Report No. 052004/1

QUESTA TAILINGS FACILITY – REVISED CLOSURE PLAN

1.0 Introduction And Terms Of Reference

Molycorp, Inc. (Molycorp) owns and operates tailings impoundments located adjacent to the town of Questa, New Mexico. These impoundments contain the tailings from the Questa molybdenum mine, which is located 3.5 miles east of Questa. It is anticipated that these tailings facilities will be operated for at least another 20 years. However provision must be made for the eventual reclamation and closure of these tailings impoundments.

Under the terms of the approval granted by the Groundwater Protection and Remediation Bureau of the New Mexico Environmental Department (NMED) for Molycorps Discharge Plan (DP-933), Molycorp was required to prepare a Revised Closure Plan (RCP) for the Questa tailings impoundments. The schedule for submitting documents that support a revised closure plan for the tailings impoundments were to be as follows:

i) Stage Two Investigation: December 1, 1996.

ii) Report on Stage Two Investigation: July 1,1997.

iii) Modeling and Cover Evaluation: November 1, 1997.

iv) Request for Modification, Revised Closure Plan; Adjusted Cost Estimate and Adjusted Financial Assurance Proposal; May 1, 1998.

Items i) to iii) were submitted to the NMED by the due dates. This Revised Closure Plan includes an Adjusted Cost Estimate for implementation of the closure plan and is submitted in partial completion of the submissions due May 1, 1998.

The Revised Closure Plan has been prepared to include the general requirements of the:

1. The Discharge Plan (DP-933),
2. "Closeout Plan Guidelines" dated June 1995 from the State of New Mexico Energy, Minerals and Natural Resources Department – Mining and Minerals Division (MMD).
3. Financial Assurance Regulations from the NMED dated May, 1996.

This Revised Closure Plan follows on two previous submissions on tailings dam closure:

1. "Final Closure Plan of Tailings Impoundment Area" dated December 15, 1993, and prepared by Molycorp, Inc. for the NMED

2. "Questa Mine Tailings Impoundment Contingency Closure Plan for 2001" dated August 1996, prepared for Molycorp by Robertson GeoConsultants Inc. in association with Steffen, Robertson & Kirsten (US) Inc. This plan was submitted as part of the 1996 Discharge Plan approval application.

This Revised Closure Plan builds on these earlier plans.

In Section 2 of this plan a description is provided of the site conditions and land-use prior to the development of the tailings impoundments. Section 3 describes the site development that has occurred with particular emphasis on the nature of the structures that have been constructed, the physical and geochemical characteristics of the tailings deposits, the tailings water management and measures implemented to protect the ground and surface water quality of the State. It then reviews the planned development for the projected facility life of 23 years. In Section 4 the Revised Closure Plan is defined as a set of eight closure plans as follows:

1. Surface Shaping Plan
2. Buildings and Clean-up Plan
3. Cover Placement Plan
4. Drainage Plan
5. Re-vegetation Plan
6. Groundwater Interception Plan
7. Monitoring and Maintenance Plan
8. Post Closure Land-use Plan

In Section 5 a closure cost estimate is prepared for the implementation of all the requirements contained in these plans. This closure cost estimate is the Adjusted Cost Estimate.

During the development of this closure plan meetings were held with the NMED to discuss the results of investigations, studies and alternatives evaluations on February 6th 1998 and March 31st, 1998, and a joint field inspection of vegetation growth was made on April 16th, 1998. As a consequence of these meetings Molycorp has made additions and modifications to some original closure plan measures.

2 Pre-Tailings Impoundment Development Conditions

2.1 Location and Climate

The Questa Tailings Facility is located near the village of Questa in Taos County, New Mexico (Figure 2-1). The village of Questa lies in an alluvial plain at an elevation of about 7600 feet a.s.l., bordered by the Sangre de Cristo Mountains to the east and the Guadalupe Mountains to the west. To the south of Questa, the Red River and its tributary, Cabresto Creek, have cut a prominent valley 100 to 200 feet below the level of the alluvial plain (Figure 2-1). To the north, the piedmont alluvial plain extends past the village of Cerro, and into Sunshine Valley.

The climate of the study area is semi-arid. Precipitation and temperature vary considerably in the area owing to differences in elevation and proximity to the nearby mountains. In general, average precipitation increases and temperatures decrease with increase in elevation from the alluvial plain and into the Sangre de Cristo Mountains. The nearest weather station to the Questa Tailings Facility is located at Cerro, only three miles north of Questa in the alluvial plain (altitude 7665 feet a.s.l.). Table 2.1 lists mean monthly values of precipitation, daily maximum and daily minimum temperature for this weather station.

