section 3.0). EPA guidance states that if ARARs are available, contaminant levels should be compared with these requirements. The geometric mean and the maximum concentrations of the contaminants in potential drinking water sources are compared with the ARARs to determine if these standards have been exceeded.

Although an ARAR is available for arsenic in drinking water and concentrations of arsenic in water are compared with this standard, the upper bound excess lifetime cancer risk will also be calculated for groundwater sources. This approach is taken because the ARAR for arsenic was derived without consideration of the potential carcinogenicity of the metalloid. The EPA Carcinogen Assessment Group has determined that arsenic is a Group A carcinogen with an oral cancer potency factor of 15 $(mg/kg/day)^{-1}$. Lifetime exposure to the MCL of 50 ug/liter (the ARAR) for the average 70-kg person ingesting 2 liters of water per day (for a CDI of $1.4x10^{-3}$ mg/kg/day) would be associated with an upper bound excess cancer risk of $2x10^{-2}$, well above target risk levels commonly used by EPA. EPA has convened an intra-agency working group to address the issue of arsenic regulations. Until a final decision on the regulation of arsenic is reached, it is appropriate to present both a comparison with the ARAR and the risk associated with lifetime exposure to arsenic in the drinking water.

### 10.6.1 SURFACE WATER

Exposure to contaminants in surface water is considered likely to occur via any of four pathways: ingestion of drinking water in the city of Golden, incidental ingestion of water while swimming in Clear Creek, consumption of fish from Clear Creek or North Clear Creek, and incidental contact with mine drainage water.

#### Drinking

Drinking water in Golden is treated at a municipal water treatment facility after it is obtained from Clear Creek. As noted in section 10.5.2, it is anticipated that this treatment will reduce the levels of contaminants present in Golden's drinking water to levels below those found in Clear Creek, but it is difficult to quantify this expected decrease. In order to determine if contaminants from the Clear Creek/Central City area could have an adverse effect on the drinking water in Golden, contaminant levels in

Clear Creek below the confluence with North Clear Creek (see Table 10-3) were compared to ARARs. As previously discussed, concentrations at this station are similar to those at Golden. Based on this comparison (see Table 10-15), and considering that contaminant levels are likely to be reduced by water treatment, levels of metals, arsenic, and fluoride in Golden's drinking water supply are below regulatory target concentrations.

Swimming

As noted in section 10.4, individuals swimming in Clear Creek may be exposed to metals, arsenic, and fluoride through inadvertant ingestion of small quantities of water from the creek. Table 10-16 presents the risks associated with incidental ingestion of water from Clear Creek for both the average and maximum plausible scenarios. As noted in this table, ingestion of arsenic leads to risks of $5x10^{-6}$ and $2x10^{-5}$ under the average and maximum plausible scenarios, respectively. However, it should be noted that the level of arsenic in the water, 44 ug/liter, is probably close to background levels for the region. Level of dissolved arsenic in the Colorado River were reported to be around 5 ug/liter (USGS 1981).

Direct Contact with Discharge

Water flowing from the Argo tunnel and Big Five Mine has a pH of about 3. Tourists and children may dabble their hands in the water could inadvertantly get this water into their eyes. In sensitive individuals, such contact could cause eye irritation. It is unlikely that water with this pH would have an adverse affect on the skin.

Consumption of Fish

As noted in Section 10.5, fish in Clear Creek and North Clear Creek may bioaccumulate metals, arsenic, and fluoride from water and persons consuming these fish would be exposed to any accumulated contaminants. The risks to people who consume fish from the Clear Creek/Central City area on

TABLE 10-15
COMPARISON OF CONTAMINANT LEVELS TO STANDARDS - DRINKING WATER IN GOLDEN

| Chemical | Water Concentration (ug/l) Geometric Mean | Water Concentration (ug/l) Maximum | Applicable or Relevant and Appropriate Requirements (ARAR) (ug/l) | Concentration:ARAR Ratio Geometric Mean | Concentration:ARAR Ratio Maximum |
|---|---|---|---|---|---|
| Aluminum | 378 | 633 | NA | NQ | NQ |
| Arsenic | 3.94 | 10.0 | 50 (a) | 8E-02 | 2E-01 |
| Cadmium | 2.51 | 5.00 | 10 (a) | 3E-01 | 5E-01 |
| Chromium | 4.76 | 8.00 | 50 (a) | 1E-01 | 2E-01 |
| Copper | 40.7 | 51.0 | 1300 (b) | 3E-02 | 4E-02 |
| Fluoride | 575 | 770 | 4000 (a) | 1E-01 | 2E-01 |
| Lead | 4.95 | 8.00 | 50 (a) | 1E-01 | 2E-01 |
| Manganese | 1250 | 2300 | NA | NQ | NQ |
| Nickel | 9.05 | 20.0 | 150 (d) | 6E-02 | 1E-01 |
| Silver | 0.669 | 5.00 | 50 (a) | 1E-02 | 1E-01 |
| Zinc | 485 | 793 | 5000 (c) | 1E-01 | 2E-01 |

a. Safe Drinking Water Act Maximum Contaminant Level (MCL)

b. Safe Drinking Water Act proposed Recommended Maximum Contaminant Level

c. Clean Water Act Ambient Water Quality Criteria for Protection of Human Health

d. Safe Drinking Water Act Guidance Level

NQ = Not Quantified

TABLE 10.16
RISKS RESULTING FROM INCIDENTAL INGESTION OF WATER WHILE SWIMMING

Carcinogens

| | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor (a) (mg/kg/day)-1 | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 3.1E-07 | 1.4E-06 | 15 (A)[c] | 5E-06 | 2E-05 |

Noncarcinogens

| | Chronic Daily Intake (mg/kg/day) | | Health Criterion (a) (mg/kg/day) | Dose:Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 4.2E-04 | 6.0E-04 | NA | NQ | NQ |
| Cadmium | 1.6E-06 | 3.5E-06 | 2.9E-04 | 5E-03 | 1E-02 |
| Chromium VI | NQ | NQ | 5.0E-03 | NQ | NQ |
| Copper | 6.0E-05 | 1.4E-04 | 3.7E-02 | 2E-03 | 4E-03 |
| Fluoride | 3.3E-04 | 4.5E-04 | 6.0E-02 | 6E-03 | 8E-03 |
| Lead | 1.0E-06 | 7.4E-06 | 1.4E-03 | 2E-03 | 5E-03 |
| Manganese | 7.5E-04 | 3.1E-03 | 2.2E-01 | 3E-03 | 1E-02 |
| Nickel | 3.3E-06 | 9.9E-06 | 1.0E-02 | 3E-04 | 1E-03 |
| Silver | 3.3E-07 | 2.5E-06 | 3.0E-03 | 1E-04 | 8E-04 |
| Zinc | 3.6E-04 | 1.3E-03 | 2.1E-01 | 2E-03 | 6E-03 |
| | | | | 2E-02 | 5E-02 |

a. Source: EPA 1986a

b. Intake is prorated over a 70 year lifetime.

c. Weight of evidence for carcinogenicity.

NA = Not available
NQ = Not quantified

a regular basis is presented in Table 10-17 and 10-18. Ingesting fish from Clear Creek under the average and maximum plausible scenarios leads to excess cancer risks of $4x10^{-5}$ and $9x10^{-4}$, respectively. However, arsenic is metabolized in fish to organic arsenical compounds which are rapidly excreted in an unchanged form by most animals and presumably by humans. It is unclear if organic arsenicals are carcinogenic; they are clearly less potent systemic toxicants than inorganic arsenic. Because of the rapid elimination of these compounds and their questionable carcinogenicity, the actual cancer risk from consumption of arsenic-contaminated fish will be well below that presented in Table 10-17, if there is any risk at all.

Ingestion of fish from either Clear Creek or North Clear Creek under the average or maximum plausible scenarios leads to a chronic daily intake of several noncarcinogenic contaminants that exceeds the reference dose for these metals. Therefore, regular consumption of fish from the Clear Creek/Central City area could pose a health risk.

10.6.2 GROUNDWATER

The primary route of exposure to metals, arsenic, and fluoride in groundwater is through use of Clear Creek/Central City groundwater as a drinking water. Table 10-19 compares the geometric mean and maximum contaminant levels with ARARs for a hypothetical well in the Clear Creek subbasin; Table 10-20 presents a similar comparison for the North Clear Creek subbasin. Arsenic is present in the Clear Creek subbasin and the North Clear Creek subbasin at geometric mean concentrations of 23 ug/liter and 17 ug/liter, respectively. Assuming an average 70-kg person drinks 2 liters of water per day for a lifetime from either of the two subbasins, the CDI for arsenic would be $6.6x10^{-4}$ and $4.9x10^{-4}$ mg/kg/day for the Clear Creek and North Clear Creek subbasins, respectively. The upperbound excess lifetime cancer risk associated with exposure via drinking water are $1x10^{-2}$ for the Clear Creek subbasin and $7x10^{-3}$ for the North Clear Creek subbasin.

TABLE 10-17
RISKS RESULTING FROM INGESTION OF FISH FROM CLEAR CREEK

| Carcinogens | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] (mg/kg/day)-1 | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 1.0E-06 | 5.7E-05 | 15 (A)[b] | 4E-05 | 9E-04 |

| Noncarcinogens | Chronic Daily Intake (mg/kg/day) | | Health Criterion[a] (mg/kg/day) | Dose:Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 1.5E-03 | 2.0E-02 | NA | NQ | NQ |
| Cadmium | 8.3E-05 | 1.5E-05 | 2.9E-04 | 3E-01 | 5E+00 |
| Chromium VI | NQ | NQ | 5.0E-03 | NQ | NQ |
| Copper | 6.0E-03 | 1.2E-01 | 3.7E-02 | 2E-01 | 3E+00 |
| Fluoride | 1.5E-04 | 1.7E-03 | 6.0E-02 | 2E-03 | 3E-02 |
| Lead | 4.7E-05 | 9.6E-04 | 1.4E-03 | 3E-02 | 7E-01 |
| Manganese | 6.6E-03 | 2.2E-01 | 2.2E-01 | 3E-02 | 1E+00 |
| Nickel | 1.3E-06 | 3.1E-05 | 1.0E-02 | 1E-04 | 3E-03 |
| Silver | 3.5E-04 | 2.2E-02 | 3.0E-03 | 1E-01 | 7E+00 |
| Zinc | 5.4E-02 | 1.7E+00 | 2.1E-01 | 3E-01 | 8E+00 |
| TOTAL | | | | 9E-01 | 3E+01 |

a. Source: EPA 1986a

b. Weight of evidence for carcinogenicity

NA = Not Available
NQ = Not Quantified

TABLE 10.16
RISKS RESULTING FROM INGESTION OF FISH FROM NORTH CLEAR CREEK

| Carcinogens | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | (mg/kg/day)-1 | Average Case | Maximum Plausible Case |
| Arsenic | NQ | NQ | 15 (A)[b] | NQ | NQ |

| Noncarcinogens | Chronic Daily Intake (mg/kg/day) | | Health Criterion[a] (mg/kg/day) | Dose:Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 1.1E-03 | 1.6E-02 | NA | NQ | NQ |
| Cadmium | 1.4E-04 | 3.0E-03 | 2.9E-04 | 5E-01 | 1E+01 |
| Chromium VI | 2.0E-06 | 3.9E-05 | 5.0E-03 | 6E-04 | 8E-03 |
| Copper | 3.4E-03 | 6.9E-02 | 3.7E-02 | 9E-02 | 2E+00 |
| Fluoride | 3.6E-05 | 4.1E-04 | 6.0E-02 | 6E-04 | 7E-03 |
| Lead | 6.8E-05 | 9.6E-04 | 1.6E-03 | 5E-02 | 7E-01 |
| Manganese | 7.2E-03 | 1.7E-01 | 2.2E-01 | 3E-02 | 8E-01 |
| Nickel | 4.1E-06 | 5.7E-05 | 1.0E-02 | 4E-04 | 6E-03 |
| Silver | 1.3E-04 | 2.2E-02 | 3.0E-03 | 1E-01 | 7E+00 |
| Zinc | 6.2E-02 | 1.2E+00 | 2.1E-01 | 3E-01 | 5E+00 |
| | | | | 1E+00 | 3E+01 |

a. Source: EPA 1986a

b. Weight of evidence for carcinogenicity

NA = Not Available
NQ = Not Quantified

TABLE 10-19
COMPARISON OF CONTAMINANT LEVELS TO STANDARDS - GROUNDWATER: CLEAR CREEK

| Chemical | Water Concentration (mg/l) Geometric Mean | Water Concentration (mg/l) Maximum | Applicable or Relevant and Appropriate Requirements (ARAR) (ug/l) | Concentration/ARAR Ratio Geometric Mean | Concentration/ARAR Ratio Maximum |
|---|---|---|---|---|---|
| Aluminum | 3.5E-01 | 3.1E+00 | NA | NQ | NQ |
| Arsenic | 6.5E-04 | 5.4E-03 | 50 (a) | 1E-02 | 7E-02 |
| Cadmium | 1.0E-03 | 5.3E-03 | 10 (a) | 1E-01 | 5E-01 |
| Chromium | 5.1E-04 | 2.9E-03 | 50 (a) | 1E-02 | 6E-02 |
| Copper | 2.4E-02 | 2.5E-01 | 1300 (b) | 2E-02 | 2E-01 |
| Fluoride | 4.3E-02 | 9.7E-02 | 4000 (a) | 1E-02 | 2E-02 |
| Lead | 9.7E-04 | 1.5E-02 | 50 (a) | 2E-02 | 3E-01 |
| Manganese | 7.1E-01 | 2.4E+00 | NA | NQ | NQ |
| Nickel | 4.2E-03 | 1.1E-02 | 150 (d) | NQ | NQ |
| Silver | 3.0E-05 | 1.4E-04 | 50 (a) | 7E-04 | 3E-03 |
| Zinc | 1.0E-01 | 1.1E+00 | 5000 (c) | 4E-02 | 2E-01 |

a. Safe Drinking Water Act Maximum Contaminant Level (MCL)

b. Safe Drinking Water Act Recommended Maximum Contaminant Level (RMCL)

c. Clean Water Act Ambient Water Quality Criteria for Protection of Human Health

d. Safe Drinking Water Act Guidance Level

NA = Not available
NQ = Not quantified

TABLE 10-20
COMPARISON OF CONTAMINANT LEVELS TO STANDARDS - GROUNDWATER; NORTH CLEAR CREEK SUBBASIN

| Chemical | Water Concentration (mg/l) Geometric Mean | Water Concentration (mg/l) Maximum | Applicable or Relevant and Appropriate Requirements (ARAR) (ug/l) | Concentration:ARAR Ratio Geometric Mean | Concentration:ARAR Ratio Maximum |
|---|---|---|---|---|---|
| Aluminum | 1.4E-01 | 6.2E+00 | NA | NQ | NQ |
| Arsenic | 4.8E-04 | 3.4E-02 | 50 (a) | 1E-02 | 7E-01 |
| Cadmium | 8.3E-04 | 1.8E-02 | 10 (a) | 8E-02 | 2E+00 |
| Chromium | 8.3E-04 | 5.7E-02 | 50 (a) | 2E-02 | 1E+00 |
| Copper | 1.6E-02 | 2.4E+00 | 1300 (b) | 1E-02 | 2E+00 |
| Fluoride | 2.5E-02 | 7.1E-02 | 4000 (a) | 6E-03 | 2E-02 |
| Lead | 5.8E-04 | 8.3E-03 | 50 (a) | 1E-02 | 2E-01 |
| Manganese | 9.1E-01 | 6.4E+00 | NA | NQ | NQ |
| Nickel | 7.0E-03 | 2.8E-02 | 150 (d) | 5E-02 | 2E-01 |
| Silver | 6.7E-05 | 9.7E-04 | 50 (a) | 1E-03 | 2E-02 |
| Zinc | 3.0E-01 | 3.3E+00 | 5000 (c) | 6E-02 | 7E-01 |

a. Safe Drinking Water Act Maximum Contaminant Level (MCL)

b. Safe Drinking Water Act Recommended Maximum Contaminant Level (RMCL)

c. Clean Water Act Ambient Water Quality Criteria for Protection of Human Health

d. Safe Drinking Water Act Guidance Level

NA = Not available
NQ = Not quantified

Maximum concentrations of arsenic in both subbasins exceeded the ARAR as did the maximum concentrations of several metals including cadmium, chromium, copper, lead, and zinc. In addition, the geometric mean concentrations of cadmium and lead were both above ARARs, which in the case of these two metals were health based. Finally, the levels of manganese in the groundwater at both locations exceed secondary drinking water standards.

### 10.6.3 AIR

As noted in Section 10.5, dust blown from the tailings may lead to exposure to residents living in the vicinity of the tailings piles. Estimates of the risk associated with exposure to windblown particulates are presented in Table 10-21 for residents in the vicinity of the Gregory tailings pile and in Table 10-22 for residents living near the Argo tailings pile. In the vicinity of the Gregory tailings pile, the upperbound excess lifetime risks of cancer associated with the average and maximum plausible cases are $7x10^{-6}$ and $3x10^{-5}$, respectively. For residents living near the Argo tailings pile, the excess risks of cancer under the average and maximum plausible cases are $2x10^{-5}$ and $1x10^{-5}$, respectively.

Children playing on the tailings piles are likely to be exposed to higher concentrations of contaminants than area residents, but their duration of exposure may be much shorter. These factors probably balance each other, and inhalation exposure while playing on the tailings piles is likely to pose a health risk similar to that experienced by area residents.

Table 10-23 presents the risks associated with exposure to dust generated by dirt bikes on the Gregory tailings pile. Under the average and maximum plausible scenarios, carcinogenic risks to residents living near the Gregory tailings pile are $5x10^{-6}$ and $1x10^{-4}$, respectively.

Table 10-21
RISKS RESULTING FROM EXPOSURE TO WINDBORNE DUST: GREGORY TAILINGS PIT

Carcinogens

| | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] (mg/kg/day)$^{-1}$ | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 1.0E-07 | 4.1E-07 | 50 (A)[b] | 5E-06 | 2E-05 |
| Cadmium | 1.5E-08 | 2.9E-08 | 6.1 (B1)[b] | 9E-08 | 2E-07 |
| Chromium | 4.4E-08 | 1.5E-07 | 41 (A)[b] | 2E-06 | 6E-06 |
| Nickel | 2.6E-08 | 3.7E-08 | 1.15 (A)[b] | 3E-08 | 4E-08 |
| | | | | 7E-06 | 3E-05 |

Noncarcinogens

| | Chronic Daily Intake (mg/kg/day) | | Health Criterion[a] (mg/kg/day) | Dose/Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 1.6E-06 | 5.2E-06 | NA | NQ | NQ |
| Copper | 2.2E-07 | 2.6E-06 | 1.0E-02 | 2E-05 | 3E-04 |
| Fluoride | NQ | NQ | NA | NQ | NQ |
| Lead | 7.4E-07 | 1.2E-06 | 4.3E-04 | 2E-03 | 3E-03 |
| Manganese | 5.5E-06 | 2.2E-07 | 3.0E-04 | 2E-04 | 7E-04 |
| Silver | 5.6E-08 | 1.1E-07 | NA | NQ | NQ |
| Zinc | 1.7E-07 | 4.2E-08 | 1.0E-02 | 2E-05 | 4E-06 |
| | | | | 2E-03 | 4E-03 |

a. Source: EPA 1986a

b. Weight of evidence for carcinogenicity

NA = Not available
NQ = Not quantified

TABLE 10-22
RISKS RESULTING FROM EXPOSURE TO WINDBORNE DUST: ARCO TAILINGS PILE

Carcinogens

| | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] (mg/kg/day)-1 | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 2.0E-07 | 4.0E-07 | 50 (A)[b] | 1E-05 | 2E-05 |
| Cadmium | 8.4E-09 | 1.3E-08 | 6.1 (B1)[b] | 5E-08 | 8E-08 |
| Chromium | 1.1E-08 | 7.0E-08 | 41 (A)[b] | 1E-06 | 3E-06 |
| Nickel | 1.1E-08 | 1.5E-08 | 1.15 (A)[b] | 1E-08 | 2E-08 |
| | | | | 2E-05 | 5E-05 |

Noncarcinogens

| | Chronic Daily Intake (mg/kg/day) | | Health Criterion[a] (mg/kg/day) | Dose:Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 5.7E-06 | 9.0E-06 | NA | NQ | NQ |
| Copper | 2.3E-07 | 7.3E-07 | 1.0E-02 | 2E-05 | 7E-05 |
| Fluoride | NQ | NQ | NA | NQ | NQ |
| Lead | 1.5E-06 | 2.5E-06 | 4.3E-04 | 4E-03 | 6E-03 |
| Manganese | 2.6E-07 | 1.5E-07 | 1.0E-04 | 9E-04 | 1E-03 |
| Silver | 2.9E-08 | 3.6E-08 | NA | NQ | NQ |
| Zinc | 3.6E-07 | 4.2E-07 | 1.0E-02 | 4E-05 | 4E-05 |
| | | | | 4E-03 | 7E-03 |

a. Source: EPA 1986a

b. Weight of evidence for carcinogenicity

NA = Not available
NQ = Not quantified

TABLE 10.23
RISKS RESULTING FROM EXPOSURE TO DUST GENERATED BY DIRT BIKES : GREGORY TAILINGS PILE

| Carcinogens | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor (mg/kg/day)$^{-1}$ [a] | | Lifetime Risk | |
|---|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | | Average Case | Maximum Plausible Case |
| Arsenic | 6.6E-08 | 2.1E-06 | 50 | (A)[b] | 3E-06 | 1E-04 |
| Cadmium | 1.0E-08 | 1.5E-07 | 6.1 | (B1)[b] | 6E-08 | 9E-07 |
| Chromium | 3.0E-08 | 7.6E-07 | 41 | (A)[b] | 1E-06 | 3E-05 |
| Nickel | 1.7E-08 | 1.9E-07 | 1.15 | (A)[b] | 2E-08 | 2E-07 |
| TOTAL | | | | | 5E-06 | 1E-04 |

| Noncarcinogens | Chronic Daily Intake (mg/kg/day) | | Health Criterion (mg/kg/day)[a] | Dose/Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 1.1E-06 | 2.7E-05 | NA | NQ | NQ |
| Copper | 1.5E-07 | 1.3E-05 | 1.0E-02 | 1E-05 | 1E-03 |
| Fluoride | NQ | NQ | NA | NQ | NQ |
| Lead | 5.0E-07 | 6.1E-06 | 4.1E-04 | 1E-03 | 1E-02 |
| Manganese | 3.6E-06 | 1.1E-05 | 3.0E-04 | 1E-04 | 4E-03 |
| Silver | 3.9E-09 | 5.0E-07 | NA | NQ | NQ |
| Zinc | 1.1E-07 | 2.1E-07 | 1.0E-02 | 1E-05 | 2E-05 |
| TOTAL | | | | 1E-03 | 2E-02 |

a Source: EPA 1986a

b Weight of evidence for carcinogenicity

NA = Not Available
NQ = Not Quantified

### 10.6.4 SOIL/TAILINGS

Table 10-24 presents the risks associated with incidental ingestion of tailings from the Gregory tailings pile and Table 10-25 presents the risks associated with incidental ingestion of tailings from the Argo tailings pile. Based on these calculations, ingestion of arsenic from the Gregory tailings poses a lifetime cancer risk of $1x10^{-5}$ under the average case scenario and $3x10^{-4}$ under the maximum plausible case scenario. Ingestion of arsenic-contaminated soil from the Argo tailings pile poses a lifetime cancer risk of $8x10^{-5}$ under the average case and $1x10^{-3}$ under the maximum plausible case scenarios. The only chronic daily intake value that exceeded the appropriate health criterion was for lead under the maximum plausible scenario at the Argo tailings pile. Geometric mean concentrations of lead at the Argo tailings pile were above levels the Centers for Disease Control (CDC 1985) considers allowable in residential soil (500-1,000 mg/kg).

### 10.6.5 MULTIMEDIA EXPOSURE

Exposure via one of the pathways discussed in Section 10.5 generally does not preclude exposure via another pathway. For example, an individual drinking groundwater from the Clear Creek subbasin could also eat fish regularly from Clear Creek. Such multimedia exposure would increase the risk to an individual, possibly to a substantial degree. However, in most cases, exposure by one route will dominate the exposure calculations and adding exposure from other routes will have an insignificant effect. For example, under the average scenarios, the chronic daily intake of arsenic for drinking water from the Clear Creek subbasin, incidentally ingesting water while swimming, and regularly consuming fish from Clear Creek are $6.6x10^{-4}$, $3.1x10^{-7}$, and $1.0x10^{-6}$ mg/kg/day, respectively. The sum of these values rounded to two significant figures is $6.6x10^{-4}$, the same intake associated with just drinking groundwater from the Clear Creek subbasin.

TABLE 10-24
RISKS RESULTING FROM INCIDENTAL INGESTION OF SOIL AT GREGORY

Carcinogens

| | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] (mg/kg/day)-1 | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 1.0E-06[b] | 3.1E-05[b] | 15 (A)[c] | 1E-05 | 5E-04 |

Noncarcinogens

| | Chronic Daily Intake (mg/kg/day) | | Health Criterion (a) (mg/kg/day) | Dose:Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 1.1E-04 | 2.8E-03 | NA | NQ | NQ |
| Cadmium | 1.1E-06 | 1.6E-05 | 2.9E-04 | 4E-03 | 5E-02 |
| Chromium VI | 3.1E-06 | 7.9E-05 | 5.0E-03 | 6E-04 | 2E-02 |
| Copper | 1.5E-05 | 1.4E-03 | 3.7E-02 | 4E-04 | 4E-02 |
| Fluoride | NQ | NQ | 6.0E-02 | NQ | NQ |
| Lead | 5.1E-05 | 6.3E-04 | 1.4E-03 | 4E-02 | 4E-01 |
| Manganese | 3.7E-06 | 1.2E-04 | 2.2E-01 | 2E-05 | 5E-04 |
| Nickel | 1.6E-06 | 2.0E-05 | 1.0E-02 | 2E-04 | 2E-03 |
| Silver | 4.0E-06 | 6.1E-05 | 3.0E-03 | 1E-03 | 2E-02 |
| Zinc | 1.2E-05 | 2.2E-04 | 2.1E-01 | 5E-05 | 1E-03 |
| Total | | | | 4E-02 | 6E-01 |

a. Source: EPA 1986a

b. Intakes are prorated for a 70 year lifetime.

c. Weight of evidence for carcinogenicity

NQ = Not quantified
NA = Not available

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TABLE 10-25
RISKS RESULTING FROM INCIDENTAL INGESTION OF SOIL AT ARCO

Carcinogens

| | Chronic Daily Intake (mg/kg/day) | | Cancer Potency Factor[a] (mg/kg/day)-1 | Lifetime Risk | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Arsenic | 5.3E-06 | 7.1E-05[b] | 15 (A)[c] | 8E-05 | 1E-03 |

Noncarcinogens

| | Chronic Daily Intake (mg/kg/day) | | Health Criterion (a) (mg/kg/day) | Dose/Criterion Ratio | |
|---|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | | Average Case | Maximum Plausible Case |
| Aluminum | 7.5E-04 | 9.3E-03 | NA | NQ | NQ |
| Cadmium | 1.1E-06 | 1.4E-05 | 2.9E-04 | 4E-03 | 5E-02 |
| Chromium VI | 1.1E-06 | 8.1E-05 | 5.0E-03 | 8E-04 | 2E-02 |
| Copper | 5.0E-05 | 7.6E-04 | 3.7E-02 | 8E-04 | 2E-02 |
| Fluoride | NQ | NQ | 6.0E-02 | NQ | NQ |
| Lead | 2.0E-04 | 2.6E-03 | 1.4E-03 | 1E-01 | 2E+00 |
| Manganese | 3.4E-05 | 3.6E-04 | 2.2E-01 | 2E-04 | 2E-03 |
| Nickel | 1.5E-06 | 1.8E-05 | 1.0E-02 | 1E-04 | 2E-03 |
| Silver | 3.9E-06 | 3.7E-05 | 5.0E-03 | 1E-03 | 1E-02 |
| Zinc | 5.0E-05 | 6.4E-04 | 2.1E-01 | 2E-04 | 2E-03 |
| TOTAL | | | | 2E-01 | 2E+00 |

a. Source: EPA 1986a

b. Intakes are prorated for a 70-year lifetime.

c. Weight of evidence for carcinogenicity

NA = Not available
NQ = Not quantified

being filmed.

In situations where intake via different pathways is similar, summing the total exposure can lead to risk estimates several time higher than those associated with any single route of exposure. However, given other uncertainties in the risk estimate and considering the added uncertainty associated with determining if individuals are in fact likely to be exposed via several routes, the increased risk associated with summing the intake from several exposure pathways is likely to be of limited importance. Consequently, multimedia exposure was not considered quantitatively in this assessment.

## 10.7 AQUATIC LIFE RISK ASSESSMENT

In this section, the risks to aquatic life from exposure to inorganic chemicals in Clear Creek, North Clear Creek, and the marsh below National Tunnel are discussed.

### 10.7.1 COMPARISON CHEMICAL CONCENTRATIONS WITH AMBIENT WATER QUALITY CRITERIA

In Tables 10-26, 10-27, and 10-28, the ambient water quality criteria are compared with the exposure point concentrations in Clear Creek, North Clear Creek and the marsh below the National Tunnel. There are no AWQC or proposed AWQC for fluoride or manganese; therefore, the lowest reported concentrations associated with an adverse effect are shown in the tables for the purposes of comparison. The AWQC vary from location to location for cadmium, copper, nickel, silver, and zinc because the toxicity of these chemicals has been shown to depend on water hardness. Water hardnesses (calculated as $CaCO_3$ equivalents according to APHA 1985) were 71.8 mg/liter for Clear Creek, 118 mg/liter for North Clear Creek, and 486 mg/liter for the marsh below the National Tunnel.

The AWQC are expressed as 4-day average and 1-hour average concentrations (EPA 1985f, EPA 1986i,j). The intent of using two criteria is to protect against both chronic and acute effects, respectively. In Tables 10-26,



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TABLE 10-2a
COMPARISON OF CONCENTRATIONS OF CHEMICALS IN CLEAR CREEK WITH
THE AMBIENT WATER QUALITY CRITERIA (AWQC)

| Chemical | Clear Creek (ug/liter) [a,b] Geometric Mean | Clear Creek (ug/liter) [a,b] Maximum | Ambient Water Quality Criteria (ug/liter) [c,d,e] Chronic | Ambient Water Quality Criteria (ug/liter) [c,d,e] Acute | Concentration:AWQC Ratio Chronic | Concentration:AWQC Ratio Acute |
|---|---|---|---|---|---|---|
| Aluminum | 8.6E+02 | 1.4E+03 | 1.5E+02 | 9.5E+02 | 6E+00 | 1E+00 |
| Arsenic | 4.4E+00 | 1.0E+01 | 1.9E+02 | 3.6E+02 | 2E-02 | 3E-02 |
| Cadmium | 3.2E+00 | 7.0E+00 | 9.0E-01 | 2.8E+00 | 4E+00 | 2E+00 |
| Chromium | ND | ND | 1.1E+01 | 1.6E+01 | ND | ND |
| Copper | 1.2E+02 | 2.9E+02 | 9.1E+00 | 1.3E+01 | 1E+01 | 2E+01 |
| Fluoride | 6.7E+02 | 9.2E+02 | 1.5E+03 | 1.5E+03 | 4E-01 | 6E-01 |
| Lead | 6.1E+00 | 1.5E+01 | 2.2E+00 | 5.6E+01 | 3E+00 | 3E-01 |
| Manganese | 1.5E+03 | 6.2E+03 | 9.6E+02 | 9.6E+02 | 2E+00 | 6E+00 |
| Nickel | 6.7E+00 | 2.0E+01 | 1.2E+02 | 1.1E+03 | 6E-02 | 2E-02 |
| Silver | 6.7E-01 | 5.0E+00 | 1.2E-01 | 2.4E+00 | 6E+00 | 2E+00 |
| Zinc | 7.1E+02 | 2.7E+03 | 6.7E+01 | 7.5E+01 | 1E+01 | 4E+01 |
| pH | 7.2 | 7.2 | 6.5 | 6.5 | ND | ND |

a. The sampling station used to calculate exposure point concentrations for Clear Creek was SW-21.

b. Water concentrations are total metal, except for fluoride, which is dissolved.

c. No AWQC are available for fluoride or manganese toxicity or silver chronic toxicity for these chemicals. The values shown are lowest observed effect levels.

d. AWQC listed for aluminum, nickel, and zinc are proposed criteria.

e. AWQC for cadmium, copper, lead, nickel, silver, and zinc were calculated based on on a water hardness of 75 mg/liter.

ND = Not Detected
NQ = Not quantified

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TABLE 10-27
COMPARISON OF CONCENTRATIONS OF CHEMICALS IN NORTH CLEAR CREEK WITH THE AMBIENT WATER QUALITY CRITERIA (AWQC)

| | North Clear Creek (ug/liter)[a,b] | | Ambient Water Quality Criteria (ug/liter)[c,d,e] | | Concentration:AWQC Ratio | |
|---|---|---|---|---|---|---|
| Chemical | Geometric Mean | Maximum | Chronic | Acute | Chronic | Acute |
| Aluminum | 6.4E+02 | 9.5E+02 | 1.5E+02 | 9.5E+02 | 4E+00 | 1E+00 |
| Arsenic | ND | ND | 1.9E+02 | 3.6E+02 | NQ | NQ |
| Cadmium | 5.5E+00 | 1.4E+01 | 1.4E+00 | 5.2E+00 | 4E+00 | 3E+00 |
| Chromium | 4.6E+00 | 8.0E+00 | 1.1E+01 | 1.6E+01 | 4E-01 | 5E-01 |
| Copper | 8.9E+01 | 1.7E+02 | 1.5E+01 | 2.2E+01 | 5E+00 | 8E+00 |
| Fluoride | 1.6E+02 | 2.2E+02 | 1.5E+03 | 1.5E+03 | 1E-01 | 1E-01 |
| Lead | 8.8E+00 | 1.5E+01 | 4.4E+00 | 1.1E+02 | 2E+00 | 1E-01 |
| Manganese | 1.7E+03 | 4.7E+03 | 9.6E+02 | 9.6E+02 | 2E+00 | 5E+00 |
| Nickel | 2.2E+01 | 3.6E+01 | 1.9E+02 | 1.7E+03 | 1E-01 | 2E-02 |
| Silver | 6.7E-01 | 5.0E+00 | 1.2E-01 | 6.2E+00 | 6E+00 | 8E-01 |
| Zinc | 8.4E+02 | 1.9E+03 | 1.1E+02 | 1.2E+02 | 8E+00 | 2E+01 |
| pH | 5.7 | 4.7 | 6.5 | 6.5 | NQ | NQ |

a. The sampling station used to calculate exposure point concentrations for North Clear Creek was SW 5.

b. Water concentrations are total metal, except for fluoride, which is dissolved.

c. No AWQC are available for fluoride or manganese toxicity or silver chronic toxicity. For these chemicals, the values shown are lowest-observed-effect levels.

d. AWQC listed for aluminum, nickel, and zinc are proposed criteria.

e. AWQC for cadmium, copper, lead, nickel, silver, and zinc were calculated based on on a water hardness of 120 mg/liter.

ND - Not Detected
NQ - Not quantified

TABLE 10-28
COMPARISON OF CONCENTRATIONS OF CHEMICALS IN THE MARSH BELOW NATIONAL TUNNEL
WITH THE AMBIENT WATER QUALITY CRITERIA (AWQC)

| | Marsh Below the National Tunnel (ug/liter)[a,b] | | Ambient Water Quality Criteria (ug/liter)[c,d,e] | | Concentration:AWQC Ratio | |
|---|---|---|---|---|---|---|
| Chemical | Geometric Mean | Maximum | Chronic | Acute | Chronic | Acute |
| Aluminum | 5.0E+02 | 7.9E+02 | 1.5E+02 | 9.5E+02 | 3E+00 | 8E-01 |
| Arsenic | 9.3E+00 | 1.0E+01 | 1.9E+02 | 3.6E+02 | 5E-02 | 3E-02 |
| Cadmium | 5.2E+00 | 6.7E+00 | 3.9E+00 | 2.3E+01 | 1E+00 | 3E-01 |
| Chromium | 5.5E+00 | 7.1E+00 | 1.1E+01 | 1.6E+01 | 5E-01 | 4E-01 |
| Copper | 2.0E+02 | 2.8E+02 | 4.6E+01 | 7.9E+01 | 4E+00 | 4E+00 |
| Fluoride | 3.4E+02 | 4.0E+02 | 1.5E+03 | 1.5E+03 | 2E-01 | 3E-01 |
| Lead | 1.7E+01 | 5.0E+01 | 2.4E+01 | 6.1E+02 | 7E-01 | 8E-02 |
| Manganese | 1.2E+04 | 1.7E+04 | 9.6E+02 | 9.6E+02 | 1E+01 | 2E+01 |
| Nickel | 1.2E+02 | 2.2E+02 | 6.0E+02 | 5.4E+03 | 2E-01 | 4E-02 |
| Silver | 4.1E-01 | 4.0E+00 | 1.2E-01 | 6.2E+01 | 3E+00 | 6E-02 |
| Zinc | 4.4E+03 | 6.7E+03 | 3.2E+02 | 3.5E+02 | 1E+01 | 2E+01 |
| pH | 3.7 | 3.4 | 6.5 | 6.5 | NQ | NQ |

a. The sampling station used to calculate exposure point concentrations for the marsh was SW-7.

b. Water concentrations are total metal, except for fluoride, which is dissolved.

c. No AWQC are available for fluoride or manganese toxicity or silver chronic toxicity. For these chemicals, the values shown are lowest observed effect levels.

d. AWQC listed for aluminum, nickel, and zinc are proposed criteria.

e. AWQC for cadmium, copper, lead, nickel, silver, and zinc were calculated based on on a water hardness of 400 mg/liter.



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10-27, and 10-28, the geometric mean concentrations are compared with chronic criteria and the maximum concentrations are compared with the acute criteria. For clarity, the comparison is shown as a ratio of the concentration to the AWQC. If the concentration:criterion ratio is greater than one, the concentration exceeds the AWQC, and hence is likely to cause adverse effects. If the ratio is less than one, the criterion is not exceeded.

As can be seen in the tables, several of the AWQC are exceeded at all of the exposure points, which indicates that toxic effects to aquatic life are likely. In addition, concentrations of manganese at all three points exceed the $LC_{10}$ for early-life-stages of rainbow trout. The pH of North Clear Creek and the marsh below National Tunnel are lower than the AWQC. These results are consistent with the paucity of aquatic life actually found in Clear Creek and North Clear Creek.

### 10.7.1 SENSITIVE SPECIES

The AWQC are not designed to protect 100% of the aquatic species and life stages that may be present in an area (EPA 1980e). Thus, some adverse effects might occur even at concentrations that meet the criteria. In areas in which there is an important local species, EPA suggests that data regarding that species be considered when establishing site-specific criteria (EPA 1980e). In the Clear Creek watershed, trout are an important species for sportfishing. Salmonids, such as rainbow trout, are very sensitive to many pollutants.

In Table 10-29, selected toxicity data for trout species are presented. In choosing the data in this table, an attempt was made to identify the lowest concentration associated with adverse effects (the LOAEL) or the highest concentration associated with no adverse effects (the NOEL) for any trout species. When comparing these data with the AWQC in Tables 10-26, 10-27, and 10-28, several points should be noted. First, the hardness of the water in Clear Creek and North Clear Creek (averaging 74 and 128 mg/liter,

TABLE 10-29

SELECTED TROUT TOXICITY DATA FOR INORGANIC CHEMICALS OF CONCERN

| Chemical | Concentration (ug/liter) | Response | Species/ lifestage | Hardness | References |
|---|---|---|---|---|---|
| Aluminum | 100 | Respiratory impairment threshold | Rainbow trout adult | Unknown | Ogilvie and Stechey 1983 |
| | 369 | $EC_{10}$[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |
| Arsenic (III) | 134 | $EC_{10}$[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |
| | 1,000 | Decrease in fat weight gain | Rainbow trout juvenile | Unknown | Speyer 1974 |
| Cadmium | 9 | MATC[b] | Rainbow trout embryo-larva | 187 | Sauter et al. 1976 |
| Chromium (IV) | 73 | MATC[b] | Rainbow trout | 31.4 | Sauter et al. 1976 |
| | 180 | $LC_{50}$[c] | Rainbow trout embryo-larva | 91-105 | Birge 1978 |
| Copper | 0.3 | MATC[b] | Brook trout | 187 | Sauter et al. 1976 |
| Fluoride | 2,700-4,700 for 48-240 hrs. | $LC_{50}$[c] | Rainbow trout | Unknown | Neuhold and Sigler 1960 |
| | 1,500 | 7-10 day delay in hatching | "trout" eggs | Unknown | Ellis et al. 1948 |
| | 75,000[d] | No mortality after 3 weeks | Rainbow trout | "hard" | Hebert and Shurben 1964 |

TABLE 10-29 (Continued)

| Chemical | Concentration (ug/liter) | Response | Species/ lifestage | Hardness | References |
|---|---|---|---|---|---|
| Lead | 40.9 | 4-day EC[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |
| | 5.6 | MATC[b] | Rainbow trout | "soft" | Davies et al. 1976 |
| | 10 | Inhibition of ALA-D activity | Rainbow trout | 135 | Hodson et al. 1977 |
| Manganese | 954 | 4-day EC[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |
| Nickel | 50 | 4-day EC[b] | Rainbow trout embryo-larva | 93-105 | Birge 1978 |
| | 350 | MATC[b] | Rainbow trout | 50 | Nebeker et al. 1985 |
| Silver | 0.12 | MATC[b] | Rainbow trout early-life stage | 20 | Davies et al. 1978 |
| | 12 | MATC[b] | Rainbow trout early-life stage | "moderately hard" | Nebeker et al. manuscript |
| | 0.9 | 4-day EC[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |



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TABLE 10-29 (Continued)

| Chemical | Concentration (µg/liter) | Response | Species/ lifestage | Hardness | References |
|---|---|---|---|---|---|
| Zinc | 451 | 4-day $EC_{10}$[a] | Rainbow trout embryo-larva | "moderately hard" | Birge et al. 1981 |
| | 277 | MATC[b] | Rainbow trout early-life stage | 26 | Sinley et al. 1974 |
| | 852 | MATC[b] | Brook trout life cycle | 45 | Holcombe et al. 1979 |

[a]The concentration resulting, on the average, in 10% mortality in the test species.

[b]Maximum acceptable toxicant concentration

[c]The concentration resulting, on the average, in 50% mortality in the test species.

[d]The same author reported 5 and 50% mortality of rainbow trout exposed to 4.0 and 8.5 ppm F, respectively in soft water for 3 weeks.

respectively) should be considered when making comparisons. Data on metal toxicity from experiments using soft water is likely to overestimate risks to organisms living in hard water. Conversely, data from experiments using hard water may under estimate risks to organisms living in soft water. In addition, the LOAEL is often associated with early-life stages of trout. This is not suprising since early-life stages are often the most sensitive to metal toxicity (Birge et al. 1981). Thus, stocked adult trout may be more tolerant to these chemicals. Still, the data indicate that aluminum, copper, lead and nickel may cause adverse effects in trout at contaminant concentrations below the AWQC.

Although trout are not expected to live in the marsh below National Tunnel, this area could provide habitat for amphibians. Amphibians are not normally used as test organisms, but the available data suggest that amphibians are at least as sensitive to inorganic chemicals as fish. For example, in early-life-stage tests using five species of amphibians, three of the species (the narrow-mouthed toad, southern gray treefrog, and northern leopard frog) were more sensitive to copper than rainbow trout (Birge and Black 1979).

10.7.3 TOXICITY OF THE MIXTURE

The AWQC are based solely on the toxic action of individual pollutants. Therefore, these criteria may not protect aquatic life exposed to a mixture of chemicals. For example, Spehar and Fiandt (1986) exposed fathead minnows, rainbow trout, and daphnids to a mixture of arsenic, cadmium, chromium, copper, mercury, and lead at concentrations corresponding to the AWQC. In acute assays, the mixture caused nearly 100% mortality of rainbow trout and the daphnid. In chronic assays, decreased growth was noted in the fathead minnows (a fish often thought to be rather tolerant) and reproductive impairment of the daphnids was reported.

The toxic interaction of chemicals in a mixture appears to depend on many factors, including the water hardness, pH, concentration of the chemicals, test species, and life-stage of the test organism (Spehar and Fiandt 1986, Birge and Black 1979). The toxicity of a mixture can be strictly additive, more than additive, or less than additive than the toxicity of its constituents. In general, toxicity is expected to be additive when the mechanism of toxic action is similar, but not limited by competition. For example, chemicals that cause narcosis in fish (e.g., aliphatic hydrocarbons) are usually considered to have additive toxicity in a mixture. There is information on the interactions of some of the chemicals of concern at the Clear Creek/Central City site in mixtures. At high concentrations, the toxicity of a mixture of zinc and copper was greater-than-additive in soft water to fathead minnows (Doudoroff 1952). At lower concentrations and in harder water, the combined toxicity was more strictly additive (Lloyd 1961, Sprague and Ramsay 1965). The toxicity of a mixture of copper, nickel, and zinc was additive in acute tests using rainbow trout. However, the toxicities of zinc, copper, and cadmium were strongly less-than-additive in acute studies using chinook salmon (Finlayson and Verrue 1982). In chronic tests, a mixture of arsenic, cadmium, chromium, mercury, and lead was approximately additive in toxicity to daphnids, but was less-than-additive to fathead minnows (Spehar and Fiandt 1986). The same mixture in acute experiments was still additive in toxicity to the daphnids, but was more-than-additive in toxicity to fatheads.

The information presented above does not enable firm conclusions to be drawn about the interactions of the chemicals of concern at Clear Creek in a mixture. It does suggest, however, that assuming additive action may provide a useful first approximation of the toxicity of the mixture (EPA 1986c). If the action of the chemicals in a mixture is assumed to be additive, then the toxicity of the mixture can be estimated by using a hazard index. A hazard index can be defined as the ratio of the water concentration over an "acceptable" concentration. In this case the

"acceptable" concentration would be the AWQC. Then, the hazard indices calculated for all of the chemicals in a mixture are summed. If the sum exceeds one, the mixture is toxic.

In Table 10-30, the acute toxicity of the geometric mean concentrations of chemicals in Clear Creek water was evaluated using this approach. Fluoride and manganese were not included in this analysis because AWQCs for these chemicals were not available. As shown, the highest concentration: AWQC ratio for an individual chemical is 9.8 for zinc. However, the sum of the hazard indices is 22, indicating that the mixture is acutely toxic. Similarly, the sum of the ratios for North Clear Creek and the marsh below National tunnel are 12 and 16, respectively. Thus, concentrations of chemicals at these exposure points may cause greater toxicity than would be expected by simply comparing individual chemical concentrations with the appropriate AWQC.

### 10.7.4 ACCLIMATION AND POLLUTION TOLERANCE

Creel surveys taken on Clear Creek and North Clear Creek indicate that cutthroat and brown trout continue to be caught in these streams even though neither of these species have been stocked recently (see Section 9.0). Thus, it appears that these fish may have developed some tolerance to the chemicals in Clear Creek and North Clear Creek.

The acclimation of fish to high concentrations of chemicals has been documented both in the field and in the laboratory and has been reviewed recently by Weis and Weis (1981) and Hamilton and Mehrle (1986). Aquatic organisms can become tolerant to chemicals either permanently or temporarily. A permanent development of tolerance in a population is usually associated with a genetic change in the organisms through the process of natural selection. Because the change is genetic, organisms retain the tolerance even when placed in a "clean" environment. Such a change, however, takes many generations to occur for most organisms. There

TABLE 10-13
ACUTE TOXICITY OF THE MIXTURE OF CHEMICALS IN CLEAR CREEK
ASSUMING ADDITIVITY OF TOXIC EFFECTS

| Chemical | Clear Creek [a,b] (ug/liter) Geometric Mean | Ambient Water Quality Criteria [c,d] (ug/liter) Acute | Concentration:AWQC Ratio |
|---|---|---|---|
| Aluminum | 8.8E+02 | 9.5E+02 | 9.0E-01 |
| Arsenic | 4.4E+00 | 3.6E+02 | 1.2E-02 |
| Cadmium | 3.2E+00 | 2.8E+00 | 1.1E+00 |
| Chromium | ND | 1.6E+01 | NQ |
| Copper | 1.2E+02 | 1.3E+01 | 9.3E+00 |
| Lead | 6.1E+00 | 5.6E+01 | 1.1E-01 |
| Nickel | 6.7E+00 | 1.1E+03 | 6.1E-03 |
| Silver | 5.7E-01 | 2.4E+00 | 2.0E-01 |
| Zinc | 7.3E+02 | 7.5E+01 | 9.8E+00 |
| Total | | | 2.2E+01 |

a. The sampling station used to calculate exposure point concentrations for Clear Creek was SW-21.

b. Water concentrations are total metal, except for fluoride, which is dissolved.

c. AWQC listed for aluminum, nickel, and zinc are proposed criteria.

d. AWQC for cadmium, copper, lead, nickel, silver, and zinc were calculated based on a water hardness of 74 mg/liter.

ND = Not detected
NQ = Not quantified

are few documented cases of permanent tolerance and most instances have been reported for algae and invertebrates (Weis and Weis 1983).

Temporary tolerance to inorganic chemicals can happen through several mechanisms. In all of these instances, though, when the organism is returned to a "clean" environment, the tolerance is lost. The most familiar example of the temporary tolerance mechanisms is the induction of low-molecular-weight proteins that bind metals. When organisms are exposed to low concentrations of metals, the production of these proteins is induced. Subsequent exposure to higher concentrations of the metal results in lower mortality than in organisms that had not been preexposed. Thelnin (the protein component of metallothelnin) sequesters metals primarily in groups IA and IIA of the periodic table, including cadmium, copper, mercury, silver and zinc. Thelnin is not the only metal-binding protein that may be induced; in rainbow trout, it appears that another low-molecular-weight protein is the primary binder of cadmium (Hamilton and Mehrle 1986).

Lysosomes, small, membrane-bound bodies in the cytoplasm that are usually associated with enzymes, appear to be another mechanism for isolating metals. In addition to copper and zinc, lead and iron have been found in lysosomes, indicating that this process is not solely linked with metallothelnin induction. Increased excretion has been associated with increased tolerance to arsenic (Dixon and Sprague 1981b).

Although any of the tolerance mechanisms discussed above may enhance an organism's ability to survive otherwise lethal exposures, they do not guarantee that no adverse effects will occur. For example, excessive amounts of metals in lysosomes interfere with the normal structure and function of these organelles (Sternlieb and Goldfischer 1976). White suckers from a lake with high concentrations of zinc, copper and cadmium showed symptoms of chronic toxicity including reduced spawning success, increased larval mortality and decreased longevity (McFarlane and Franzin 1978 as cited in Weis and Weis 1983). In some cases only early-life stages

are tolerant. In studies with methylmercury, adults from tolerant eggs were actually less tolerant to subsequent exposure to methylmercury than adults from less tolerant eggs (Weis and Weis 1983). Even if the changes are genetic, natural selection as a result of a stress due to one factor is likely to decrease the genetic variability in the population and hence may render it more susceptible to other stresses (Weis and Weis 1983). Finally, tolerant organisms may accumulate higher concentrations of metals than non-tolerant organisms, increasing exposure of higher trophic levels (Dixon and Sprague 1981a, Wies and Wies 1983, Sprague 1985).

## 10.6 UNCERTAINTIES IN RISK ASSESSMENT

The procedures and inputs used to assess potential human health risks in this evaluation are subject to a wide variety of uncertainties. In general, there are six main sources of uncertainty:

- Environmental chemistry sampling and analysis
- Environmental parameter measurement
- Fate and transport modeling
- Exposure parameter estimation
- Toxicological data
- Errors through combinations of the above

In the Table 10-31, the major assumptions used in each of these areas are listed, and their likely effects on the risk assessment are identified. First, it is indicated whether the use of assumption is likely to overestimate or underestimate risk. In addition, the sensitivity of the risk assessment to each assumption is qualitatively evaluated as high, moderate, or low. The basis of this evaluation is best professional judgment and experience gained from the literature on hazardous site risk assessment (e.g., Evans et al. 1986). It should be noted that all of the individual errors from different sources may be propagated into larger

TABLE 10-31

ASSUMPTIONS AND EFFECT ON RISK

| Assumption | Effect on Risk: May Over-Estimate Risk | Effect on Risk: May Under-Estimate Risk | Effect on Risk: May Over or Under Estimate Risk |
|---|---|---|---|
| <u>Environmental Sampling and Analysis</u> | | | |
| Sufficient samples may not have been taken to characterize the matrices being evaluated. | | | Low |
| Systematic or random errors in the chemical analyses may yield erroneous data. | | | Low |
| Chemical concentrations reported as "below method detection limit" or "detected but less than the contract required quantification limit" are used as equal to the quantification limit. | Moderate | | |
| Chemical analysis did not distinguish between valence state for chromium. Chromium is assumed for comparisons to be in the hexavalent form. | High | | |
| Chemical analysis did not distinguish between valence states for arsenic. | | | Moderate |
| The public health evaluation is based on the chemical of concern only. These chemicals may represent a subset of the chemicals possible at the site. | | Moderate | |

TABLE 10-31 (continued)

ASSUMPTIONS AND EFFECT ON RISK

| Assumption | Effect on Risk: May Over-Estimate Risk | May Under-Estimate Risk | May Over or Under Estimate Risk |
|---|---|---|---|
| **Exposure Parameter Estimation** | | | |
| The standard assumptions regarding body weight, period exposed, life expectancy, population characteristics, and lifestyle may not be representative for any actual exposure situation. | | | Moderate |
| The amount of media intake is assumed to be constant and representative of the exposed population. | Moderate | | |
| Exposure to contaminants remains constant over exposure period. | Moderate | | |
| Concentration of contaminants remains constant over exposure period | Low | | |
| For most contaminants all intake is assumed to come from the medium being evaluated. This does not take into account other contaminant sources such as diet, exposures occurring at locations other than the exposure point being evaluated, or other environmental media which may contribute to the intake of the chemical (i.e., relative source contribution is not accounted for). | | Moderate | |
| **Environmental Parameter Measurement** | | | |
| Use of highest bioconcentration factors reported for fish. | Moderate | | |

TABLE 10-31 (continued)

ASSUMPTIONS AND EFFECT ON RISK

| Assumption | Effect on Risk: May Over-Estimate Risk | May Under-Estimate Risk | May Over or Under Estimate Risk |
|---|---|---|---|
| Food does not contribute to chemical residues in fish. | | Moderate | |
| Dermal absorption of inorganic chemicals while swimming is negligible. | | Low | |
| Dermal absorption of inorganic chemicals from soil is negligible. | | Low | |
| Use of meteorological data from Stapleton Airport. | | | High |
| <u>Fate and Transport Modeling</u> | | | |
| Chemicals in fish will be at equilibrium with chemical concentrations in water. | Low | | |
| Use of a Gaussian dispersion model to estimate air concentrations. | | | Low |
| Use of Cowherd's model to estimate vehicle emission factors. | | Moderate | |
| <u>Toxicological Data</u> | | | |
| The cancer potencies used are upper 95 percent confidence limits derived from the linearized multi-stage model. This is considered to be unlikely to underestimate the true risk. | High | | |
| Risks are assumed to be additive. Risks may not be additive because of synergistic or antagonistic actions of other chemicals. | | | Moderate |

TABLE 10-31 (continued)

ASSUMPTIONS AND EFFECT ON RISK

| Assumption | Effect on Risk: May Over-Estimate Risk | Effect on Risk: May Under-Estimate Risk | Effect on Risk: May Over or Under Estimate Risk |
|---|---|---|---|
| Cancer potencies and acceptable intake levels are primarily derived using laboratory animal studies and, when available, human epidemiological or clinical studies. Extrapolation of data from high to low doses, from one species to another, and from one exposure route to another may introduce uncertainty. In general, conservative assumptions tend to be used. | Moderate | | |
| Not all carcinogenic potencies or acceptable intakes used present the same degree of certainty. All are subject to change as new evidence becomes available. | | | Moderate |
| Assumes absorption is equivalent across species. This is implicit in the derivation of the acceptable intakes or cancer potencies factors used in this assessment. | | | Low |
| Extrapolation of aquatic toxicity data from species to species, and from laboratory animals to animals in the field. | | | Moderate |

errors by mathematical combination in the risk assessment. For purposes of evaluating remedial alternatives, however, risk assessment may provide a useful decision-making tool despite the uncertainties.

## 10.9 SUMMARY AND CONCLUSIONS

This public health evaluation, performed for the Clear Creek/Central City site is a baseline assessment, in that it evaluates potential impacts in the absence of remedial actions. Based on sampling of environmental media, and consideration of toxicity, 12 chemicals of concern were identified. These chemicals are aluminum, arsenic, cadmium, chromium, copper, fluoride, lead, manganese, nickel, silver, zinc and the hydrogen ion (pH).

### Exposures of Human Populations

Under current land use conditions at the study areas and neighboring offsite areas, the principal exposure pathways by which human receptors could potentially be exposed to site contaminants are:

- Fishing and swimming in Clear Creek and North Clear Creek;
- Drinking water from groundwater wells screened in the alluvial aquifer, or from the Golden water supply;
- Inhalation of dust from tailings piles;
- Direct contact of children with the tailings, or direct contact of tourists with mine discharge;

Exposure scenarios for average and maximum plausible cases were developed for each of these potential exposure pathways and concentrations of chemicals to which individuals might be exposed were estimated. Based on these estimates of exposure and a quantitative description of each contaminant's toxicity, human health risks were then assessed. The major conclusions of this assessment are presented in Table 10-32 and can be summarized as follows:

TABLE 10-32

SUMMARY OF RISK ASSESSMENT RESULTS FOR HUMAN EXPOSURE TO CONTAMINANTS AT THE CLEAR CREEK/CENTRAL CITY SITE

| Exposure Pathway | Total Excess Upper-Bound Lifetime Cancer Risk[a] | | Hazard Index for Noncarcinogenic Effects | |
|---|---|---|---|---|
| | Average Case | Maximum Plausible Case | Average Case | Maximum Plausible Case |
| Direct contact and incidental ingestion of water while swimming | | | | |
| Clear Creek | $5\times10^{-6}$ | $2\times10^{-5}$ | <1 | <1 |
| Ingestion of fish | | | | |
| Clear Creek | $4\times10^{-5}$ | $9\times10^{-4}$ | <1 | 35 |
| North Clear Creek | NE | NE | 1 | 20 |
| Ingestion of drinking water from alluvial wells | | | | |
| Clear Creek Subbasin | $1\times10^{-2}$ | NE | NE | NE |
| North Clear Creek Subbasin | $7\times10^{-3}$ | NE | NE | NE |
| Inhalation of dust entrained by wind | | | | |
| Gregory | $7\times10^{-6}$ | $1\times10^{-5}$ | <1 | <1 |
| Argo | $2\times10^{-5}$ | $3\times10^{-5}$ | <1 | <1 |
| Inhalation of dust generated by motorcycles | | | | |
| Gregory | $5\times10^{-6}$ | $1\times10^{-4}$ | <1 | <1 |
| Direct contact and incidental ingestion of coal and tailings | | | | |
| Gregory | $1\times10^{-2}$ | $5\times10^{-4}$ | <1 | <1 |
| Argo | $8\times10^{-5}$ | $1\times10^{-3}$ | <1 | 2 |

NE = not estimated

[a]Note that excess cancer risks greater than $1\times10^{-6}$ may be unacceptable.



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- Concentrations of chemicals in Clear Creek water upstream of the intake for the City of Golden Water supply are below regulatory target concentrations. Ingestion of drinking water from groundwater wells screened in the alluvial aquifer, however, results in a upperbound lifetime risk of $1 \times 10^{-2}$ and $7 \times 10^{-3}$ from exposure to the geometric mean concentrations of arsenic in the Clear Creek subbasin groundwater and the North Clear Creek subbasin groundwater, respectively. Maximum concentrations of arsenic in both subbasins exceeded the ARAR as did the maximum concentrations of several metals including cadmium, chromium, copper, lead and zinc. The geometric mean concentrations of cadmium and lead were both above the ARARs.

- Incidental ingestion of arsenic while swimming in Clear Creek may result in an upperbound risk of $5 \times 10^{-6}$ and $2 \times 10^{-5}$, under the average and maximum plausible scenarios, respectively. However, it should be noted that arsenic concentrations in Clear Creek are similar to concentrations of arsenic in other Colorado rivers. Direct contact with mine discharge water at the Big Five mine and Argo tunnel will probably not irritate hands, but may cause eye irritation.

- Under the maximum plausible scenario, ingestion of fish from Clear Creek may result in doses greater than the health-based criteria for cadmium, copper, silver and zinc. Ingestion of fish caught from North Clear Creek may also result in doses of copper, silver and zinc that exceed the criteria. Upperbound lifetime excess cancer risks of $9 \times 10^{-4}$ and $4 \times 10^{-5}$ were calculated for ingestion of fish from Clear Creek under the maximum plausible and average scenarios, respectively, based on arsenic. Because arsenic is metabolized in fish to a less toxic form, the actual risk is probably lower. In addition, neither creek may support enough fish to result in the assumed intake.

- Inhalation of wind-entrained dust from the Gregory Tailings pile results in upperbound lifetime excess cancer risks of $3x10^{-5}$ and $7x10^{-6}$ for the maximum plausible and average cases, respectively, primarily from exposure to arsenic. Inhalation of wind-entrained dust from the Argo tailings pile results in upperbound lifetime excess cancer risks of $3x10^{-5}$ and $2x10^{-5}$, for the maximum plausible and average cases, respectively. Generation of dust by dirt bikes ridden at the Gregory Tailings piles results in upperbound risks of $5x10^{-6}$ and $1x10^{-4}$, for the average and maximum plausible cases, respectively. Ingestion of arsenic-contaminated tailings from the Gregory tailings pile poses an upperbound lifetime excess cancer risk of $1x10^{-5}$ under the average case and $5x10^{-4}$ under the maximum plausible scenarios. Ingestion of arsenic-contaminated tailings from the Argo tailings pile poses upperbound lifetime excess cancer risks of $8x10^{-5}$ and $1x10^{-3}$ under the average and maximum plausible scenarios, respectively

Exposures to Aquatic Life

The exposure of aquatic life in Clear Creek, North Clear Creek, and the marsh below National tunnel were considered. The major conclusions of this assessment can be summarized as follows.

- Several of the chemicals of concern present at all three locations are at concentrations that exceed the ambient water quality criteria for the protection of freshwater aquatic life (AWQC). In particular, concentrations of zinc, copper, and aluminum consistently exceed the acute and chronic AWQC. The pH of all three locations is lower than the range of pHs suggested by EPA for the protection of freshwater aquatic life. In addition, concentrations of manganese in the water at all three locations exceed the lowest observed effect level in rainbow trout. Because aquatic organisms are exposed to a mixture and not individual chemicals, toxic effects may be even greater than indicated by comparison to the AWQC.

Although some fish may tolerate the chemicals in the creeks, it is highly unlikely that the populations of fish found in these creeks are free of toxic effects.

## 11.0 TREATABILITY STUDIES

The need for several treatability studies has been identified to support feasibility studies for mine water treatment and tailings remediation. The treatability studies have been scoped and are summarized in this section.

### Bench Scale Precipitation Studies

Bench scale precipitation studies have been conducted on Argo Tunnel mine drainage in order to determine the most technically acceptable and cost effective method for removal of heavy metals from the discharge to Clear Creek. The report on the treatability studies will be included in the Feasibility Study for Operable Unit I and in the Administrative Record. The feasibility study report is scheduled to be submitted to EPA in June 1987.

### Passive Treatment Studies

Concentrations of heavy metals present in acid mine drainage are reduced as mine drainage flows through natural bogs and wetlands. A pilot passive treatment plant will be constructed to treat a portion of the discharge from the Big Five Tunnel and demonstrate how effectively a simulated wetlands will treat the acid discharge. If effective, the discharge could be treated with little or no maintenance. These studies are planned to start in July 1987.

### Reprocessing of Tailings/Waste Rock

Preliminary screening studies will be performed to determine the economics of reprocessing both tailings and waste rock piles within the RI/FS study

area. In particular, removal of the contaminants of concern will be examined. The study is currently planned to start in June 1987.

Solidification Studies

Laboratory studies will be conducted to determine the feasibility and economics of using chemical additives to stabilize/fix the contaminants in the tailings and waste rock. Various fixation agents such as kiln dust and fly ash will be evaluated. The first phase of these studies were completed in April 1987.

# 12.0 DATA QUALITY ASSESSMENT

## 12.1 INTRODUCTION

This section consists of the following parts:

- 12.2 - Data Validation and Usability Summary
- 12.3 - Summary of Field QA/QC Results
- 12.4 - Comparison of Dissolved and Total Metal Results
- 12.5 - Evaluation of the Consistency of Water Analyses

Section 12.2 is a data usability report that summarizes the results of the data validation process described in Section 4.10. The second part of this section (12.3) summarizes the results of the field QA/QC samples. These samples include field splits, decontamination samples, trip blanks, and blind standards as described in Section 4.6. The field results are also compared to the laboratory QA/QC results to evaluate possible sources of inaccuracy and imprecision. Section 12.4 evaluates the discrepancies observed between dissolved and total concentrations in selected samples. Section 12.5 summarizes the results of the evaluation of the consistency of the water quality data. Such methods as charge balances and calculation of total dissolved solids were used.

## 12.2 DATA VALIDATION AND USABILITY SUMMARY

The following data usability summary identifies analytical data deficiencies based on the CLP data validation SOP document and provides some additional guidance in the use of the data from an analytical point of view. In addition to reporting contract violations, the usability summary also highlights problems that may affect the data, even if no contract violation exists.

Table 12A-1 through 12A-4 in Appendix 12A summarizes the samples and parameters which have been qualified in accordance with the specification of the CLP data validation SOP document (EPA, May 14, 1985, Draft Inorganic Data validation SOP). All data not listed as having been "qualified" during the data validation process should be considered to be "valid" within the context of the CLP quality assurance program and analytical quality control requirements. The qualifiers used in Appendix 12A are defined as follows:

JS: The reported value (positive or detection limit) should be considered to be estimated based on the matrix spike results which exceeded control limits.

JC: The reported value (positive or detection limit) should be considered to be estimated based on instrument calibration problems.

JE: The reported value (positive or detection limit) should be considered to be estimated based on interference problems (ICP serial dilution or poor analytical spike recovery by graphite furnace)

J*: The reported value (positive or detection limit) should be considered to be estimated based on duplicate sample results which exceeded control limits.

JHT: The reported value (positive or detection limit) should be considered to be estimated based on holding time results which exceeded control limits.

R: The reported value (positive or detection limit) should be considered to be <u>Rejected</u> based on laboratory results (poor matrix spike recovery).

-: No qualifier added.

12.2.1 FIRST QUARTER DATA USABILITY SUMMARY

The first quarter sampling involved 37 samples total (34 water and 3 soil) for the analysis of the RAS and SAS parameters listed in Table 12-1.

All reported sample results for selenium, silver, boron (total and dissolved), and tin (total) should be considered to be estimated, based on calibration and/or matrix spike results. Forty percent of the reported

TABLE 12-1

SUMMARY OF RAS AND SAS INORGANIC PARAMETERS
FOR FIRST QUARTER SAMPLING AT CLEAR CREEK

| METALS (Total) | METALS (Dissolved) | SAS Parameters |
|---|---|---|
| Aluminum | Aluminum | $NO_2$ |
| Antimony | Antimony | $NO_3$ |
| Arsenic | Arsenic | $HCO_3/CO_3$ |
| Barium | Barium | Acidity |
| Beryllium | Beryllium | Cl |
| Cadmium | Cadmium | F |
| Calcium | Calcium | $SO_4$ |
| Chromium | Chromium | TDS |
| Cobalt | Cobalt | pH |
| Copper | Copper | Specific Conductance |
| Iron | Iron | TSS |
| Lead | Lead | B (Total) |
| Magnesium | Magnesium | B (Dissolved) |
| Manganese | Manganese | Mo (Total) |
| Mercury | Mercury | Mo (Dissolved) |
| Nickel | Nickel | Sr (Total) |
| Potassium | Potassium | Sr (Dissolved) |
| Selenium | Selenium | Cd (Total) |
| Silver | Silver | Cd (Dissolved) |
| Sodium | Sodium | Au (Total) |
| Thallium | Thallium | Au (Dissolved) |
| Tin | Tin | Ag (Total) |
| Vanadium | Vanadium | Ag (Dissolved) |
| Zinc | Zinc | |
| Cyanide | Cyanide | |

sample values for thallium, tin, and magnesium should be considered to be estimated based on matrix spike results. For these analytes, qualitative results should be considered to be acceptable, however quantitative results should be used with caution.

A summary table of the percentage of samples analyzed that were qualified based on laboratory QC, is provided in Table 12-2.

### 12.2.2 SECOND QUARTER DATA USABILITY SUMMARY

The second quarter sampling involved 172 samples total (66 water and 106 soil) for the analysis of the RAS and SAS parameters listed in Table 12-3.

Based on matrix spike results, reported selenium results should be considered to be rejected for 44% of the total Se water analyses, 61% of the dissolved Se water analyses, and 40% of the total Se soil analyses. Based on matrix spike results, reported selenium results should be considered to be estimated for 13% of the total Se water analyses, and 12% of the total Se soil analyses. Rejected results are invalid and unusable values, estimated results should be used with caution as there exists a possibility of a low bias of the reported positive value as well as the possibility of false-negatives being reported.

Based on violations of the holding time requirements, a percentage of the following dissolved water results should be considered to be estimated, $NO_3/NO_2$ (30%), $HCO_3/CO_3$ (55%), Acidity (85%), $SO_4$ (75%), TDS (85%), TOC (55%), and Cr(VI) (80%). Reported positive results may be biased low and the possibility of false-negatives being reported exists.

Based on matrix spike results, reported CN results should be considered to be rejected for 30% of the total CN water analyses. Based on holding time results, 10% of the total CN water analyses, and 40% of the total CN soil analyses should be considered to be estimated. Rejected results are invalid and unusable values, estimated results should be used with caution

TABLE 12-2

SUMMARY OF SAMPLE DATA DEFICIENCIES (QUALIFIERS)
First Quarter Data Usability Summary

| Analyte | Qualifier (% of total samples analyzed) JS | JC |
|---|---|---|
| **Metals (Total)** | | |
| Selenium | 100 | - |
| Silver | - | 100 |
| Thallium | 40 | - |
| Tin | 100 | - |
| **Metals (Dissolved)** | | |
| Selenium | 100 | - |
| Silver | - | 100 |
| Thallium | 40 | - |
| Tin | 40 | - |
| Magnesium | 40 | - |
| **SAS Parameters** | | |
| % (Total) | 100 | - |
| % (Dissolved) | 100 | - |

TABLE 10-3

SUMMARY OF RAS AND SAS INORGANIC PARAMETERS
FOR SECOND QUARTER SAMPLING AT CLEAR CREEK

| METALS (Total) | METALS (Dissolved) | SAS Parameters |
|---|---|---|
| Aluminum | Aluminum | $NO_2$ |
| Antimony | Antimony | $NO_3$ |
| Arsenic | Arsenic | $HCO_3/CO_3$ |
| Barium | Barium | Acidity |
| Beryllium | Beryllium | Cl |
| Cadmium | Cadmium | F |
| Calcium | Calcium | $SO_4$ |
| Chromium | Chromium | TDS |
| Cobalt | Cobalt | pH |
| Copper | Copper | Specific Conductance |
| Iron | Iron | TSS |
| Lead | Lead | B (Total) |
| Magnesium | Magnesium | B (Dissolved) |
| Manganese | Manganese | Mo (Total) |
| Mercury | Mercury | Mo (Dissolved) |
| Nickel | Nickel | Sr (Total) |
| Potassium | Potassium | Sr (Dissolved) |
| Selenium | Selenium | Cd (Total) |
| Silver | Silver | Cd (Dissolved) |
| Sodium | Sodium | Au (Total) |
| Thallium | Thallium | Au (Dissolved) |
| Tin | Tin | Ag (Total) |
| Vanadium | Vanadium | Ag (Dissolved) |
| Zinc | Zinc | Neutralization Potential |
| Cyanide | Cyanide | Acid Potential |
| | | Total Sulfur |
| | | Sulfate Sulfur |
| | | Pyritic Sulfur |
| | | Organic Sulfur |
| | | % Sand, Silt, Clay |

as there exists a possibility of a low bias of the reported positive value as well as the possibility of false-negatives being reported.

Based on matrix spike results, a percentage of the total water results for the following analytes should be considered to be estimated: As (27%), Ba (27%), Be (27%), Ni (27%), Sn (27%), Tl (14%).

Based on the matrix spike results, a percentage of the "dissolved" water results for the following analytes should be considered to be estimated: Ag (21%), Sn (27%), Zn (26%), Au (60%).

Based on matrix spike results, a percentage of the soil results for the following analytes should be considered to be estimated: Sb (46%), Mn (15%), Hg (18%), Tl (25%), Au (30%).

Based on duplicate precision results, a percentage of the water (dissolved and total) and soil results for the following analytes should be considered to be estimated: Pb (Total $H_2O$, 20%); Mo (total $H_2O$, 30%); Pyritic and Organic Sulfur (water, 50%).

Reported Mo results should be considered to be estimated for 11% of the total Mo soil analyses based on calibration precision results.

Estimated values should be considered to be acceptable qualitatively, however, quantitative results should be used with caution as the possibility of positive results (high or low) biases exists, dependent upon the QC parameter that led to the reported value being qualified as estimated.

The following items have been noted on the data review summaries and the data usabilities for the individual sample packages. The data were not qualified based on these results, however, the data user should be aware of the possible effect on data.

1. For all samples in this sampling quarter, the laboratory pH values reported (not field pH) should be considered to be estimated, based on the holding time results. Although no contract holding time was specified, the method requested in the SAS request, stated that pH measurements should be taken as soon as possible.

2. For samples MHE224 through MHE243, MHE250, MHE262, MHE263, MHE265, MBC373, MBC375, MBC378, MBC381, MBC385 through MBC395, MBC369, MBC370 through MBC372, MBC374, MBC376, MBC377, MBC379, MBC380, MBC382 through MBC384 the reported cyanide and mercury data should be considered to be estimated based on the holding time results. Although no contract holding times are specified for soils, the contract does have recommended holding time guidelines, which were exceeded for these samples.

3. Organic sulfur results were not possible to report for samples: MHE225, MHE228, MHE233, MHE236, MHE237, MHE238, MHE240, MHE242, MHE202, MHE203, MHE212, MHE218, MHE221, MHE245, MHE247, MHE248, MBC363, MBC364, MBC365, MBC495, MHE265, MBC381, MBC385, MBC390, MBC391, MBC393, MBC395, MHE266, MHE267, MHE268, MHE271, MHE272, MHE278, MHE279, MHE280. The total sulfur results were less than the sum of the sulfate sulfur and pyritic sulfur results for the above listed samples. The laboratory stated that reanalysis of these samples was not possible due to insufficient sample amounts. The reported results for total sulfur, pyritic sulfur, and sulfate sulfur should be considered to be estimated and used with caution.

4. For all samples, the CrVI detection limit reported by the laboratory was two times higher than the detection limit required in the SAS request. There exists the possibility that CrVI has not been detected in the range (5 ug/L to 10 ug/L) between the SAS required detection limits and the laboratory reported detection limit.

A summary table of the percentage of samples analyzed that were qualified based on laboratory QC is provided in Table 12-4.

### 12.2.3 THIRD QUARTER DATA USABILITY SUMMARY

The third quarter sampling involved 105 samples total (95 water and 10 soils) for the analysis of the RAS and SAS parameters listed in Table 12-5.

Based on matrix spike recovery results, the reported selenium and lead results should be considered to be rejected for 35% of the total Se water analyses; 35% of the dissolved Se water analyses; 10% of the dissolved Pb water analyses; and 80% of the total Se soil analyses. Rejected results are invalid, unusable values.

TABLE 12-4

SUMMARY OF SAMPLE DATA DEFICIENCIES (QUALIFIERS)
Second Quarter Data Usability Summary

| | Qualifier (% of Total Samples Analyzed) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | JS | | JD | | J* | | JET | | R | |
| Analyte | Water | Soil | Water | Soil | Water | Soil | Water | Soil | Water | Soil |
| **Metals (Total)** | | | | | | | | | | |
| Antimony | - | 46 | - | - | - | - | - | - | - | - |
| Arsenic | 27 | - | - | - | - | - | - | - | - | - |
| Barium | 27 | - | - | - | - | - | - | - | - | - |
| Beryllium | 27 | - | - | - | - | - | - | - | - | - |
| Lead | - | - | - | - | 20 | - | - | - | - | - |
| Manganese | - | 15 | - | - | - | - | - | - | - | - |
| Mercury | - | 38 | - | - | - | - | - | - | - | - |
| Nickel | 27 | - | - | - | - | - | - | - | - | - |
| Selenium | 33 | 33 | - | - | - | - | - | - | 44 | 40 |
| Silver | - | - | - | - | - | - | - | - | - | - |
| Thallium | 14 | 25 | - | - | - | - | - | - | - | - |
| Zinc | 27 | - | - | - | - | - | - | - | - | - |
| Cyanide | - | - | - | - | - | - | 10 | 60 | 30 | - |
| **Metals (Dissolved)** | | | | | | | | | | |
| Selenium | - | - | - | - | - | - | - | - | 62 | - |
| Silver | 23 | - | - | - | - | - | - | - | - | - |
| Zinc | 27 | - | - | - | - | - | - | - | - | - |
| **SAS Parameters** | | | | | | | | | | |
| $NO_2/NO_3$ | - | - | - | - | - | - | 30 | - | - | - |
| $HCO_3/CO_3$ | - | - | - | - | - | - | 55 | - | - | - |
| Acidity | - | - | - | - | - | - | 85 | - | - | - |
| $SO_4$ | - | - | - | - | - | - | 75 | - | - | - |
| TDS | - | - | - | - | - | - | 85 | - | - | - |
| TOC | - | - | - | - | - | - | 55 | - | - | - |
| Cr | - | - | - | - | - | - | 80 | - | - | - |
| Mo (Total) | | | | 11 | 10 | - | - | - | - | - |
| Au (Total) | | 30 | - | - | - | - | - | - | - | - |
| Au (Dissolved) | 60 | - | - | - | - | - | - | - | - | - |
| Pyritic Sulfur | - | - | - | - | 50 | - | - | - | - | - |
| Organic Sulfur | - | - | - | - | 50 | - | - | - | - | - |

TABLE 10-5

SUMMARY OF RAS AND SAS INORGANIC PARAMETERS
FOR THIRD QUARTER SAMPLING AT CLEAR CREEK

| METALS (Total) | METALS (Dissolved) | SAS Parameters |
|---|---|---|
| Aluminum | Aluminum | $NO_2$ |
| Antimony | Antimony | $NO_3$ |
| Arsenic | Arsenic | $HCO_3/CO_3$ |
| Barium | Barium | Acidity |
| Beryllium | Beryllium | Cl |
| Cadmium | Cadmium | F |
| Calcium | Calcium | $SO_4$ |
| Chromium | Chromium | TDS |
| Cobalt | Cobalt | pH |
| Copper | Copper | Specific Conductance |
| Iron | Iron | TSS |
| Lead | Lead | B (Total) |
| Magnesium | Magnesium | B (Dissolved) |
| Manganese | Manganese | Mo (Total) |
| Mercury | Mercury | Mo (Dissolved) |
| Nickel | Nickel | Sr (Total) |
| Potassium | Potassium | Sr (Dissolved) |
| Selenium | Selenium | Cd (Total) |
| Silver | Silver | Cd (Dissolved) |
| Sodium | Sodium | Au (Total) |
| Thallium | Thallium | Au (Dissolved) |
| Tin | Tin | Ag (Total) |
| Vanadium | Vanadium | Ag (Dissolved) |
| Zinc | Zinc | Neutralization Poten. |
| | | Acid Potential |
| Cyanide | Cyanide | Total Sulfur |
| | | Sulfate Sulfur |
| | | Pyritic Sulfur |
| | | Organic Sulfur |
| | | % Sand, Silt, Clay |

Based on matrix spike recovery results, a percentage of the results for the following analytes should be considered to be estimated.

Total Water: Al (25%), Sb (70%), Ca (15%), Cu (15%), Fe (15%), Mg (15%), Mn (15%), Ag (55%), Se (35%), Tl (55%), Acidity (15%), Sulfate (35%), Sn (15%), Zn (15%)

Dissolved Water: Al (20%), Sb (50%), Pb (20%), Ag (65%), Tl (35%), Sn (15%), Se (35%), Zn (26%)

Soils: Sb (50%), Se (80%)

Estimated values (based on matrix spike results) should be used with caution as there exists a possibility of a low bias of the reported positive results as well as the possibility of false-negatives being reported.

Based on reported interference results, a percentage of the results for the following analytes should be considered to be estimated:

Total Waters: Be (20%), Cd (20%), Fe (20%)
Dissolved Water: Ni (20%)
Soil: Zn (20%)

Based on duplicate precision results, reported results for Zn in soil should be considered to be estimated for 80% of the samples analyzed.

Based on calibration precision results, reported results for $SO_4$ in water should be considered to be estimated for 20% of the samples analyzed.

Estimated values should be considered to be acceptable qualitatively. However, quantitative results should be used with caution as the possibility of positive result (high or low) biases exist, dependent upon the QC parameter result that led to the reported value being qualified as estimated.

The following items have been noted in the data review summaries and the data usabilities for the individual sample packages. The data were not qualified based on these results, however, the data user should be aware of the possible effect on data.

1. For all water samples in the third quarter sampling, the reported detection limits for $NO_2/NO_3$, CrVI, $NO_2$, and $NO_3$ were higher than the SAS requested detection limit. There exists the possibility that the above parameters were not detected in the range between the SAS required detection limits and the laboratory reported detection limits.

2. For samples MEB421, MEB426, MEB428, MEB469, MEB471, MEB482, MEB485, MEB540, MEB429, MEB430, MEB431, MEB475, MEB479, MEB562, MEB563, and MEB564 (QC report #55730) the laboratory pH data should be considered to be estimated, based on the holding time results. Although no contract holding time was specified, the method requested in the SAS request, stated that the pH measurements should be taken as soon as possible.

A summary table of the percentage of samples analyzed that were qualified based on laboratory QC is provided in Table 12-6.

12.2.4 FOURTH QUARTER DATA USABILITY SUMMARY

The fourth quarter sampling involved 110 samples total (79 water and 31 soil) for the analysis of the RAS and SAS parameters listed in Table 12-7.

Reported selenium, silver, tin, and thallium results should be considered to be rejected for 45% of the total Se water analyses and Se soil analyses, 90% of the dissolved Se water analyses; 45% of the total Ag water analyses; 40% of the total Sn water analyses; 90% of the dissolved Tl water analyses, based on matrix spike recovery results. Rejected results are invalid, unusable values.

Based on matrix spike recovery results, a percentage of the reported results for the following percentages of listed analytes should be considered to be estimated.

TABLE II-6

SUMMARY OF SAMPLE DATA DEFICIENCIES (QUALIFIERS)
Third Quarter Data Usability Summary

| Analyte | Qualifier (% of Total Samples Analyzed) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | JS | | JC | | JE | | J* | | R | |
| | Water | Soil | Water | Soil | Water | Soil | Water | Soil | Water | Soil |
| **Metals (Total)** | | | | | | | | | | |
| Aluminum | 25 | - | - | - | - | - | - | - | - | - |
| Antimony | 70 | 50 | - | - | - | - | - | - | - | - |
| Beryllium | - | - | - | - | 20 | - | - | - | - | - |
| Cadmium | - | - | - | - | 20 | - | - | - | - | - |
| Calcium | 15 | - | - | - | - | - | - | - | - | - |
| Copper | 15 | - | - | - | - | - | - | - | - | - |
| Iron | 15 | - | - | - | 20 | - | - | - | - | - |
| Magnesium | 15 | - | - | - | - | - | - | - | - | - |
| Manganese | 15 | - | - | - | - | - | - | - | - | - |
| Selenium | 35 | 80 | - | - | - | - | - | - | 35 | 20 |
| Iron | 55 | - | - | - | - | - | - | - | - | - |
| Thallium | 55 | - | - | - | - | - | - | - | - | - |
| Tin | 15 | - | - | - | - | - | - | - | - | - |
| Zinc | 15 | - | - | - | - | 20 | - | 80 | - | - |
| **Metals (Dissolved)** | | | | | | | | | | |
| Aluminum | 20 | - | - | - | - | - | - | - | - | - |
| Antimony | 50 | - | - | - | - | - | - | - | - | - |
| Lead | 20 | - | - | - | - | - | - | - | 20 | - |
| Nickel | - | - | - | - | 20 | - | - | - | - | - |
| Selenium | 35 | - | - | - | - | - | - | - | 35 | - |
| Silver | 65 | - | - | - | - | - | - | - | - | - |
| Thallium | 35 | - | - | - | - | - | - | - | - | - |
| Tin | 15 | - | - | - | - | - | - | - | - | - |
| Zinc | 26 | - | - | - | - | - | - | - | - | - |
| **SAS Parameters** | | | | | | | | | | |
| Acidity | 15 | - | - | - | - | - | - | - | - | - |
| $SO_4$ | 35 | - | 10 | - | - | - | - | - | - | - |

TABLE 12-7

SUMMARY OF RAS AND SAS INORGANIC PARAMETERS
FOR FOURTH QUARTER SAMPLING AT CLEAR CREEK

| METALS (Total) | METALS (Dissolved) | SAS Parameters |
|---|---|---|
| Aluminum | Aluminum | $NO_2$ |
| Antimony | Antimony | $NO_3$ |
| Arsenic | Arsenic | $BOD_5/CO_3$ |
| Barium | Barium | Acidity |
| beryllium | Beryllium | Cl |
| Cadmium | Cadmium | F |
| Calcium | Calcium | $SO_4$ |
| Chromium | Chromium | TDS |
| Cobalt | Cobalt | $Si_{6+}$ |
| Copper | Copper | $Cr$ |
| Iron | Iron | pH |
| Lead | Lead | Specific Conductance |
| Magnesium | Magnesium | TSS |
| Manganese | Manganese | |
| Mercury | Mercury | |
| Nickel | Nickel | |
| Potassium | Potassium | |
| Selenium | Selenium | |
| Silver | Silver | |
| Sodium | Sodium | |
| Thallium | Thallium | |
| Tin | Tin | |
| Vanadium | Vanadium | |
| Zinc | Zinc | |
| Cyanide | Cyanide | |

Total Water: Pb (40%), C-VI (20%)

Dissolved Water: Al (95%), Sb (90%), As (90%), Cd (90%), Pb (95%)

Soil: Sb (75%)

Based on reported interference results, a percentage of the reported results for the following percentages of listed analytes should be considered to be estimated.

Dissolved Water: Be (95%), Fe (95%), Pb (95%), Mn (95%)
Soils: Co (75%)

Based on calibration precision results, a percentage of the reported results for the following percentages of listed analytes should be considered to be estimated.

Water: $SO_4^{=}$ (40%), TDS (40%), TSS (40%)
Soil: Ag (75%)

Based on duplicate precision results, a percentage of the reported results for the following percentages of the listed analytes should be considered to be estimated.

Water: Acidity (40%)
Soil: As (90%)

Estimated values should be considered to be acceptable qualitatively, however quantitative results should be used with caution as the possibility of positive results (high or low) biases exists, dependent upon the QC parameter result that led to the reported value being qualified as estimated.

The following items have been noted in the data review summaries and the data usabilities for the individual sample packages. The data were not

qualified based on these results, however the data user should be aware of the possible effect on data.

1. For samples MHD233 through MHD250, MHD290 through MHD300, MHD311 and MHD312 the laboratory did not spike Fe, Mn, and Zn at the SAS request specified levels (10 times the normal RAS spike level). There should be no effect on the reported data.

2. For samples MHD161 through MHD168, MHD179 through MHD184, MHD169, MHD171 through MHD173, MHD185 through MHD188, MHD198, MHD206, MHD207, MHD209 through MHD212, MHD214 through MHD216, MHC945 through MHC949, the reported detection limits for $NO_3/NO_2$ were five times higher than the SAS request specified detection limit. There exists the possibility that $NO_3/NO_2$ were not detected in the range between the SAS required detection limit and the laboratory reported detection limit.

A summary table of the percentage of samples analyzed that were qualified based on laboratory QC is provided in Table 12-8.

## 12.3 SUMMARY OF THE FIELD QA/QC RESULTS

### 12.3.1 INTRODUCTION

The Quality Assurance/Quality Control program for the field sampling program was evaluated using the results of decontamination blanks, travel blanks, blind standards, and sample splits in duplicate or triplicate. The review of these samples was performed in order to evaluate analytical accuracy and precision and to identify potential contamination problems as a result of field sampling and sample shipping procedure. The data from the field QA/QC samples are summarized in Appendix 12B. In the appendix tables, all positive sample values for blanks are included in parentheses. RPDX's (relative percent difference) and RSDX's (relative standard deviation) for all split samples are calculated and listed in the appendix tables as well.

The QC criteria used for these analytical results were based on the criteria in the EPA guideline for the Control Laboratory Program (CLP) (Draft Inorganic Data Validation SOP and CLP SOW No. 785). For all blanks, the CLP contractual required detection limits (CRDL) or the detection

TABLE 12-8

SUMMARY OF SAMPLE DATA DEFICIENCIES (QUALIFIERS)
Fourth Quarter Data Usability Summary

| | Qualifier (% of Total Samples Analyzed) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | | JS | | JC | | JB | | J* | |
| Analyte | Water | Soil | Water | Soil | Water | Soil | Water | Soil | Water | Soil |
| **Metals (Total)** | | | | | | | | | | |
| Antimony | - | - | - | 75 | - | - | - | - | - | - |
| Arsenic | - | - | - | - | - | - | - | - | - | 90 |
| Copper | - | - | - | - | - | - | - | 75 | - | - |
| Lead | - | - | 40 | - | - | - | - | - | - | - |
| Selenium | 45 | 45 | - | - | - | - | - | - | - | - |
| Silver | 45 | - | - | - | - | 75 | - | - | - | - |
| Tin | 40 | - | - | - | - | - | - | - | - | - |
| **Metals (Dissolved)** | | | | | | | | | | |
| Aluminum | - | - | 95 | - | - | - | - | - | - | - |
| Antimony | - | - | 90 | - | - | - | - | - | - | - |
| Arsenic | - | - | 90 | - | - | - | - | - | - | - |
| Beryllium | - | - | - | - | - | - | 95 | - | - | - |
| Cadmium | - | - | 90 | - | - | - | - | - | - | - |
| Iron | - | - | - | - | - | - | 95 | - | - | - |
| Lead | - | - | 95 | - | - | - | 95 | - | - | - |
| Manganese | - | - | - | - | - | - | 95 | - | - | - |
| Selenium | 90 | - | - | - | - | - | - | - | - | - |
| Thallium | 90 | - | - | - | - | - | - | - | - | - |
| **SAS Parameters** | | | | | | | | | | |
| Acidity | - | - | - | - | - | - | - | - | 40 | - |
| $SO_4$ | - | - | - | - | 40 | - | - | - | - | - |
| TDS | - | - | - | - | 40 | - | - | - | - | - |
| $Cr^{6+}$ | - | - | 20 | - | - | - | - | - | - | - |
| TSS | - | - | - | - | 40 | - | - | - | - | - |

limits specified in the request for Special Analytical Service (Appendix 4B) for all parameters were used as the blank QC criteria. For all sample splits, ±20% was used for water samples and ±35% was used for soil samples for both RPD% and RSD%. The target ranges used for all blind standards were supplied by the ERA (the company supplying the certified standards).

### 12.3.2 TRAVEL/BLANKS

The results of evaluations of the travel blanks are summarized in Appendix Table 12B-1. The analytical results for bicarbonate, fluoride, chloride, and sulfate in the second quarter travel blanks (Sample Nos. MBC441, MBC442, and MBC443) exceeded the control limit (above detection limits). The results of the evaluations of the decontamination blanks are summarized in Appendix Table 12B-1. However, some of these data were flagged as estimated in accordance with the laboratory QC criteria requirements (see Section 12.2). All other travel blank analytical results are within the control limits. Overall, the sample shipping procedures is considered to be adequate. The blanks should be considered as having no contaminants above detection limits.

### 12.3.3 DECONTAMINATION BLANKS

Decontamination blanks were typically collected following sampling of contaminated waters of relatively high concentration in order to verify that the decontamination procedures were adequate and to identify any cross-contamination problem that may exist. The results of the evaluations of the decontamination blanks are summarized in Appendix Table 12B-1. For first quarter, decontamination blanks (Sample Nos. MBC305 and MBC316), sodium and boron contents are outside the control limits (above detection limits). However, the travel blanks (MBC307 and MBC313) collected in the same period of time do not show the same contamination. The manganese value for the second quarter decontamination blank, MBC 452, exceeded the control limit (± CRDL, 15 ug/l). However, the Mn result for the travel

blank in the same period of time is within the control limit. For all other decontamination blanks, the parameters are within the control limits.

The isolated contamination that occurred in the field blank analyses is probably indicative of minor contamination of equipment by handling during collection of the blanks and is not considered to cause any contamination of samples.

12.3.4 SPLIT SAMPLES (DUPLICATES AND TRIPLICATES)

Sample splits were either collected in duplicate or triplicate. RPD was used as the parameter for duplicate QC and RSD was used as the parameter for triplicate QC results. The control limit for both RPD and RSD is 20% for water samples and 35% for soil samples. The RPD and RSD for some of the parameters were not calculated (NC) betause at least one value was below the detection limit (undetected) and one value was above the detection limit. The results of the evaluations of the split samples are summarized in Appendix Tables 12B-2 (water) and 12B-3 (solids).

For the trace metal analyses for the first quarter water samples (one triplicate and one duplicate), cadmium, cobalt, iron, and silver show at least one result out of the control limits. This is also true for aluminum, antimony, beryllium, boron, copper, iron, molybdenum, and silver for the second (two triplicates and two duplicates) and the third quarter (one quadruplicate and one duplicate) samples. For the fourth quarter split samples (one duplicate), 11 out of 28 trace metal parameters are classified as "NC" which means one result is below the detection limit and the other is above it. Overall, few values exceed the criteria of 20% and thus the sample results are considered valid.

In order to examine the tailing sample homogeneity, two types of tailings split samples were prepared: ground and raw tailings samples. The ground samples were homogenized by grinding before splitting while the raw samples

were not ground before splitting. As expected, ground tailing samples showed much less variation as evidenced from duplicate precision than did the raw tailing samples.

For the three duplicate ground (powder) samples, one analysis of organic sulfur, mercury, sulfur and silver exceeded the RPD value of 35%. For the six duplicate raw samples, the following parameters exceeded the 35% RPD.

- Ca (4 samples)
- Ag (3 samples)
- Hg (3 samples)
- S (3 samples)
- Se (3 samples)
- Cu (3 samples)
- Cr (3 samples)
- As (2 samples)
- Au (2 samples)
- Cd (2 samples)
- Mo (2 samples)
- Na (2 samples)
- Zn (2 samples)

Based on these results, it is imperative to homogenize samples (preferably by grinding) before sample analysis.

12.3.5 BLIND STANDARDS

For all water blind standards, the analytical results were reported as "G" (good) if within the designated target range. Otherwise, the numerical values are listed to indicate how far the component recovery is from the target range. The results of the evaluation are summarized in Appendix Table 12B-4. Poor results were consistently reported for Ag, Ca, Cd, Cr, Fe, Hg, K, Pb, Mn, Na, and Se. Overall results for the first and third quarters were good. Results for both fourth quarter standards were typically outside the target range for Ba, Cd, Cr, Fe, Pb, Mn and Ag. Based on these results, fourth quarter data for these parameters should be used with caution.

A Smuggler Mountain tailings sample was used to examine the inter-laboratory analyses of solid samples. It has been analyzed by four

independent laboratories and the results are listed in Appendix Table 12B-5. As indicated, the error associated with inter-laboratory analyses can be substantial and may exceed the intra-laboratory precision. As indicated by the analyses, the values reported during the Clear Creek/Central City RI investigation (Laboratory No 1) were within the criteria of one standard deviation from the mean. Because only limited data are available, conclusions should be made with caution.

12.3.6 IMPLICATIONS OF THE QA/QC RESULTS FOR MODELING

Based on this review, Al, Cu, Zn, and F have been analyzed with good precision and accuracy and can be used in the modeling effort (refer to Section 13.0).

## 12.4 COMPARISONS OF DISSOLVED AND TOTAL METALS RESULTS FOR SURFACE WATER SAMPLES

A review of the surface water analytical results indicates possible discrepancies between the dissolved metals and total metals analyses results for some samples. In particular, the dissolved concentrations for selected parameters exceed the total concentrations for some samples. To evaluate the reasons for these apparent discrepancies, samples with observed values of dissolved greater than total were selected. Specifically, the parameters Al, Ca, Fe and Si from these samples were evaluated in relation to the total suspended solids (TSS) concentrations. These parameters were selected because they are the major components of the suspended material (see Section 5.0) and therefore should reflect the largest differences between total and dissolved concentrations. For the samples listed in Table 12-9, selected values of Al, Ca, Fe, and Si for total metals and dissolved metals do not follow the anticipated results when the values reported for Total Suspended Solids (TSS) are taken into consideration. That is, for selected parameters, dissolved concentrations are greater than total concentrations. Possible reasons for the "reversals" are discussed below.

TABLE 12-9

COMPARISON SUMMARY OF TOTAL AND DISSOLVED CONCENTRATIONS

| Sample I.D. | Al (ug/L) Total | Al (ug/L) Diss | Ca (ug/L) Total | Ca (ug/L) Diss | Fe (ug/L) Total | Fe (ug/L) Diss | Si (ug/L) Total | Si (ug/L) Diss | TSS (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| MHE 423 | 243 | 230 | 186,000 | 195,000 | 44,200 | 36,800 | 41,800 | 42,900 | 50 |
| MHE 469 | 267 | [115] | 196,000 | 207,000 | 46,400 | 41,100 | 43,600 | 43,600 | 42 |
| MHE 472 | 254 | 299 | 49,900 | 55,600 | 21,900 | 24,900 | 16,800 | 17,500 | 18 |
| MHE 429 | 2,400 | 2,770 | 276,000 | 284,000 | 142,000 | 153,000 | 35,900 | 37,900 | 6.5 |
| MHE 428 | 13,400 | 19,600 | 258,000 | 344,000 | 109,000 | 152,000 | 36,900 | 49,000 | 3.5 |
| MHC 466 | 31 | 761 | 13,300 | 18,800 | 977 | 6,600 | -- | -- | 20 |
| MHC 470 | 530 | 554 | 34,400 | 35,800 | 15,400 | 16,000 | -- | -- | 32 |
| MHD 173 | 13,400 | 14,600 | 110,000 | 173,000 | 45,800 | 48,000 | 31,300 | 30,600 | 78 |
| MHD 187 | 4,970 | 5,840 | 196,000 | 234,000 | 121,000 | 129,000 | 34,700 | 33,900 | 68 |
| MHD 188 | 5,030 | 5,400 | 190,000 | 232,000 | 122,000 | 128,000 | 35,300 | 35,100 | 64 |
| MHD 206 | 22,300 | 22,800 | 276,000 | 309,000 | 137,000 | 138,000 | 40,800 | 40,700 | 73 |

U = Undetected
-- = Not analyzed
[ ] = Reported value below Contract Required Detection Limit and above Instrument Detection Limit.

The results for samples MEE 423, MEE 469, MEE 472, MEE 429, and MEE 428 collected during the fourth quarter were submitted together in the same laboratory data package. The laboratory case narrative submitted in the data package discussed the apparent discrepancies in the total metals and dissolved metals analysis results. The laboratory reanalyzed the above samples and verified the reported results. The laboratory suggested in the narrative that sampling errors had possibly occurred (e.g., bottle were labeled wrong). However, a review of the field records and sample shipment documents did not provide any evidence of sample identification errors by the sampling personnel.

The dissolved metals samples for the 2nd, 3rd, and 4th quarters were analyzed by direct aspiration into the ICP and graphite furnace AA while the total metals samples were acid digested prior to analysis. (Based on the SAS requested, both sample types should have been subjected to acid digestion) before analysis. This difference in analytical procedures could possibly account for the apparent discrepancies in the total versus dissolved metals results. That is, during the digestion process, some of the "total" concentrations could have been lost. However, a review of the blind field standard samples does not indicate that the acid digestion procedure resulted in the loss of analytes.

No consistent trends can be observed in the variation from the expected results with respect to the total metals and dissolved metals analyses. If the digestion procedure for total analyses actually dissolved all of the suspended solids, than an increase in the total concentrations should be observed proportional to the TSS values. However, the samples listed in Table 12-9 are all relatively low in TSS and, therefore, no large differences exist between total and dissolved concentrations. In fact, with the exception of sample MEC 446, the differences in total metals results and dissolved metals results are within the expected range of analytical error. Table 12-10 is a listing of samples which were collected during rain events and thus contain relatively high amounts of TSS. The results of Table 12-10 show that for samples with relatively high amounts

TABLE 12-10

COMPARISON OF TOTAL AND DISSOLVED CONCENTRATIONS
HIGH TSS SAMPLES

| Sample I.D. | Al (ug/L) Total | Al (ug/L) Diss | Ca (ug/L) Total | Ca (ug/L) Diss | Fe (ug/L) Total | Fe (ug/L) Diss | TSS (mg/L) |
|---|---|---|---|---|---|---|---|
| MHC 306 | 39,400 | 117 | 18,600 | 11,500 | 84,300 | 142 | 1350 |
| MHD 219 | 1,900 | 70U | 7,920 | 7,090 | 3,220 | 110 | - |
| MHD 220 | 5,240 | 70U | 6,590 | 4,350 | 9,320 | 75 | - |
| MHD 221 | 7,100 | 70U | 8,300 | 6,200 | 15,900 | 265 | - |
| MHD 222 | 4,870 | 70U | 6,880 | 5,240 | 9,540 | 386 | - |
| MHD 223 | 5,860 | 70U | 9,720 | 8,120 | 16,000 | 398 | - |

U = Undetected
- = Not analyzed

of total suspended solids, the total results are significantly higher (by several orders of magnitude) than the dissolved metals results, as expected. Therefore, it is apparent that when large concentrations of TSS exist, actual differences between total and dissolved concentration are observed. However, when the TSS values are low, the differences between dissolved and total values are usually minor and can be, in some cases, attributed to routine analytical imprecision and inaccuracy.

## 12.5 EVALUATION OF THE CONSISTENCY OF WATER ANALYSES

QA/QC of laboratory procedures is vitally important to assuring high-quality data. However, even after various analyses have been scrutinized individually (Section 12.2), more information can be gained by looking at the compilation of analyses for each sample. The consistency, completeness and accuracy of a water analysis can be checked by examining the charge balance, calculating theoretical total dissolved solids (TDS) values, comparing the ratio of total dissolved solids (TDS) to specific conductance (SC), comparing field and laboratory values for pH, SC and TDS, and comparing analyses from the same or similar sites. All of these techniques were used to check the analyses selected in Section 6.2.5 and Section 7.2, to illustrate major ion chemistry of surface and ground waters. The results of the evaluation are provided in Tables 12-11 (surface water), 12-12 (discharge/portal water) and 12-13 (ground water). The evaluation criteria used are provided on Table 12-14 and the formulas used to calculate TDS and charge balance are provided in Table 12-15.

The charge balance of the first- and second-quarter stream waters (see Table 12-11) appeared acceptable except for one analysis. That is, the difference of equivalents of major anions minus equivalents of major cations, divided by the sum of equivalents of anions and cations, expressed as a percent, was less than 10 percent in all but one case. The first-quarter samples averaged a deviation of 6.0 ± 3.3 percent charge balance; the range was from 1.2 percent to 14.4 percent (SW5, North Clear Creek below National Tunnel). Charge balances for the second-quarter

TABLE 12-11

RESULTS OF ANALYTICAL ACCEPTABILITY CHECKS
SELECTED STREAM WATER SAMPLES

| Parameter | First Quarter | | | | | Second Quarter | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SW1 | SW2 | SW3 | SW5 | SW11 | SW1 | SW2 | SW3 | SW5 | SW11 | SW29 |
| Charge Balance[a], % | -1.2 | -3.8 | -7.7 | -14.4 | +3.0 | +4.7 | +3.2 | +.4 | -6.55 | -1.9 | +1.6 |
| Calculated TDS, mg/l | 78.1 | 76.0 | 140.7 | 137.6 | 61.9 | 163.4 | 175.7 | 230.6 | 224.8 | 75.1 | 139.9 |
| Calc. TDS/Field SC | .65 | .61 | .95 | .76 | .79 | .76 | .83 | .70 | .64 | -- | .77 |
| Meas. TDS/Lab SC | .71 | .75 | .73 | .69 | .78 | .22[b] | .45[b] | .89 | .69 | .54 | .51 |
| Calc. TDS/Lab SC | .76 | .67 | .66 | .76 | .80 | .46 | .78 | .98 | .64 | .68 | .71 |
| Field SC/Lab SC | 1.16 | 1.10 | .70 | 1.00 | 1.00 | .60 | .95 | 1.40 | 1.01 | -- | .92 |
| Field pH/Lab pH | .98 | .88 | 1.05 | 1.03 | .93 | 1.03 | .99 | 1.04 | -- | -- | -- |
| Calc. TDS/Meas. TDS | 1.08 | .89 | .91 | 1.10 | 1.03 | 2.04[b] | 1.76[b] | 1.10[b] | .94[b] | 1.25[b] | 1.40[b] |

[a] Note: "+" sign denotes excess cations (or deficient anions)
"-" sign denotes excess anions (or deficient cations)

[b] TDS qualified as an estimate, "JSHF" or "JHF".

"--" - Not calculated (data not available).

TABLE 12-12

RESULTS OF ANALYTICAL ACCEPTABILITY CHECKS
SELECTED SECOND-QUARTER PORTAL DISCHARGES

| Parameter | SW8 NT | SW12 CT | SW16 OK | SW20 AO | SW23 BF |
|---|---|---|---|---|---|
| Charge Balance[a] | -10.2 | -7.3 | -41.1 | -30.5 | -11.9 |
| Calculated TDS | 1287.0 | 1714.4 | 4316.3 | 2985.1 | 2758.5 |
| Calc. TDS/Field SC | .87 | __ | __ | .98 | __ |
| Meas. TDS/Lab SC | .88 | 1.00 | 1.45 | 1.14 | 1.06 |
| Calc. TDS/Lab SC | .84 | .78 | 1.04 | .88 | .93 |
| Field SC/Lab SC | .96 | __ | __ | .99 | __ |
| Field pH/Lab pH | 1.33 | __ | .93 | .89 | __ |
| Calc. TDS/Meas. TDS | .96 | .78 | .72 | .85 | .87 |

[a] Note: "+" sign denotes excess cations (or deficient anions)
"-" sign denotes excess anions (or deficient cations)

"__" = Not calculated (data not available).

TABLE 12-11

RESULTS OF ANALYTICAL ACCEPTABILITY CHECKS
SELECTED GROUND WATER SAMPLES

| Parameter | MW3-1[c] | MW1-1 | MW2-1 | OH1-1 | OH2-1 | OH2-2 | OH13-1 | OH13-2 | OH13-3 |
|---|---|---|---|---|---|---|---|---|---|
| Charge Balance[a] | +.8 | -12.1 | +4.9 | -35.0[b] | -20.2 | -8.8 | -15.6 | -7.0 | -21.5 |
| Calculated TDS | 742.5 | 2418.7 | 618.0 | 4376.8[b] | 3152.8 | 2061.0 | 906.2 | 793.2 | 1065.4 |
| Calc. TDS/Field SC | .79 | .88 | .73 | 1.12[b] | --- | --- | .78 | .81 | .45 |
| Meas. TDS/Lab SC | .70 | 1.06 | .79 | 1.46[b] | 1.21 | 1.01 | .87 | .99 | .95 |
| Calc. TDS/Lab SC | .77 | .96 | .73 | 1.12[b] | 1.03 | .71 | .73 | .74 | .72 |
| Field SC/Lab SC | .97 | .99 | 1.00 | 1.00 | --- | --- | .94 | .92 | 1.59 |
| Field pH/Lab pH | .99 | .99 | .94 | .91 | .94 | --- | 1.12 | .93 | 1.77 |
| Calc. TDS/Meas. TDS | 1.09 | .82[d] | .92 | .77[b] | .85 | .76 | .84 | .75 | .76 |

[a] Note: "+" sign denotes excess cations
"-" sign denotes excess anions

[b] Lab TDS value is qualified as an estimate, "J5", and sulfate value is qualified as an estimate, "JHT".

[c] Number after hyphen gives quarter of sample.

[d] Lab TDS value is qualified as an estimate, "JHT".

"---" = Not calculated (data not available).

TABLE 12-14

ACCEPTABILITY CRITERIA

| Test | Criteria |
|---|---|
| Charge Balance | < 10% |
| Measured Total Dissolved Solids (TDS)/ Specific Conductance (SC) | 0.6 - 0.9 |
| Calculated TDS/SC | 0.6 - 0.9 |
| Field SC/Laboratory SC | 0.9 - 1.1 |
| Field pH/Laboratory pH | 0.9 - 1.1 |
| Calculated TDS/Measured TDS | 0.9 - 1.1 |

TABLE 10-15

FORMULAS USED TO CHECK ANALYTICAL ACCEPTABILITY/CONSISTENCE

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$$\text{Charge Balance} = \frac{\Sigma(\text{meq Anion}) - \Sigma(\text{meq Cation})}{\Sigma(\text{meq Anion}) + \Sigma(\text{meq Cation})} \times 100\%$$

where: $\Sigma(\text{meq Cations}) = \text{meq Ca} + \text{meq Mg} + \text{meq Na} + \text{meq K}$

meq of Ca = mg/L Ca x 0.04999
meq of Mg = mg/L Mg x 0.08226
meq of Na = mg/L Na x 0.04350
meq of K = mg/L K x 0.02557

$\Sigma(\text{meq Anions}) = \text{meq } CO_3 + \text{meq } HCO_3 + \text{meq } SO_4 + \text{meq Cl} + \text{meq } NO_3$

meq of $CO_3$ = mg/L x 0.0333
meq of $HCO_3$ = meq/L x 0.01639
meq of $SO_4$ = mg/L x 0.02082
meq of Cl = mg/L x 0.02821
meq of $NO_3$ = mg/L x 0.01613

Calculated TDS = (mg/L Ca) + (mg/L Mg) + (mg/L Na) + (mg/L K) +

(0.50 mg/L $CO_3$) + (0.49 mg/L $HCO_3$) + (mg/L Cl) +

(mg/L $SO_4$) + (mg/L $NO_3$)

---

analyses appeared better, at 3.0 ± 2.4 percent, ranging from 0.42 to 6.55 percent. In all cases, the largest charge imbalance, was negative indicating an excess of anions or a lack of cations. In these cases, the calculated TDS and measured SC are within criteria limits, therefore no conclusion can be made as to which condition (excess anions or deficient cations) exists.

The discharge (Table 12-12) and ground water (Table 12-13) samples did not charge balance as well as the surface waters. This was expected, because these waters had lower pH values, higher metal contents, higher concentrations of major ions, and had substantially different percentages of charged and uncharged complexes. The mean charge balance for discharges was 20.2 ± 14.8 percent, with a range of 7.3 to 41.1 percent. The deviation from balance for ground waters was 14.0 ± 10.0, with a range of 0.78 to 35 percent. Except for AR3 (Argo Well No. 3) and NT1 (National Tunnel Well No. 1), all discharges and ground waters showed a negative charge balance. In these cases, the ratios of TDS (especially measured) to SC were high. This may indicate that some ionic species were present that were not measured or included in the charge balance. Therefore, the imbalance can be attributed to deficient cations, probably the hydronium ion that was not included in the charge balance.

Simple charge balances may be deceptive in waters of this type, as was shown by modeling of the water analyses using the geochemical program MINTEQ (Felmy et al., 1983). This model speciates all parameters at the measured pH and Eh conditions. After speciation the groundwater and drainages, charge balances improved significantly.

When comparing calculated TDS to field SC, the stream water samples showed a relatively constant ratio of 0.71 to 0.76 for TDS/SC. This is at the upper limit of the range given by Hem (1985). Hem states that a range of 0.55 to 0.77 is normal but that waters rich in calcium and sulfate may show high TDS values. As waters with high calcium and sulfate are evaporated to determine TDS, they may precipitate gypsum, which may not fully dehydrated

even after an hour at 180°C. Since TDS was determined by evaporating these samples to constant weight at 180°C, the reported values should be fairly uniform. The comparison of TDS/SC is particularly useful in reviewing related sample data, since waters of similar composition should yield a nearly constant ratio of TDS/SC.

The discharges and ground waters, being of lower pH and higher concentrations of calcium and sulfate, present more obstacles to determining true TDS. As noted by Hem, gypsum, $CaSO_4 2H_2O$, may precipitate and not completely dehydrate. In addition, according to Hem, heavy liquids such as $H_2SO_4$ may form from low-pH waters as the sample evaporates. The ratio TDS/SC for discharges averaged 0.93. For ground waters for which the field SC was available, calculated TDS/field SC averaged 0.79 ± 0.20. In addition to the problem noted above, sulfate pairing may occur at high concentrations resulting in low values of SC. Both of these problems (high TDS and low SC) will result in high TDS/SC ratios.

The ratios of field pH/laboratory pH and field SC/laboratory SC are used to determine if the samples have undergone any severe changes between field sampling and laboratory analysis. In most cases, when values were not qualified, the ratios are in the acceptable range of 0.9 to 1.0. Selected samples that are outside this range include:

- SW1 - second quarter (Table 12-11), Field SC/Lab SC = 0.6. This sample appears to be caused by a high laboratory SC value.
- SW8 - (Table 12-12), Field pH/Lab pH = 1.83. The laboratory value appears to be low. Substantial changes to this sample may have occurred before analysis.
- OC11 - (Table 12-13), Field pH/Lab pH = 1.17 and Field SC/Lab SC = 1.59. The field SC values appear to be high. The results from this sample should be used with caution.

Comparison of analyses with those from the same or similar sites disclosed several errors. For example, the values for calcium and magnesium were transposed in sample No. MSC492. In comparing the values for calcium and magnesium for other Argo wells the mistake was apparent.

Using a combination of these methods to check complete analyses, a number of other possible problem areas were identified:

- Inspection of the four quarters of Argo discharge indicates that calculated TDS and charge balance were extremely variable. The measured TDS and major cations were very constant (less than six percent coefficient of variance). However, the sulfate values were variable with a coefficient of variance of 34 percent and range of values from 1,028 to 2,500 mg/L. These data clearly indicate that the sulfate concentrations may not be accurate. Inspection of ratios of TDS/SC and charge balance can indicate which sulfate values may be high or low.

- For a number of samples, the actual observed field specific conductance was entered into the data base instead of the value corrected to 25°C. At temperatures near 0°C, which were encountered in one sampling session, the "corrected to 25°C" value would be nearly twice that observed in the field. Field SC values were double-checked in the data base and corrected.

- In the long run, comparison of complete analyses from the same or similar sites can be a valuable tool, both for identifying suspect analyses and for establishing trends. For that reason, complete analyses (including major ions) should be run on key stream sites throughout the sampling period. This should show the variation in TDS and SC with low, medium and high flow and any variations in pH or ratios of major ions with flow rates and seasons.

- If analyses appear not to be charge-balanced, or even if they do, it may be important to account for ions not usually considered in "major ion" calculations. In these waters, as modeling with MINTEQ suggested, high metal levels and low pH values can substantially modify the "major ion" charge balance.

## 12.6 SUMMARY

The data validation process indicated that analytical problems existed for many of the parameters on a periodic basis. Parameters which had to be qualified a large percentage of the time include: Se, Tl, Sb, and Ag.

A summary of the overall data validation effort follows:

| Quarter | Approx. No. of Analyses Reviewed | Rejected (Percent) | Qualified (Percent) |
|---|---|---|---|
| 1 | 2,700 | 0.0 | 11 |
| 2 | 8,100 | 1.4 | 9 |
| 3 | 5,800 | 0.6 | 13 |
| 4 | 5,100 | 5.0 | 16 |

As shown, over 20,000 single analyses were reviewed during the data validation process. Of these values, three percent were rejected and 12 percent were qualified.

The field QA/QC samples indicated that the shipping procedures and decontamination procedures were adequate. Split and standard samples indicated that the laboratory precision and accuracy for critical parameters were acceptable in most cases. Split samples should be homogenized by grinding before subsampling and analysis.

Checks for consistency in sample analysis (change balance, calculated dissolved solids and ratios of field and laboratory values) indicated some problems in selected samples.

Overall, the data for critical parameters appear to be representative, precise, and accurate. However, due to the periodic rejected, inconsistent and qualified numbers, all values used for design of remedial actions should be carefully checked so that only non-qualified data are used.

# 13.0 MODELING THE CLEAR CREEK SYSTEM

## 13.1 INTRODUCTION

The objective of this section is to describe the modeling effort undertaken for the Clear Creek RI. This includes a discussion of model constraints, a sensitivity analysis, an evaluation of processes which control metal mobility, and a comparison between observed and modeled analyte concentrations in Clear Creek and North Clear Creek.

A large body of data has been collected which represents the Clear Creek system under present conditions. However, an important feature of this study is to determine the impact on the creek (and on potential receptors) of catastrophic events such as a blow-out from Argo, Big Five, or National Tunnels; the collapse of tailings into the stream at Big Five or Gregory, and the impact of these problems as a function of discharge. In addition, an estimate must be made of the effect of remedial action on a particular discharge in order to select the appropriate alternative treatment for each source. Remediation decisions can only be made by using predictive simulations which assess the deleterious impact on creek water chemistry that blowouts and tailings failure may have under different flow regimes. To quantitatively evaluate the hydrologic and chemical data collected during the Remedial Investigation (RI), computer simulations must be employed to predict downstream metal concentrations.

The scope of modeling in the RI is confined to calibration of the model using the existing data in order to show that the selected model, the Water Analysis Simulation Program (WASP) (Ambrose et al., 1986), is appropriate for the Clear Creek system. The simulations address the dilution and attenuation of metals from mine and tailings discharges. These include the Gregory tailings seep, Gregory Gulch, National Tunnel discharge, and Russell Gulch on North Clear Creek; and the Argo Tunnel and Big Five Tunnel discharges on Clear Creek. Using the model, it is possible

to determine the efficiency of the sampling network in order to ensure that all potential contaminant influents are accounted for. Impact scenarios, including a blow-out from the Argo Tunnel or collapse of tailings into the creek, will be considered under the feasibility portion of this study.

Process Controlling Metal Transport in Fluvial Systems

A detailed understanding of the mechanisms which control the mobility of toxic metals in streams is critical to an evaluation of the health risks and potential impact on receptors downstream from point discharges.

Metal concentrations and mobility in riverine systems are controlled by complex interactions between physical and chemical processes. The physical parameters (Figure 13-1) include advection, dispersion, and the erosion and deposition of sediment. The important chemical controls on metal attenuation in Clear Creek include sorption/desorption to suspended sediment and precipitation of amorphous mineral phases (Figure 13-2). The biotic component in Clear Creek plays a negligible role because the water velocity is too great for plant life to become established. The fish and invertebrate populations appear to have been adversely affected by the concentrations of metals found in the creek to the extent that they are not factors in the removal of metals from the water column and benthos respectively (U.S. Dept. of the Interior, 1967).

In evaluating the physical processes, dispersion can be discounted in Clear Creek because mine drainage are mixed rapidly in the turbulent flow. Sedimentation is limited to eddies behind large boulders. Under ambient conditions, erosion is not a significant factor because the water is clear with a low TSS (4 to 8 mg/L). The ground water impact varies between the two creeks. Based on flow measurements, ground water inputs constitute less than 10 percent of the total discharge to Clear Creek but potentially up to 40 percent in North Clear Creek. During October (the month for which

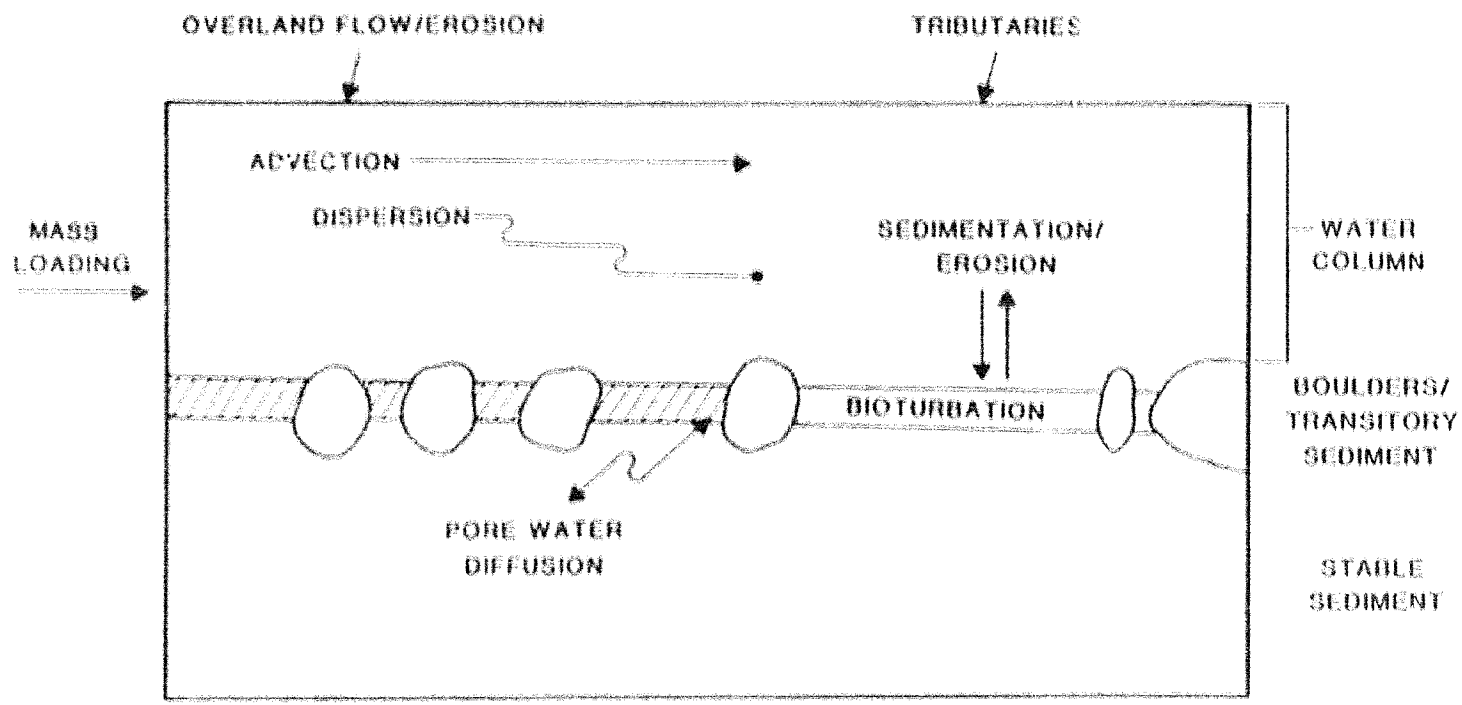


Figure 13-1 Physical Process Controlling Water & Sediment Distribution in a Fluvial System.

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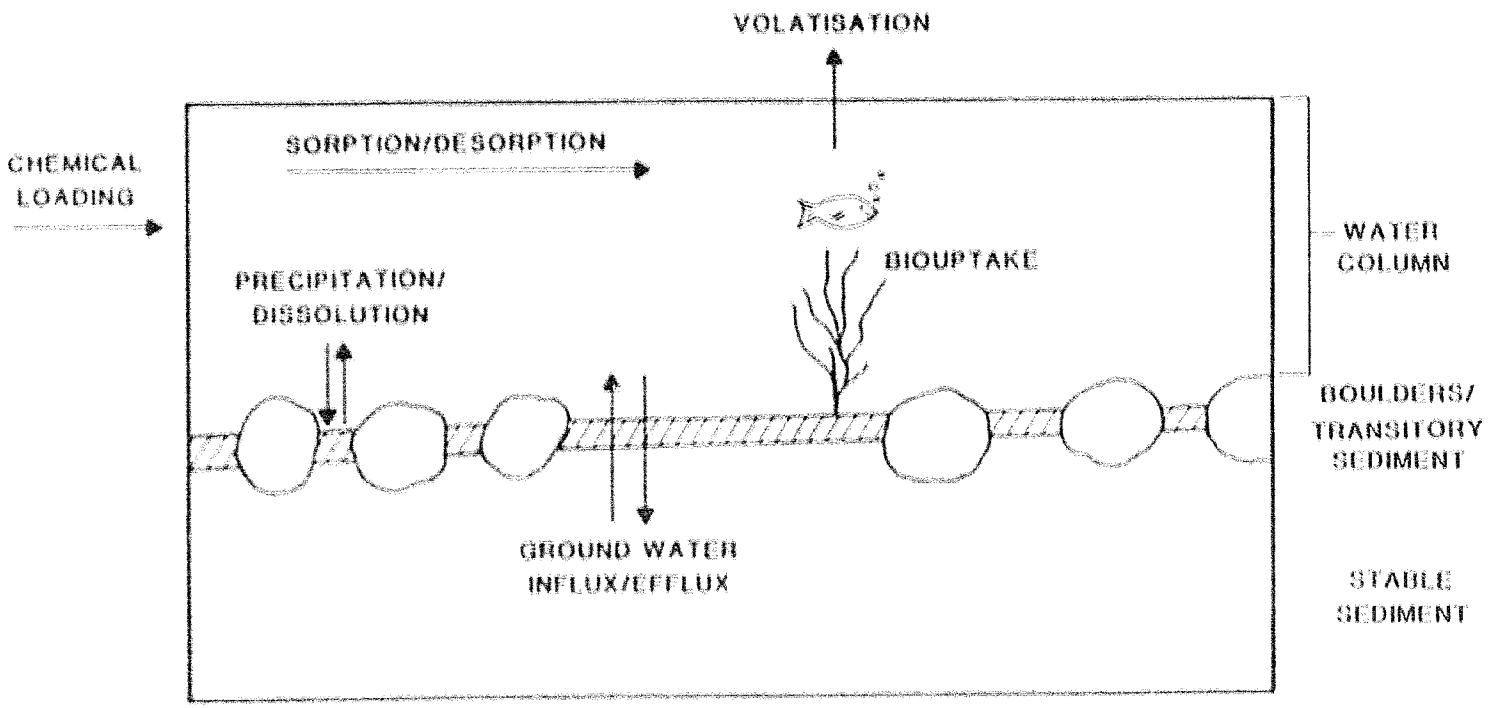


Figure 13-2 Chemical Process Controlling Analyte Distribution in a Fluvial System.

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the most flow data are available), there was no evidence of overland flows, and all discharges and tributaries were measured and accounted for in the model.

Figure 13-1 is representative of a cross-section through Clear Creek. For modeling purposes each compartment is composed of a water column segment, a transitory sediment segment and a stable sediment segment. The "transitory" sediment is a thin veneer which arbitrarily comprises one percent of the water compartment volume and is conceptualized as representing material which is readily eroded or settled out of suspension. The benthic compartment is of equal volume to the water column compartment and represents the sand and gravel base subjacent to the boulders in the creek bed. This latter segment is a convenience which allows for a continually renewable source of material to be eroded when simulating total suspended solid concentrations and the sorption of metals to the suspended fraction.

The important chemical processes influencing metal mobility in Clear Creek are probably precipitation and sorption. Precipitation of amorphous solids is evident from the manganese and iron oxides observed on North Clear Creek boulders, and from the amorphous ferric hydroxide seen to precipitate as the Argo drainage impacts Clear Creek and as Quartz Hill drainage mixes with Nevada Gulch. These amorphous solids provide a sink for co-precipitation or sorption of other metals. Following entrainment by particulate material in the water column, the total and dissolved metal concentrations will be significantly affected by the physical processes described previously. One of the goals in modeling the Clear Creek system is to define the relative importance of the physical and chemical processes which control the transport of metals in the system.

## 13.2 THE HYDRODYNAMIC AND GEOCHEMICAL CODES

WASP3 is an enhancement of the original WASP (DiToro et al., 1983). It is a compartmental model which incorporates time-varying processes of advection, dispersion, point and non-point loadings, and compartmental boundary exchange. The model has been used to examine a variety of systems, including kepone pollution of the James River Estuary (O'Connor et al., 1983), volatile organic pollution of the Delaware Estuary (Ambrose et al., 1986), and heavy metal pollution of the Deep River, North Carolina (JRB, 1984).

The WASP3 system consists of two programs, DYNHYD3 (a hydrodynamic code which simulates water movement) and WASP3 which incorporates kinetic sub-models to simulate pollution of water bodies by toxic chemicals or heavy metals. Both programs operate on the mass balance principle, in which the water volumes and the quantity of chemical constituents are accounted for over time and space through the use of mass balance equations.

The most recent version of the model has been promulgated by the U.S. EPA Environmental Research Laboratory, Athens, Georgia. The details of the program are documented in the users manual (Ambrose et al., 1986). The structure of the WASP3 input used in the RI will not be discussed at length in this section, except where it has a direct bearing on the Clear Creek modelling effort.

### 13.2.1 Design of the System

There are three major constraints on system morphology. These are that, (1) the ratio (Vi/Qi) must be similar in each compartment, where Vi is the volume of a compartment and Qi is the discharge passing through the compartment, (2) the time chosen for the simulation must generally be less than Vi/Qi and, (3) the length of the segment is dependent upon the computational stability criteria determined by:

$$l_i > \{(gy_i)^{0.5} \pm u_i\}\ \Delta t \qquad (2)$$

where:

$l_i$ = length of channel (ft)

$y_i$ = mean depth of channel i (ft)

$u_i$ = velocity in channel i (ft/sec)

$\Delta t$ = computational time step (sec)

$g$ = acceleration of gravity (32 ft/sec$^2$)

So for Clear Creek

$$l_i > \{(32*1.3)^{0.5} \pm 1.5\} * 900$$

$$\text{or} \quad 4450 < l_i < 7150 \text{ ft.}$$

Therefore, the segments should be between 0.8 and 1.3 miles in length. In practice, this defines a minimum segment length which ensures numerical stability during execution of the model. The time step of approximately 15 minutes was selected to assure this stability.

These criteria led to the partitioning of North Clear Creek into 8 x 1 mile (5,280 ft) segments and of Clear Creek into 4 x 2 mile segments (Figure 13-3). The downstream miles from the Gregory tailings and the Argo Discharge to the confluence are shown in Table 13-1. Segments on Clear Creek were longer than those on North Clear Creek in order to maintain numerical stability during WASP simulations. Below the confluence, segments are set at 3 mile intervals to evaluate the impact of upstream metal loading on users in Golden, Colorado. The upstream nodes for the model were set at compartmental boundaries in order to allow the Big Five and Gregory seep discharges to impact within the body of the upstream compartment on Clear Creek and North Clear Creek, respectively. Therefore, the most upstream point on the WASP simulation figures represents the metal concentration entering the system upstream of the first discharge.

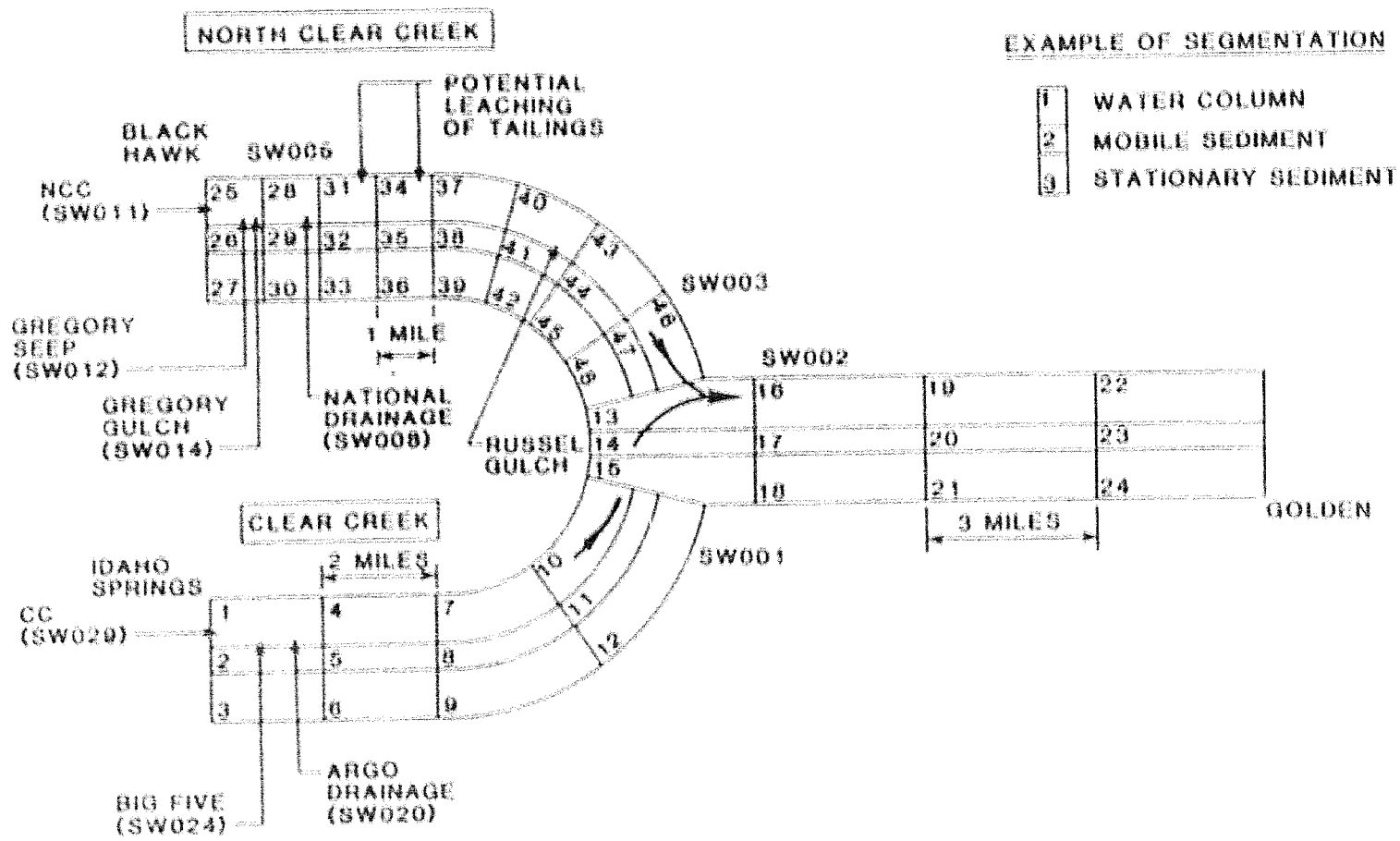


Figure 13-3 Segmentation of the Creek System Defined In WASP.

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TABLE 13-1

RIVER MILES FROM THE BIG FIVE DRAINAGE ON CLEAR CREEK AND
THE GREGORY TAILINGS ON NORTH CLEAR CREEK
TO THE CLEAR CREEK/NORTH CLEAR CREEK CONFLUENCE

| Mileage | Clear Creek Location | North Clear Creek Location | Mileage |
|---|---|---|---|
| 0 | Big Five Drainage | Gregory Tailings | 0 |
| | | Gregory Gulch | 0.2 |
| | | National Drainage | 0.7 |
| 1.2 | Argo Drainage | | |
| | | Russell Gulch | 4.0 |
| 8.5 | NCC/CC Confluence | | 7.8 |
| 20.5 | Golden Gauge Station | | 19.8 |



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The input parameters required to define the channels are their length, depth, width, hydraulic radius, and the stream velocity. The determination of the segment lengths have already been described. The volumes and discharge for each compartment were defined from the Marsh McBirney measurements at sites SW022 (above Argo), SW020 (Clear Creek below Argo), SW011 (North Clear Creek above Gregory tailings) and SW003 (North Clear Creek above Clear Creek). Flow measurements at these stations were described in Section 4.0, while results are provided in Section 6.0. Volumes and discharge in other segments were calculated by linear interpolation between the midpoints of the segments (Table 13-2). October was chosen for the calibration effort because flow measurements were not available from July 1985 or May 1986 due to high flow conditions in the creeks or in February 1986 when the creeks were iced up. The assumption is made that the cross-sections determined from the flow measurements were representative of the rest of the stream.

To maintain mass conservation below the confluence, flow at station SW002 (Clear Creek below confluence) was assumed to equal the combined flow of North Clear Creek and Clear Creek above the confluence (82.2 cfs). This exceeds the measured value by 4.7 cfs (6 percent). In October, the apparent discrepancy between the discharge above and below the Clear Creek/North Clear Creek confluence is a consequence of the inaccuracy of the Marsh McBirney technique in cobbly, deep, fast-flowing mountain streams.

The known, significant mine drainages into Clear Creek consist of Big Five (estimated to be 0.05 cfs) and Argo (0.32 cfs). North Clear Creek is impacted by the Gregory seep (estimated at 0.35 cfs), Gregory Gulch (0.24 cfs), National (0.09 cfs), and Russell Gulch (0.06 cfs). Gregory Gulch includes the impact of the Quartz Hill discharge during the summer months (Quartz Hill discharge is frozen at other times) in addition to leachate which percolates from tailings which line the gulch between Black Hawk and Central City.

TABLE 13-2

WET PARAMETERS USED IN MODELING THE CLEAR CREEK SYSTEM FOR THE SECOND QUARTER DATA

| Segment | Segment Length (mi.) | Volume (cf) | Creek Flow (cfs) | Adit Discharge (cfs) | Ground Water Discharge (cfs) | Stream Depth (ft) | Stream Velocity (ft/sec) |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 514800* | 72.5* | 0.35* | 1.63 | 1.25* | 1.45* |
| 4 | 2 | 509309 | 74 | -- | 2.0 | 1.26 | 1.49 |
| 7 | 2 | 503817 | 75.5 | -- | 2.0 | 1.27 | 1.53 |
| 10 | 2 | 498326 | 77* | -- | 2.0 | 1.28 | 1.57 |
| 13 | 3 | 739000* | 81.6 | -- | 2.3 | 1.29* | 1.60* |
| 16 | 3 | 791000 | 85.3 | -- | 0.3 | 0.38 | 0.90 |
| 19 | 3 | 800000 | 87.1 | -- | 0.3 | 0.38 | 0.90 |
| 22 | 3 | 809000 | 88.9 | -- | 0.3 | 0.38 | 0.90 |
| 25 | 1 | 15370* | 2.7* | 0.44* | 0 | 0.41* | 0.93* |
| 28 | 1 | 17316* | 3.14 | 0.09* | 0.05 | 0.41 | 0.93 |
| 31 | 1 | 19262 | 3.3 | -- | 0.3 | 0.40 | 0.92 |
| 34 | 1 | 21208 | 3.6 | -- | 0.3 | 0.40 | 0.92 |
| 37 | 1 | 23154 | 3.9 | 0.05* | 0.24 | 0.39 | 0.91 |
| 40 | 1 | 25100 | 4.2 | -- | 0.3 | 0.39 | 0.91 |
| 43 | 1 | 27046 | 4.5 | -- | 0.3 | 0.38 | 0.90 |
| 46 | 1 | 28992* | 4.8* | -- | 0.3 | 0.38* | 0.90* |

* Measured Values

All discharges in cubic feet per second.

Segment 1 receives Big Five and Argo drainage, segment 25 receives Gregory tailings seep and Gregory Gulch drainage, segment 28 receives National Tunnel drainage, and segment 37 receives Russel Gulch drainage. See Figure 1-3 for a graphical representation of this model. Flow totals include the ground water discharge into each compartment.

The boundary conditions (input or loss of metal to or from the compartment) were specified in each section as a background groundwater metal concentration determined using a groundwater analysis typical of the granitic bedrock in the region. In Clear Creek, metal loads were defined for the Big Five, and Argo Tunnel drainages. In North Clear Creek, metal loads were calculated for National drainage, Gregory tailings seep, Gregory Gulch, and Russell Gulch (Table 13-3). These loads were applied to the appropriate segment, leading to increases in the metal concentrations downstream of that segment.

### 13.2.2 Model Sensitivity

An analysis of the sensitivity of the model to variation in key parameters is necessary to quantify the error associated with each simulation. The major sources of inaccuracy and imprecision lie in the analytical analyses and in the flow measurements. Generally the analytical precision (based on replicate analyses) was ±5 percent. The flow measurements made using the Marsh McBirney, also based on replicate analyses were also ±5 percent. Therefore a worst case error margin is assumed to be ±10 percent. The upper end of the error bar was calculated in WASP by increasing loads into each compartment by 5 percent and by reducing volume, discharge and velocity values by 5 percent. The lower end of the error bar was determined by decreasing loads into each compartment by 5 percent and increasing volume, discharge and velocity values by 5 percent. The resulting error bars (see Figures 13-5 through 13-12 in Section 13.3), therefore, reflect the potential variation within the simulation based on analytical and flow measurement error.

### 13.2.3 Model Calibration

Initial WASP runs assumed that dilution was the principal factor controlling the reduction in stream metal concentration, so partition coefficients, sediment mass and sediment transport were not considered. The omission of sediment from the initial simulation is reasonable when

TABLE 13-3

THE Al, Cu, F and Zn LOADS (LB/DAY) USED IN WASP[a]

| Source | Al | Cu | F | Zn |
|---|---|---|---|---|
| Clear Creek | 60 | 5.7 | 332 | 79.5 |
| Argo Tunnel | 34 | 6.7 | 6 | 72.9 |
| Big Five | 5.2 | 0.40 | 0.38 | 2.7 |
| North Clear Creek (NCC) | 2.3 | 0.28 | 1.5 | 6.1 |
| Gregory Seep | 6 | 1.6 | 2.6 | 12.3 |
| Gregory Gulch | 1.5 | 0.24 | 0.23 | 2.9 |
| National Tunnel | 0.1 | 0.04 | 0.12 | 1.6 |
| Russell Gulch | 0.15 | 0.02 | 0.27 | 0.34 |
| Leached Tailings in NCC | 1.0 | 0.25 | - | 5 |

[a] Values used were calculated from total metal concentration (mg/L).

modeling the "total" metal concentration, because the stream velocity is rapid enough to entrain all particles of sand-size and smaller in the water column (Figure 13-4).

Using the constraints established in the previous sections, WASP was used to predict the total metal concentrations of Al, Cu, Fe, and Zn at sites downstream from National Tunnel (SW005), and above and below the confluence of North Clear Creek and Clear Creek (SW001, SW002, and SW003) (see locations on Figure 1-1). Generally the results are excellent, with the exception of station SW003 (North Clear Creek above Clear Creek). Here the metal load is consistently underestimated by up to 25 percent. The benefits of the model become apparent in this instance because it indicates that a potential source of metals was not accounted for in the second quarter sampling session. This source may either be an overlooked surface drainage, contaminated ground water discharge, or dissolution of tailings which line the creek below the National Tunnel. It is unlikely that an overland discharge was overlooked because a careful survey was made of the entire area prior to sampling. Therefore, the source of variation in the North Clear Creek metal concentrations is probably the result of metal loading into ground water which seeps through the tailings adjacent to the creek or dissolution of the tailings by the surface water. This additional input is considered during calibration runs of the model.

The introduction of contaminated seepage or surface water dissolution of tailings into Clear Creek below National Tunnel requires that additional metal loads must be added to successfully model the creek system. Estimates of tailings leaching can be made based on the metal concentrations analyzed from the leach tests of Gregory, Argo and Big Five tailings (Section 5.5). Estimates are described in detail in the subsequent analysis of the results (Section 13.3). It is important that metal concentrations be accurately simulated under present creek conditions so that the effects of blowouts and tailings failure may be superimposed on the baseline conditions to determine the increased impact upon receptors.

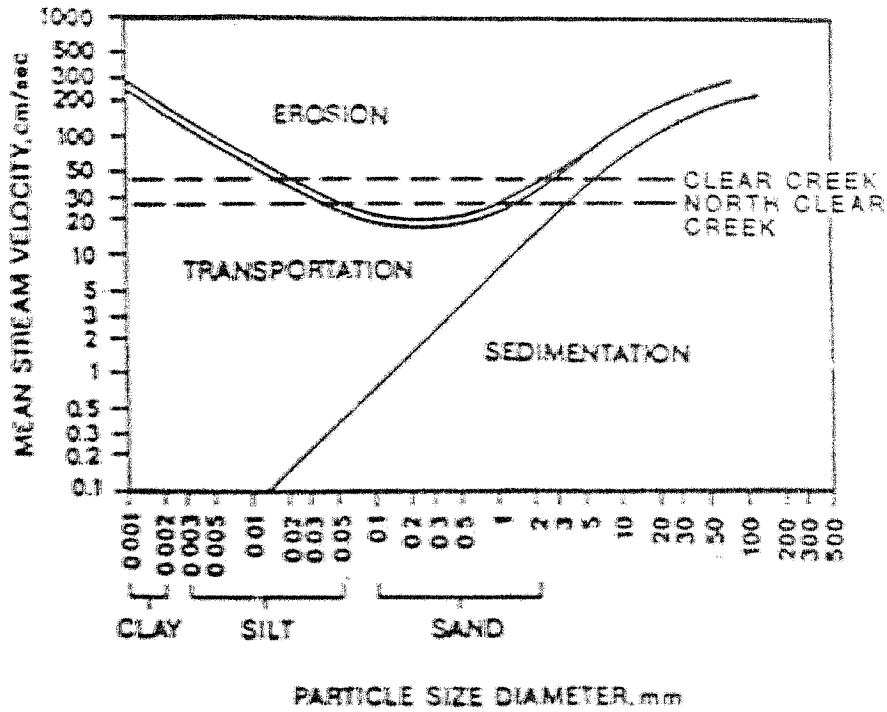


Figure 13-4 Particle Erosion, Transport and Sedimentation As A Function of Stream Velocity and Particle Size. Typical Velocities In October Are Superimposed for Clear Creek and North Clear Creek. (Taken from Ambrose et. al. 1986).

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## 13.3 SIMULATION OF TOTAL METAL CONCENTRATIONS

### 13.3.1 Aluminum

Using the metal loads specified in Table 13-3, WASP was used to calculate the concentrations of Al in the various river segments. Figure 13-5 shows the steady state total Al concentration after one day at various locations in the creek system. Model stability was attained after 5 iterations of 0.1 days each, therefore the results attained after 1 day represent equilibrium conditions. Agreement between measured and simulated Al concentrations is excellent, except in the reach of North Clear Creek between National Tunnel and the confluence of North Clear Creek and Clear Creek.

This difference is negated by the addition of 1 lb Al/day into segments 31 and 34 (Table 13-2), equivalent to loading 0.6 mg/L of Al in the 0.25 cfs assigned to ground water inflow (Table 13-3). The value of 0.6 mg/L is reasonable because the solubility of amorphous $AlOHSO_4$ (thought to control Al concentrations in the ground water of many tailing piles) may contribute this range of soluble Al concentration at pH values below 4 and above 6.5 (Davis and Runnells, 1987) (Figure 13-7). Because the acidic discharges are rapidly neutralized (in seconds), there is insufficient time for precipitation of $AlOHSO_4$, based on kinetic constraints, between the time the acidic discharge enters the creek and the time when the effluent pH is neutralized to a value above 6.5. Therefore Al remains in the soluble form.

The addition of the proposed ground water inflow or leached tailings to the simulation increases the Al concentration in North Clear Creek above the confluence to that measured in the second quarter samples (Figure 13-6). However, this has no discernible effect on the concentration of Al predicted at Golden (0.1 mg/L) because the North Clear Creek discharge contributes only 3 percent of the flow at the confluence with Clear Creek.

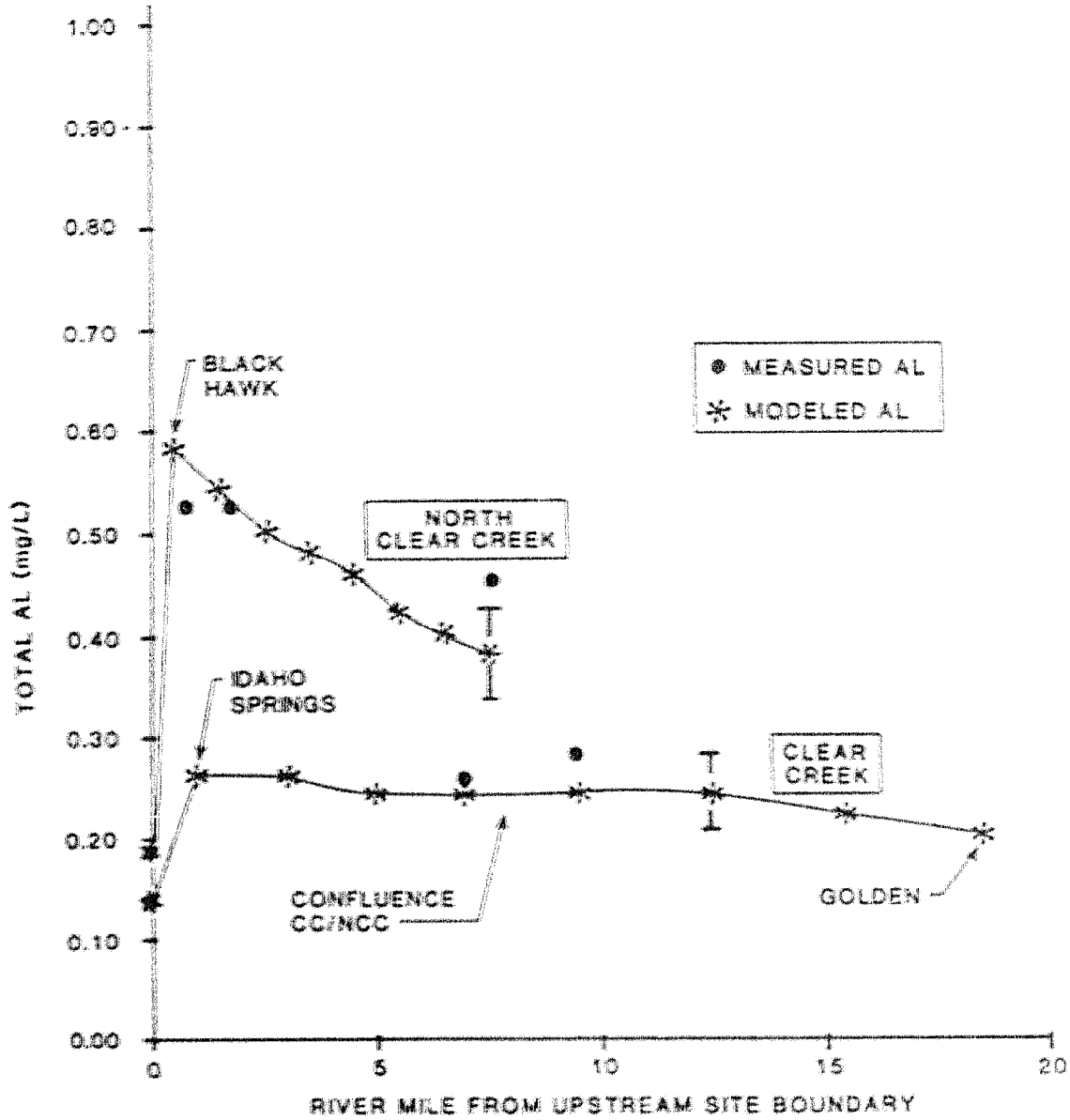


Figure 13-5 Total Aluminum in Clear Creek and North Clear Creek Excluding Potential Leaching of Aluminum From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ± 10 Percent.

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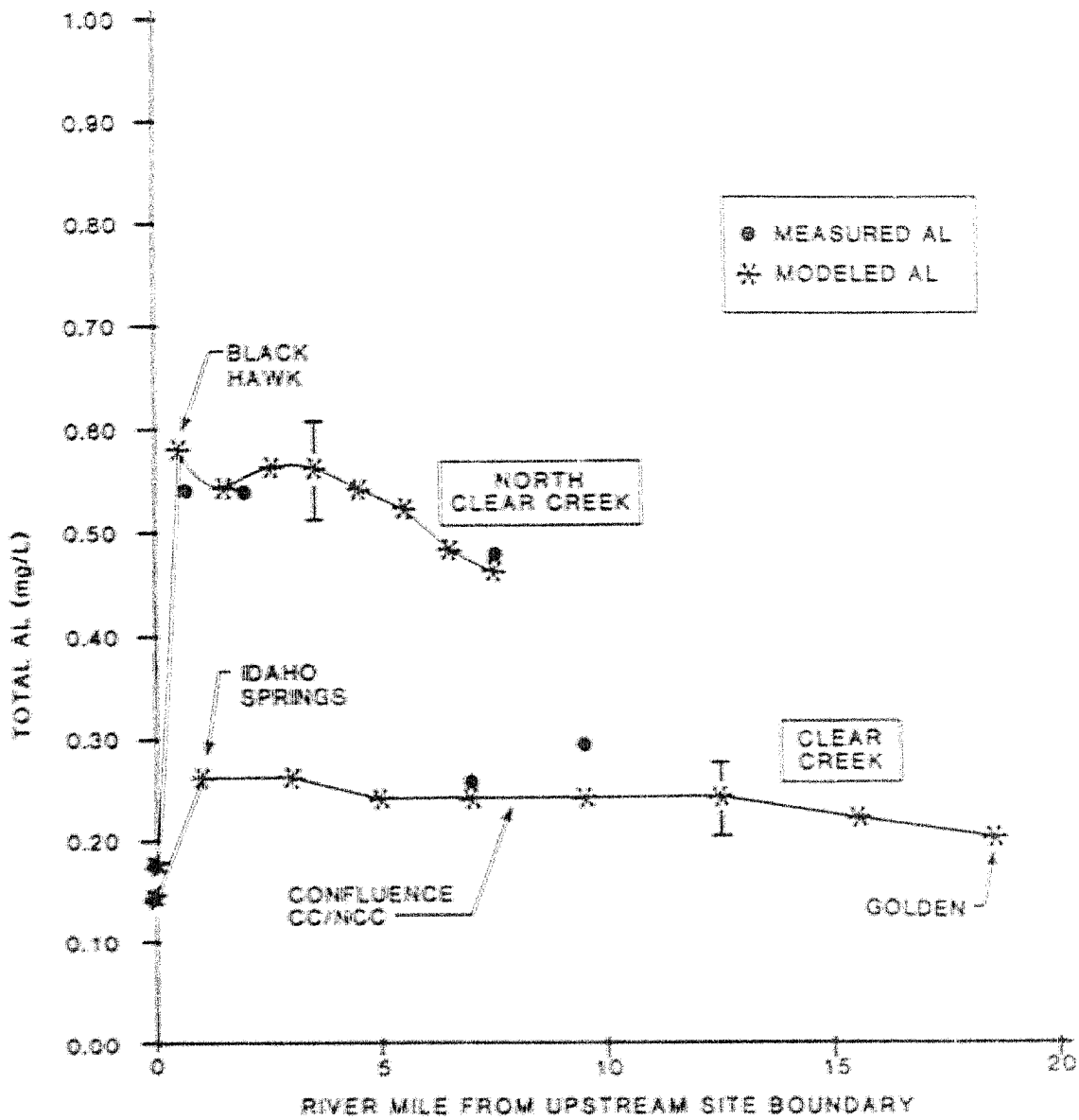


Figure 13-6 Total Aluminum in Clear Creek and North Clear Creek Including Potential Leaching of Aluminum From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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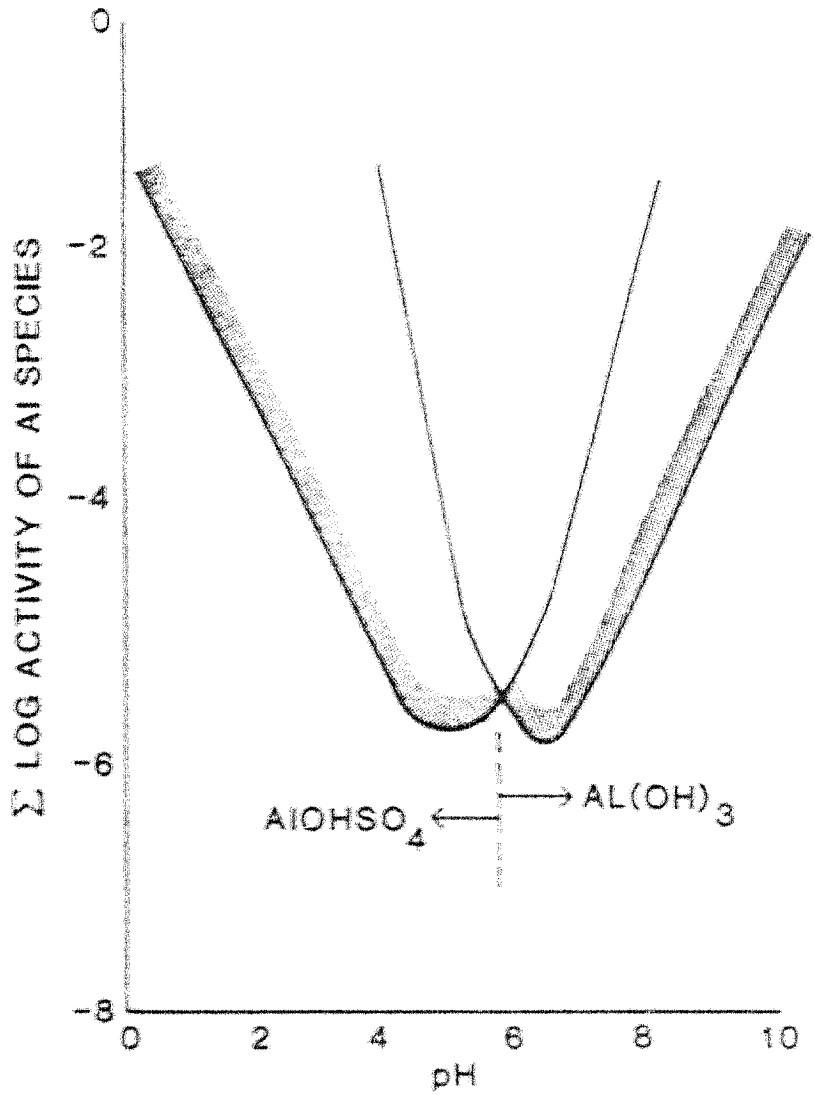


Figure 13-7 The Solubility of Amorphous $Al(OH)_3$ Compared to $AlOHSO_4$. This Figure Indicates That $Al(OH)_3$ Controls Aluminum Solubility Above a pH of 5.7 While $AlOHSO_4$ is the Control Below a pH of 5.7.

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The overwhelming contribution of Clear Creek to the total stream flow dampens any minor fluctuations in North Clear Creek Al concentrations.

The discrepancy between the analyzed and simulated concentrations below the North Clear Creek/Clear Creek confluence (SW002) may be attributed to incomplete mixing of the two creek waters. The sample collected during the second quarter probably contained a greater proportion of North Clear Creek water (and elevated Al concentration) than would be the case after more thorough mixing of the two creeks further downstream.

13.3.2 Copper

Total copper in the Clear Creek system is modeled well by assuming simple dilution of discharges. The results of WASP modeling are shown in Figure 13-8.

The discrepancy between modeled and analyzed copper at site SW003 (North Clear Creek above confluence) is 20 ug/L. As with Al, this deficiency is offset in North Clear Creek by loading North Clear Creek with copper proposed to leach from tailings along the bank (Table 13-3). An additional 0.25 lbs/day is added to segments 31 and 34, equivalent to a copper concentration of 0.19 mg/L in 0.25 cfs. The Gregory leach test at a ratio of 1:512 (tailings to water) in the batch tests leached 0.24 mg/L indicating that the value chosen (0.19) is reasonable. The resultant simulation with the additional copper input is shown in Figure 13-9. The concentration of total copper at Golden is estimated to be 32 ug/L, both in the absence of tailings leaching below National Tunnel and if the leaching scenario is included in the model. The reason for the similarity is the dilution of North Clear Creek by Clear Creek (93%) which mitigates any minor variations in metal concentrations that might occur in North Clear Creek. As stated, based on the WASP simulations, 32 ug/L are anticipated to impact receptors at Golden.

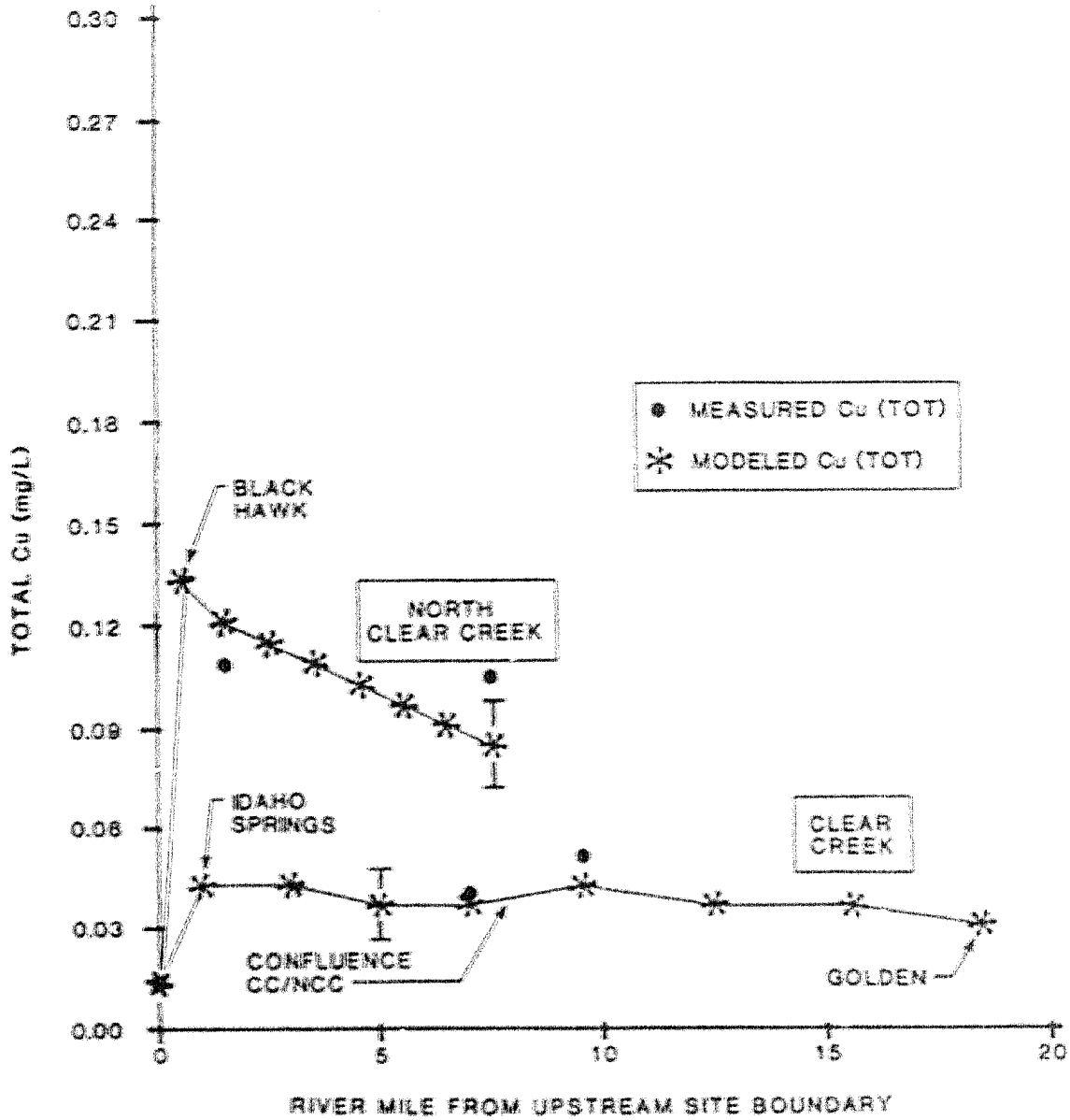


Figure 13- 8 Total Copper in Clear Creek and North Clear Creek Excluding Potential Leaching of Copper From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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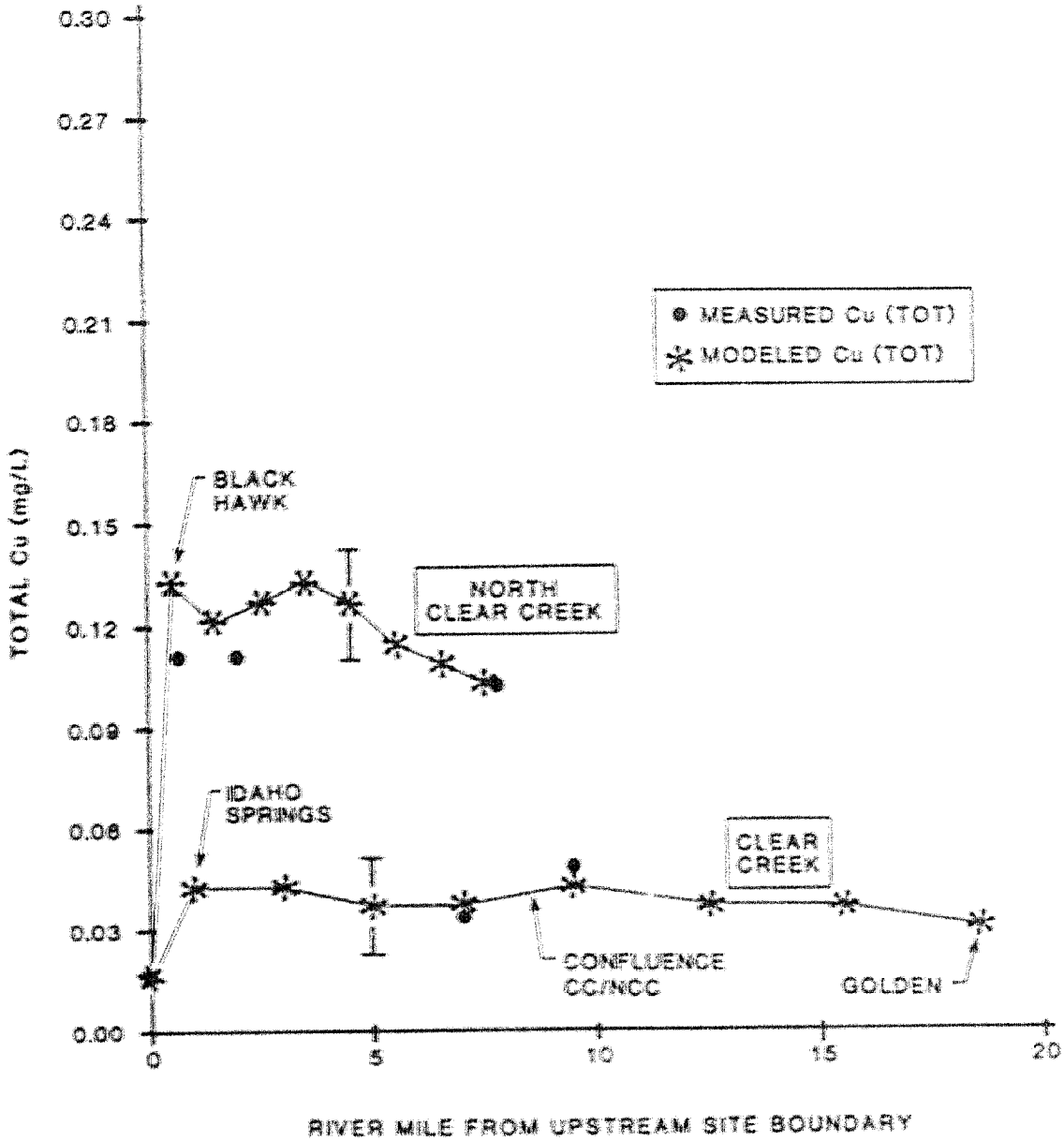


Figure 13-9 Total Copper in Clear Creek and North Clear Creek Including Potential Copper Leaching From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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### 13.3.3. Fluoride

Fluoride is the only constituent which is unequivocally more concentrated in Clear Creek than North Clear Creek. The reason for F abundance in Clear Creek is not obvious, but it may be a result of dissolution of Laramide intrusive rocks, typically intermediate to felsic in composition which are prevalent in the Clear Creek basin but rare in the North Clear Creek watershed. Intrusive rocks contain higher concentrations of trace elements (e.g., F) than the basement granites which constitute the remainder of the petrologic assemblage in the two watersheds. The major F contribution is upstream of Idaho Springs, because Clear Creek carries 0.87 mg F/L as it enters the study area above Idaho Springs. Figure 13-10 shows the excellent agreement between F concentrations measured at the Clear Creek stations and the WASP simulations. Because no fluoride data were collected from the tailings leach test, no attempt is made to define an additional loading into North Clear Creek downstream of the National Tunnel. Under ambient conditions, when Clear Creek has a discharge of approximately 75 cfs at the confluence, the concentration of F at Golden is anticipated to be 0.6 mg/L, assuming that there are no further contributions between the North Clear Creek/Clear Creek confluence and Golden.

### 13.3.4 Zinc

As shown in Figure 13-11, total zinc concentrations are modeled accurately except for Station SW001 (North Clear Creek above confluence). Below the confluence, WASP predicts a concentration which is low by 10 percent, while immediately downstream of National Tunnel there is a disparity of less than one percent. However, in North Clear Creek above the Clear Creek/North Clear Creek confluence, the error is 38% (0.95 mg/L predicted, 1.4 mg/L measured). Zinc is thought to be entering the system through dissolution of sphalerite and secondary $ZnSO_4$ in the tailings through interaction with ground water seepage or surface water along the banks of North Clear Creek below National Tunnel. Five lbs/day were added to both segments 31 and 34 to simulate this metal loading. This is equivalent to 3 mg Zn/L in the

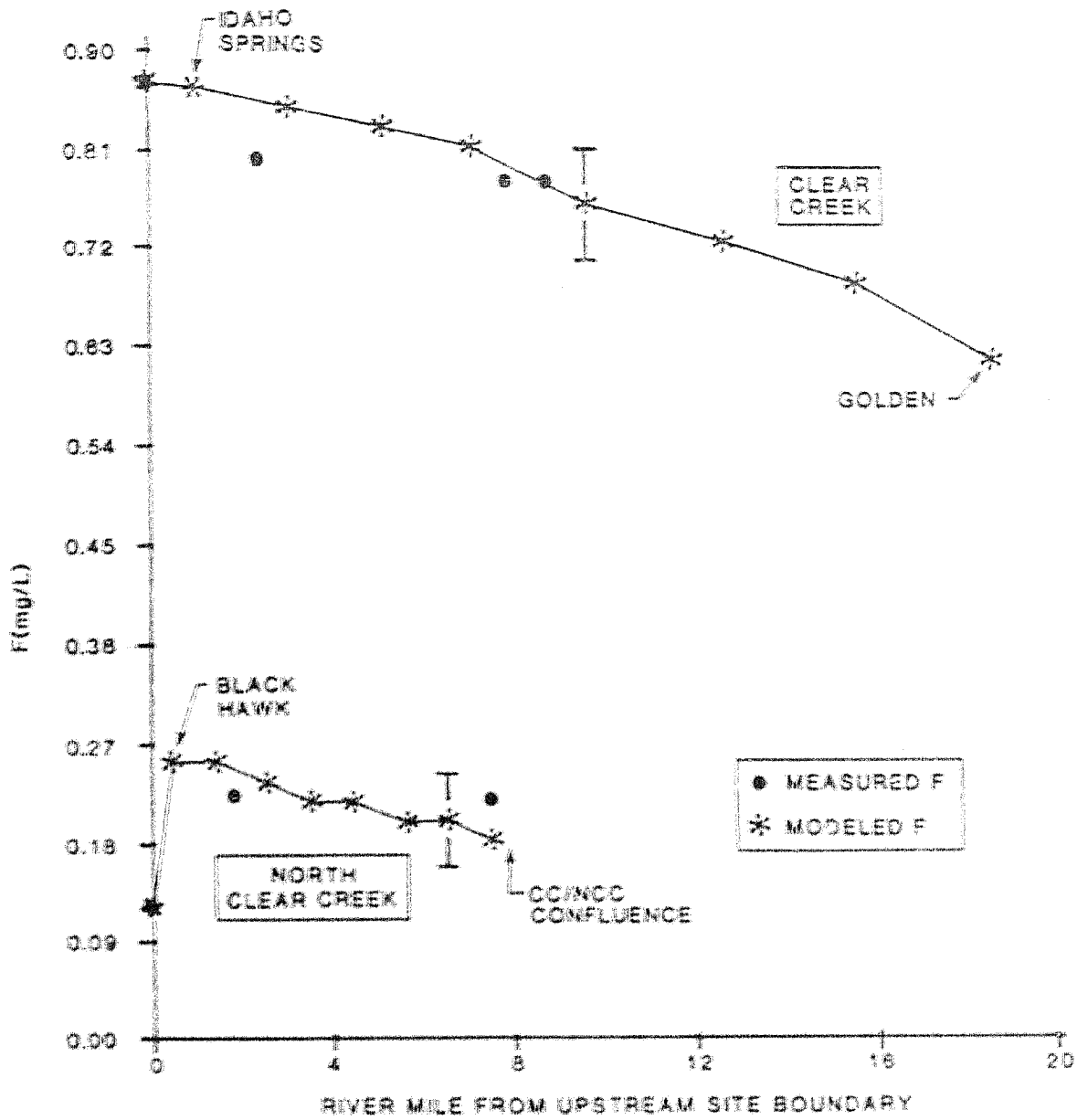


Figure 13-10 Fluoride in Clear Creek and North Clear Creek.

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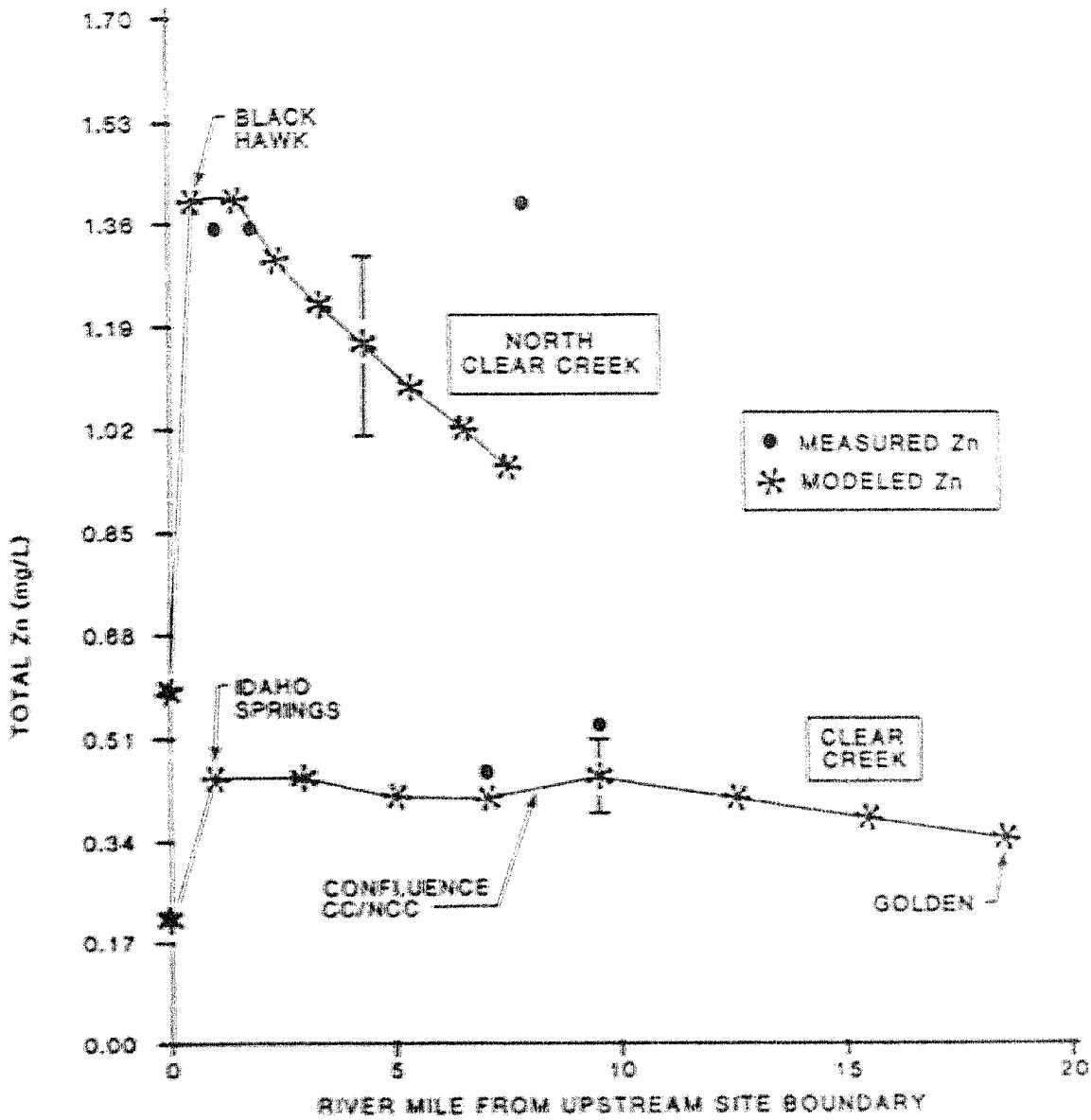


Figure 13-11 Total Zinc in Clear Creek and North Clear Creek Excluding Potential Leaching of Zinc From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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0.25 cfs groundwater thought to leach the tailings. Although tests were not conducted for National tailings, zinc concentrations leached from other tailings during batch tests ranged from 0.15 mg/L to 2.9 mg/L for the solid to liquid ratios 1:512 (Gregory tailings) and 1:32 (Argo tailings), respectively. It is noteworthy that the National tailings have one of the highest zinc concentrations analyzed in the area, therefore a steady-state leach concentration of 3 mg/L is reasonable. The resultant simulation with the additional input is illustrated in Figure 13-12. Based on simulations, 0.33 mg Zn/L is the anticipated concentration at Golden.

## 13.4 SEDIMENT TRANSPORT

The ability to simulate sediment transport in the Creek system is necessary both in order to load metals onto the suspended fraction through the sorption process and to enable a prediction of the fate of tailings should they collapse into either Clear Creek or North Clear Creek.

In North Clear Creek under current ambient conditions during the second quarter, the sediment load increases as Gregory seep enters the creek probably due to precipitation of iron hydroxide. Total Suspended Solids (TSS) remain constant through Blackhawk until downstream of the National Tunnel, despite significant sediment concentrations in North Clear Creek tributaries. Below National Tunnel, sediment settles out of the water column until, at the Clear Creek/North Clear Creek confluence, TSS concentrations have returned to the level that entered the system upstream of Gregory Tailings.

In Clear Creek, the discharges (Big Five and Argo) have negligible impact on TSS. Upstream of Big Five, TSS concentrations of 4 mg/L were measured. Just below the Argo discharge TSS increases to 18 mg/L, probably as a result of the precipitation of $Fe(OH)_3$ in the water column, (visually observed to occur) as the acidic Argo drainage is neutralized by Clear Creek. This value is probably both variable and transitory, because TSS values in the third quarter downstream of the Argo drainage varied as a

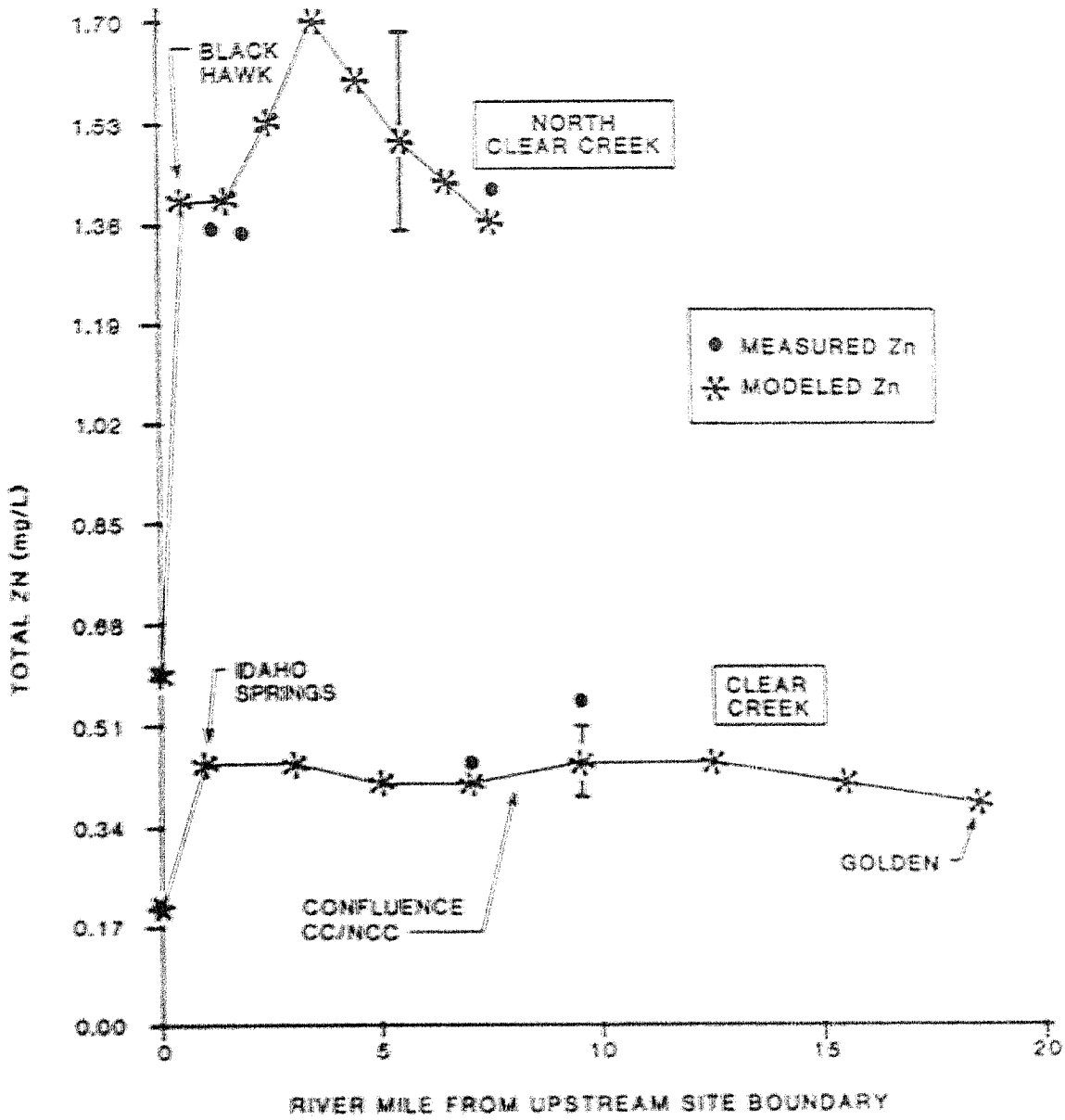


Figure 13-12 Total Zinc in Clear Creek and North Clear Creek Including Potential Leaching of Zinc From Tailings Downstream of National Marsh. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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function of pH. Furthermore, pH is dependent upon the relative proportions of the Argo drainage and Clear Creek in the mixture.

The maintenance of sediment in the water column is dependent upon two factors, the scour (erosion) rate and the settling velocity. The net scour rate for Clear Creek (0.1 cm/year) was calculated assuming that the TSS increases from 4 mg/L upstream from Big Five Tunnel to 8 mg/L below the confluence. This represents net erosion in the Creek. The settling velocity is the Stokes velocity for a particle of given density and diameter. As shown in Table 13-4, coarser, denser materials (e.g., sand) have higher settling velocities (Vs=200 m/day) than finer, less dense materials (silt, clays).

In WASP, a value of zero for Vs was used to maintain all particles in suspension, except immediately downstream of the Argo Tunnel and Gregory seep, where Vs was set at 100 m/day to maintain flocculent precipitates, silt and clays in suspension. The mass of $Fe(OH)_3$ available as a sorbent was simulated using an increased scour constant in segment 1 which resulted in 18 mg/L of total suspended sediment. In the subsequent water column segment, this load was allowed to settle out because data (see Sections 5 and 6) indicate that sediment enriched in metals are typically confined to less than 1,000 yards below the Argo drainage. Therefore, the TSS were allowed to decrease in segments below the drainage.

In North Clear Creek, TSS measurements are elevated between Gregory tailings and the National Tunnel. Therefore, the modeled TSS in the upstream segment were increased by elevating the scour rate to achieve the measured TSS and subsequently decreased downstream of National Tunnel to remove sediment from the water column.

Using the constraints described in the above paragraphs, TSS were modeled using WASP. The results are illustrated in Figure 13-11. As shown, the predicted values compare favorably with the observed concentrations except at SW002 (Clear Creek below confluence) and SW001 (North Clear Creek above

TABLE 13-4

STOKES'S SETTLING VELOCITIES AT 20°C (M/DAY)[a]

| Particle Diameter, mm | Particle Density, g/cm³ 1.8 | 2.0 | 2.5 | 2.7 |
|---|---|---|---|---|
| Fine Sand | | | | |
| 0.2 | 380 | 47 | 710 | 800 |
| 0.05 | 94 | 100 | 180 | 200 |
| Silt | | | | |
| 0.05 | 94 | 100 | 180 | 200 |
| 0.02 | 15 | 19 | 28 | 32 |
| 0.01 | 3.8 | 4.7 | 7.1 | 8.0 |
| 0.005 | 0.94 | 1.2 | 1.8 | 2.0 |
| 0.002 | 0.15 | 0.19 | 0.28 | 0.32 |
| Clay | | | | |
| 0.002 | 0.15 | 0.19 | 0.28 | 0.32 |
| 0.001 | 0.04 | 0.05 | 0.07 | 0.08 |

[a] Taken from Ambrose et al., 1986

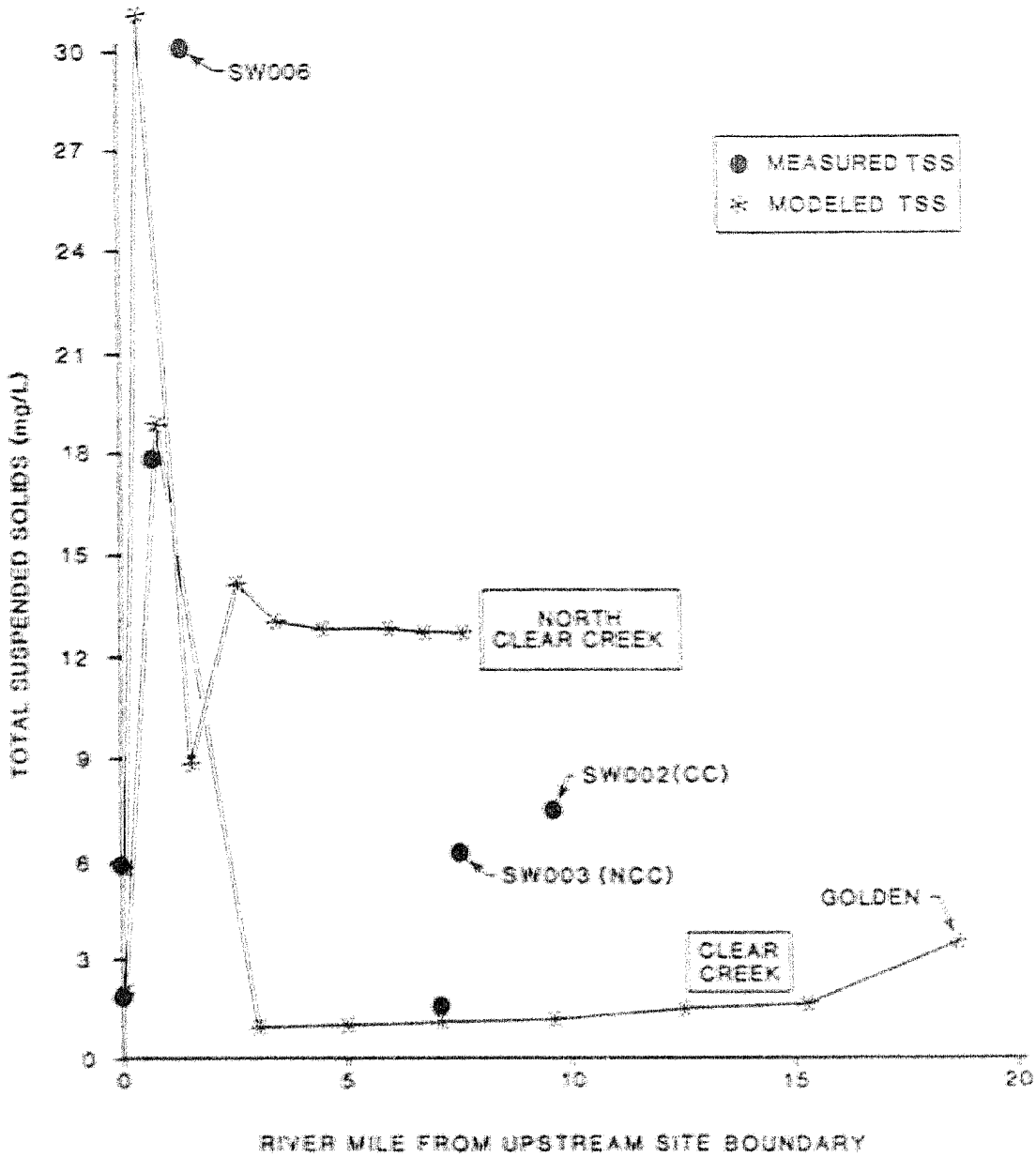


Figure 13- 13 Total Suspended Solids in Clear Creek and North Clear Creek.

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confluence). At these locations, TSS values are very low (6-8 mg/L) and difficult to measure and predict.

Having achieved a somewhat reasonable approximation of sediment transport in the creek system, the next objective is to use the sorption characteristics of the suspended solid to discriminate between total and dissolved metals. Partitioning between sorbed and dissolved metal fractions was accomplished by loading the system with the previously calculated total metal quantities and then using the measured Kp values in conjunction with the appropriate scour and deposition velocities to partition the total metal mass into dissolved and sorbed fractions in each segment. The Kp values used in WASP were calculated using actual creek samples. The results are discussed in Appendix 13A. As a verification of metal attenuation, MINTEQ was used to evaluate the significance of sorption by iron hydroxide in the Clear Creek system.

## 13.5 GEOCHEMICAL PROCESSES CONTROLLING METAL MOBILITY

Dissolved and total Al, Cu, and Zn concentrations in the Clear Creek system differ by factors of up to 10, 10, and 1.5 respectively. This suggests that greater proportions of some metals, e.g., Al and Cu, travel in the sorbed form, while other metals, e.g., Zn, occur predominately in the dissolved form in Clear Creek. This distinction may be important in a consideration of metal toxicity (defined in terms of total recoverable or acid-soluble concentrations) and hence remediation options. Copper was selected as an example for further analysis because unlike Al, there are no values below the detection limits, and because copper has been shown to be chronically toxic to aquatic organisms at low concentrations (see Table 3-1).

For most metals, the dissolved concentrations are typically less than the total metal concentrations, probably because of sorption to colloidal

material suspended in the water column. The concentration of total metals in the system is modeled simply by dilution, but the concentration of the dissolved fraction will be affected by factors controlling chemisorption. These include the pE, oxidation/reduction potential, partition coefficient, particle size, zero point of charge, ionic strength, the concentration of complexing ligands, etc. Therefore, WASP was used to simulate the mobility of total metal concentrations in the system, while MINTEQ was used to estimate the ability of amorphous ferric hydroxide to sorb dissolved metals from solution.

To successfully simulate metal sorption, the combined bound and dissolved fractions must be equivalent to the total metal concentration. Distinguishing between sorbed and soluble metal requires a more sophisticated version of the Clear Creek system which allows for a net scouring of sediment in various segments, the sorption of metals using partition coefficients, the subsequent settling of sediment into a benthic compartment, and maintenance of suspended load in the water column. The major sorbent has been defined as amorphous ferric hydroxide (see discussion in Appendix 13B) and the partition coefficients for copper in various pE regimes have been calculated (Appendix 13A).

A partition coefficient of 260,000 was measured for Cu on amorphous $Fe(OH)_3$ in Clear Creek (see Appendices 13A and 13B). Therefore, this value was used in the water column compartments. A net scouring rate of 0.15 cm per year was incorporated in WASP based on the (measured) stream velocity, and a deposition velocity of 0.1 m/day assumed in order to entrain particles smaller than sand size in suspension. A low steady-state infiltration rate of ground water into the creek sediment was input as 1.5 cfs in Clear Creek and 0.25 cfs in North Clear Creek. Dissolved copper concentrations were modeled using the version of the multiple layer model described in Section 13.2.

The total metal concentration in the creek was separated into dissolved and sorbed fractions using the partition coefficients measured for the

precipitate below the Argo outfall and the established load of suspended sediments. The measured Kp of 280,000 was used to sorb copper to sediment in Clear Creek, while in North Clear Creek, a Kp of 140,000 was found to most accurately simulate the dissolved copper load.

The constraints described above provide a simulation of dissolved and total copper which is in excellent agreement with the measured concentrations in North Clear Creek (Figure 13-14) and Clear Creek (Figure 13-15). Although this is an important verification of the model, it does not provide information as to the relative importance of iron hydroxide as a sorbent in the system as compared to the clay fraction. This is an aspect of Clear Creek geochemistry which may have a significant effect on any proposed remedial alternative. If iron hydroxide is not a significant sink for metals entering the system upstream of the Argo Discharge, neutralizing the Argo drainage prior to its impacting Clear Creek may not measurably reduce the concentrations of dissolved metals. Therefore, the contribution of amorphous ferric hydroxide to metal alteration was evaluated using the geochemical code MINTEQ (Felmy, et al., 1983).

## 13.6 GEOCHEMICAL MODELING

This study used MINTEQ (Felmy et al., 1983) to evaluate the contribution of iron hydroxide as a sorbent in the Clear Creek system. MINTEQ is a mass balance, equilibrium model which has been verified rigorously for a variety of sites and geochemical simulations (Peterson et al., 1983; Davis and Runnells, 1987). The thermodynamic data base is the most thoroughly evaluated compilation available (Ball, et al., 1979, 1980). The model allows evaluation of aqueous speciation, mineral precipitation and dissolution, sorption of metals using any of six algorithms, ion-exchange, and ionic strength correction of solubility products using either the extended Debye-Huckel or the Davies equation.

In the Clear Creek/Central City SI, MINTEQ was used to determine solid phases which may precipitate out of solution, and to remove metals from

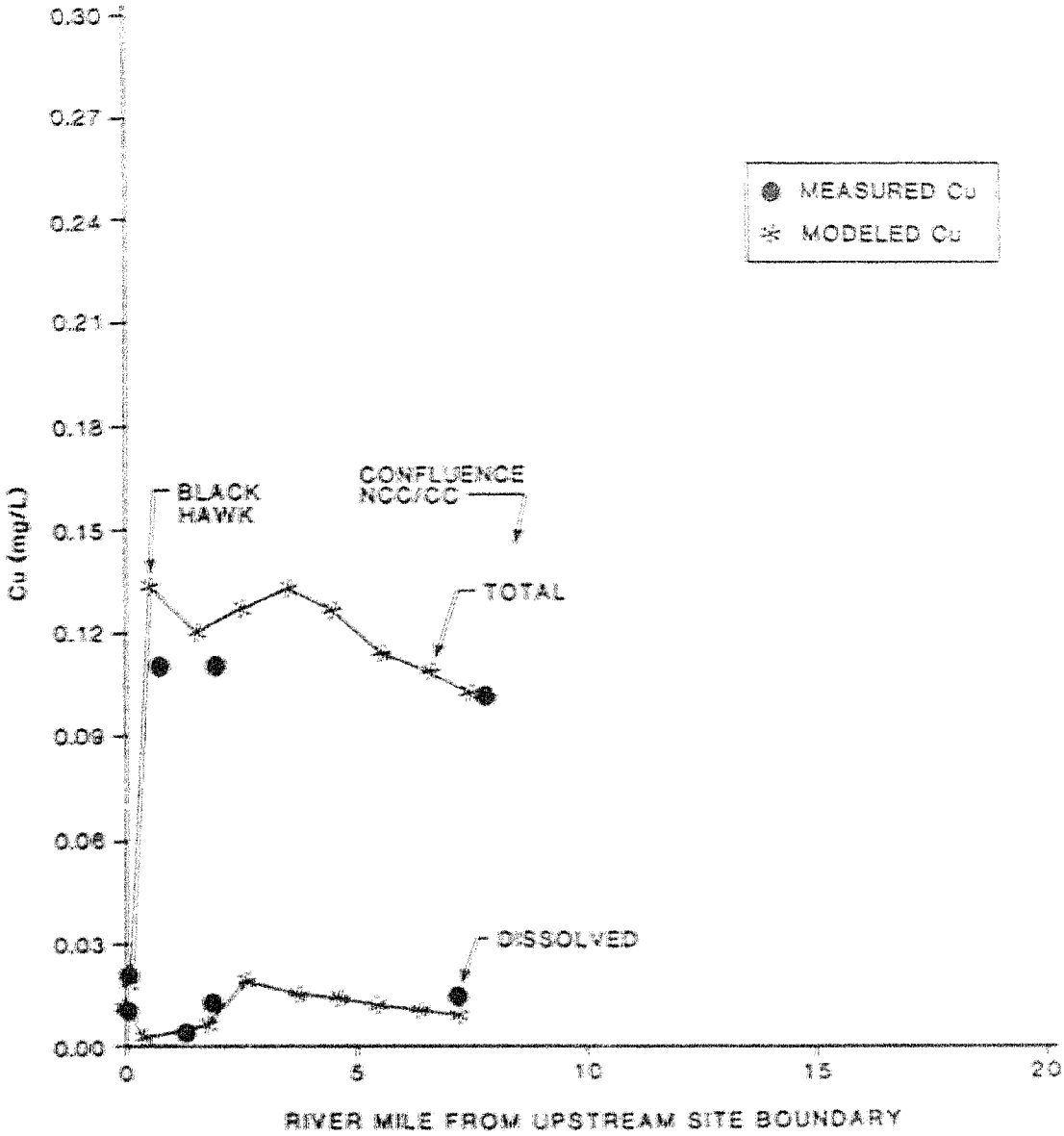


Figure 13-14 Total and Dissolved Copper in North Clear Creek Including Leaching From Tailings Downstream of National Marsh

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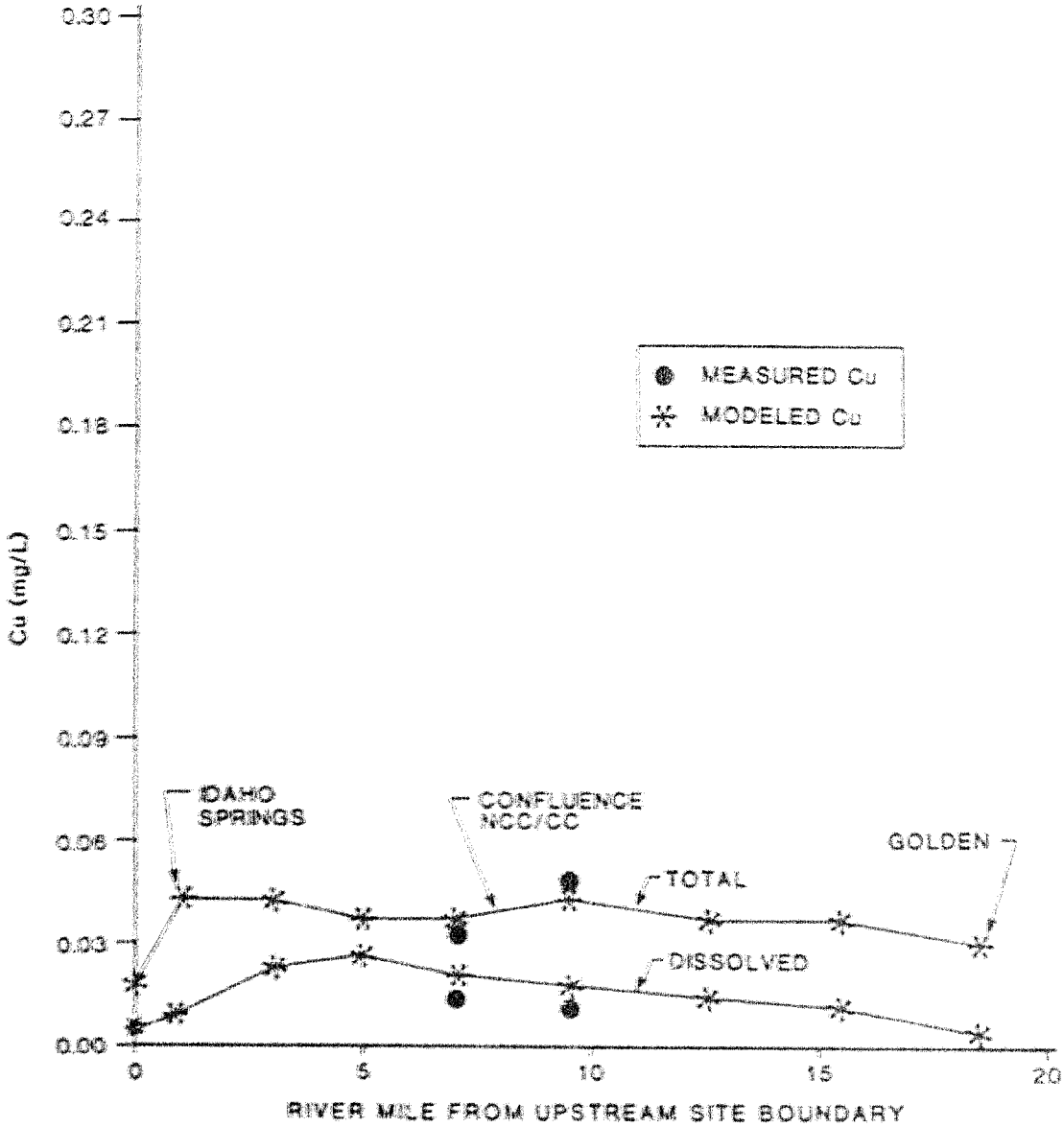


Figure 13-15 Total and Dissolved Copper in Clear Creek. The Error Bars Represent the Metal Concentration When the Analyte Concentration, Stream Discharge, Velocity, and Segment Volumes are Altered by ±10 Percent.

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solution by adsorption onto the newly-formed solids. Zinc and copper were used as examples to illustrate the potential removal of metal cations from solution by suspended solids in the water column. To ensure that sorption and not mineral precipitation controls the dissolved copper concentrations, the Clear Creek sample SW21F was used to determine the saturation states of some common copper minerals. Results are provided in Table 13-5. As shown, precipitation of copper sulfates or oxides is not predicted by MINTEQ in Clear Creek. This analysis indicates that a process other than mineral precipitation, probably adsorption, may remove copper from solution. Amorphous $Fe(OH)_3$ is well documented as an effective sorbent for other metals in solution. Precipitation of amorphous ferric hydroxide (log $K_{sp}$ = -37.1) is both observed at, and predicted by MINTEQ, in solutions where the Argo drainage mixes with Clear Creek. The mass of $Fe(OH)_3$ precipitating under equilibrium conditions (0.06 g/L) was calculated by MINTEQ. This is in good agreement with the measured mass (0.01 to 0.02 g/L) of iron hydroxide collected on filters (Appendix 13B).

Copper and zinc retardation were modeled using the triple-layer sorption routine in MINTEQ. The parameters required to define this isotherm are: (1) the p*K values for each ion (Davis and Leckie; 1978, 1979, 1980); (2) a mass of ferric hydroxide; (3) the surface area of sorbent; (4) the number of sorption sites per square nanometer (Leckie, et al., 1980); (5) the total number of sites in the system; and (6) estimates for the integral double-layer capacitances (Davis and Leckie, 1978).

Measurements of surface area for the $Fe(OH)_3$ in the vicinity of the discharges were determined using BET $N_2$ sorption (Coors Spectrochemical Laboratory, Golden, Colorado). The areas (in $m^2/g$) were 97 for material from National, 35 for Argo Portal, and 28 for Big Five. A value of 35 was used in the modeling because Clear Creek is the major stream to be modeled. Similar determinations on ferric hydroxides by other workers have given surface area values ranging from 185 to 600 $m^2/g$ (Leckie, et al., 1980).

TABLE 13-5

MINTEQ PREDICTIONS AT SITE SW21F03

| | |
|---|---|
| Charge imbalance | -8.6% |
| Ionic strength | 0.0061m |

Saturation Indices

| Mineral | Log SI | Mineral | Log SI |
|---|---|---|---|
| $Al_4(OH)_{10}SO_4$ | 4.5 | $Cu(OH)_2$ | -3.0 |
| $Fe(OH)_3$ [log Ksp = -37.1] | 1.9 | $CuCO_3$ | -4.6 |
| Gibbsite | 0.8 | $CuSO_4$ | -13.2 |
| Na-Jarosite | 0.3 | CuO | -2.0 |

Cu and Zinc Sorption to $Fe(OH)_3$

When, (1) the surface area of iron hydroxide is 35 $m^2/g$
(2) 100 mg $Fe(OH)_3$ precipitates/litre.

99 percent of copper remains in solution

1 percent of copper is sorbed

100 percent of zinc remains in solution

0 percent of zinc is sorbed

*If 500 mg/L of sorbent is used in the simulation:

85 percent of copper remains in solution

15 percent of copper is sorbed

99.6 percent of zinc remains in solution

0.4 percent of zinc is sorbed.

The number of surface sites on amorphous ferric hydroxide is approximately 10 per square nanometer (Leckie, et al., 1980). A simple conversion (35 $m^2/g$ * 1E18 $nm^2/m^2$ * 10 sites/$nm^2$) gives the total number of sites per gram (3.5E20) in the system. The capacitance values were set at 140 $uF/cm^2$ for C1 and at 20 $uF/cm^2$ for C2 as recommended by Davis and Leckie (1979).

The MINTEQ results using the data discussed above are provided in the lower half of Table 13-5. As shown, the mass of available sorbent predicted by MINTEQ or measured on the filters failed to remove significant concentrations of copper from solution. However, sorption of metals is sensitive to the mass of total sorbent in the system. For example, 0.1 g/L of sorbent sorbs one percent of copper and zero percent of dissolved zinc to the surface, while 0.5 g/L sorbs 15 percent of the total dissolved copper and 0.4 percent of the total dissolved zinc. In the Argo/Clear Creek mix, only 0.06 g/L of sorbent (measured as total suspended solids) were reported in the surface water of which only 0.01 to 0.02 g/L comprised amorphous ferric hydroxide. Therefore, sorption by suspended solids in the water column appears to play only a minor role in controlling metal mobility. By inference, the major factor affecting metal concentrations in solution is the dilution of the discharges by the creeks which they impact.

## 13.7 SUMMARY

WASP appears to accurately simulate both dissolved and total metal concentrations based on a comparison of measured and simulated concentrations. Sediment transport, based on TSS concentrations, is modeled satisfactorily using independently calculated erosion rates.

The geochemical analysis of the contribution of ferric hydroxide to metal attenuation indicates that only one percent of the total copper concentration may be attenuated by the amorphous solid. This suggests that

almost all the sorbed copper and by inference, sorbed heavy metals, are retained on the clay fraction.

A comparison between the relative importance of geochemical/chemical processes as opposed to physical (hydrologic) processes controlling metal mobility indicates that geochemical controls (precipitation, sorption, etc.) are far outweighed by physical processes (e.g., dilution), at least under current conditions, for a medium flow regime. The implication is that feasibility studies using WASP can minimize the use of geochemical controls without sacrificing any accuracy in predictive capability.

The results of this calibration test indicate that WASP accurately simulates metal transport in the Clear Creek system. Therefore, the model can be used to predict metal concentrations in the event of treatment and neutralization of the major discharges and the potential impact of a blow-out, tailings collapse, sediment transport and changes in water quality on downstream users.

## 14.0 RECOMMENDATIONS FOR ADDITIONAL STUDIES

Based on the evaluation of current data, several areas need additional investigations. Probably the largest area of concern that has not been addressed fully is the ground water regime. The original work plan by CH$_2$M Hill for the Clear Creek/Central City site contained no ground water investigation because the site was anticipated to be a surface water problem only. However, in revision of the original work plan, CDM added a limited ground water investigation task to determine if a ground water problem existed. As detailed in this RI report, significant ground water contamination has been identified at the sites based on limited investigations. Based on these findings, the EPA has scheduled a full RI for the ground water in the area. Some initial recommendations to more adequately characterize and quantify the nature and extent of the ground water contamination follow:

- Install at least one hydraulically upgradient well at each site to determine background conditions. Specific well locations would be determined by a field reconnaissance at each site in order to avoid impacts from local mine drainage and waste. This activity has not been scheduled or approved.

- Perform aquifer tests at existing wells to determine the hydraulic conductivity of the underlying materials at each site. A relatively quick and inexpensive method recommended is single well slug-tests. Two tests at each site would serve as a check against each other and provide useful information to quantify the movement of ground water and seepage rates into the surface water drainage system. Slug tests were conducted at Gregory in March 1987 and discussed briefly in Section 7.0. Tests at the remaining sites were conducted in April 1987. Detailed results will be presented in an Addendum to this report.

- Continue ground water sampling at existing wells for two or more quarterly periods to establish seasonal and temporal trends in ground water quality. This activity has not been approved or scheduled.

- Perform a door-to-door well survey of ground water use along the alluvial valley throughout the Clear Creek and North Clear Creek drainage basins. The survey should focus on unpermitted users deriving their water from the shallow alluvial aquifer. The



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severity of the potential health threat would thus be identified. This activity was conducted during the month of April 1987 and results will be presented in an Addendum to this report.

- Collect samples from the permitted wells identified in Section 7 that may be impacted by contaminated water. This activity was completed in April and May and results will be provided in an Addendum to this report.

In addition to the area of ground water, several other items need to be addressed. These include:

- Determination of Background Concentrations. Based on the data collected, sources of contamination exist above the Big Five, Gregory, and Quartz Hill. As a result of this information, the EPA will expand the study area to include upstream areas. This study will most likely result in (1) a new NPL site requiring a new RI report or (2) an expansion of the current site, resulting in an additional RI report. In order to better define a site boundary for the new site, several additional surface water samples will be collected upgradient of the existing sites. This activity has not been scheduled.

- Calibration of the Surface Water Quality Model. Based on the modelling results presented in Section 13.0, several stretches of both Clear Creek and North Clear Creek need to be sampled to confirm that the model is calibrated. This confirmation is necessary before the model is used to determine remedial action during the FS. The sampling was conducted in April and the results will be presented in an Addendum.

- Type of Analysis. Based on review of the ARARs, most of the AWQC are based on "total recoverable" or "acid soluble" values. The CLP "total" values should be slightly higher than "total recoverable" values and the CLP "dissolved" values should be less than the "acid-soluble" values. Therefore, the current set of data on surface water should bracket the criteria values. However, based on EPA and CDH comments, several samples will be collected and analyzed by all four techniques. These samples were collected in April and the results will be reported in an Addendum.

- Big Five Investigation. The geotechnical analyses performed on the Big Five waste rock pile, indicated that the pile is marginally stable. Based on this evaluation and limited chemical analyses that indicate toxic parameters of concern, three additional bore holes were drilled to the waste rock pile at the Big Five tunnel and completed as wells. This work was completed in May 1987. The results of the investigations will be provided in an Addendum to this report.

- Sample Methods. Because of the turbulent and rapid flow in Clear Creek and North Clear Creek, depth integrated samples were not collected. To determine if the grab samples collected were representative, both grab and depth integrated samples were scheduled to be collected at several sites during low flow conditions when integrated sampling may be possible. These samples were scheduled to be collected in April and the results reported in an Addendum. However, after observations in the field by the team of samplers and technical performance auditor, the decision was made that depth integrated sampling was not appropriate. This decision was based on the rapid, turbulent, shallow flow in the streams.

- Treatability Studies. In addition to the acid drainage treatability study currently being conducted, the following studies are being conducted:
  - Solidification study to determine the feasibility of fixing the metals in the tailings with various agents such as kiln dust, fly ash, etc. Phase one of this study was conducted in May 1987. Results will be provided in an Addendum to this report.

  - A preliminary reprocessing study to determine the feasibility of reprocessing tailings and removing contaminants of concern. This investigation will be completed by August 1987.

- Miscellaneous Additional Investigations. As a result of investigations during the RI, further information is needed on the condition inside the Argo Tunnel. This information is needed to access blow-out control. Additional information is also necessary in the area of Gregory Gulch to define potential source control. These studies are planned for Fiscal Year 1988.



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