Annual precipitation at Cerro averages 12.24 inches per year with much of this precipitation occurring as summer thundershowers (43% of total precipitation occurs from July to September). The summers are generally pleasant, with maximum daily temperatures in the low 80s and minimum temperatures in the low 40s. The winters are long with temperatures dropping below freezing almost every night from October through to April. However, typically clear skies bring sunshine during most days with temperatures rising to above the freezing point.

During the winter much of the precipitation falls as snow. However, fresh snowfall typically melts and/or sublimates within hours or days and a significant snow pack rarely develops. Owing to the low night temperatures and absence of a protective snow cover, the soils typically freeze during the winter. The depth of freezing (frost line) on exposed soils (e.g. on the tailings impoundments) is in the order of 18-24 inches (A. Wagner, pers. comm.).

Based on frost data collected by the U.S. Weather Bureau at Cerro a growing season of 120 days is average for the study area. However, cool season grasses, forbs and shrubs grow in spite of freezing temperatures at night, significantly extending their growing season (see below).

Unfortunately, pan evaporation is not recorded at the nearby Cerro weather station. Perhaps the most representative weather station in the area that measures pan evaporation is at Alamosa, Co, approximately 60 miles north of the study site. The potential (pan) evaporation rates are not expected to vary widely between Alamosa and Questa due to similar elevations and geographic location. The long-term averages for monthly totals of pan evaporation at Alamosa (for April to October) are also shown in Table 2.1. As expected for this semi-arid climate, the potential evaporation rates (measured as pan evaporation) far exceed precipitation rates during all months on record.

Table 2.1
Summary of Climate Data

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	TOTAL
Precipitation [1] (in inches) average for 1932 -1997	0.63	0.58	0.74	0.83	1.19	0.95	1.78	2.07	1.43	1.00	0.71	0.73	12.24
Minimum Daily **Temperature** (1 (in degrees Fahrenheit) average for 1948 -1997	7.1	12.8	20.4	27.5	35.3	43.3	49.0	47.8	41.2	30.5	18.5	9.3	
Maximum Daily **Temperature** ((in degrees Fahrenheit) average for 1948 -1997	36.0	41.1	49.1	59.4	68.5	78.2	82.2	79.9	74.3	63.9	49.1	38.4	
Pan Evaporation [2] (in inches) average for 1960-I 997	n/a	n/a	n/a	7.40	8.79	10.4'	8.95	7.63	6.48	4.94	n/a	n/a	~ 65-70

Notes:
(1) data for Cerro, NM (elev. 7662')

Evapotranspiration rates for the study area are estimated to be in the order of 0.2 to 0.25 inches per day during the growing season (Anne Wagner, pers. comm.). Some evapotranspiration will also occur during the winter months, particularly in the afternoon when temperatures rise above freezing (much of the vegetation in the area is evergreen and transpires year-round).

2.2 Physiography and Surface Drainage

The Questa Tailings Facility is located in Taos County, 5 miles north-east of the confluence of the Red River and the Rio Grande (Figure 2-2). The study area is characterized by three prominent landforms: (i) a fault block mountain range, the Sangre de Cristo Mountains; (ii) a piedmont alluvial plain; and (iii) a lava-capped plateau (Figure 2-2). The Sangre de Cristo Mountains form the eastern border of the study region. Structurally, these mountains may be related to the Basin and Range province. The western base of the mountains has been mapped as a fault scarp. The bold western face of the mountains and the presence of fault scarplets and landslide talus at the foot of the range all suggest rapid uplift along a fault zone.

The piedmont alluvial plains are located to the west of the Sangre de Cristo Mountains (Figure 2-2). The piedmont alluvial plains are sloping plains formed at the base of a high mountain range and composed largely of detritus derived from the mountains and deposited in coalescing alluvial fans by many ancient streams. Much channeling of the piedmont alluvial plains has occurred in the past (commonly called "arroyos") and is continuing in the vicinity of Questa (Figure 2-3). Here, the Red River and its tributary, Cabresto Creek, have cut a prominent valley 100 to 200 feet below the level of the piedmont alluvial plain.

A relatively undisected plateau, largely capped by Servilleta basalt lava flows ("flood basalt"), comprises most of Taos County west of the Rio Grande (Figure 2-2). Shield type volcanoes (e.g. Brushy Peak) producing low viscosity lava were the source of the vast lava flows forming the plateau. The lava flows of the plateau slope generally eastward and interfinger with the alluvial sediments of the Piedmont alluvial plains to the east of the Rio Grande.

In the study region, the physiography is further complicated by the Guadalupe Mountain (Figure 2-3). The Guadalupe Mountain consists of a pair of volcanic exogenous domes and vent structures that have overlapped and sutured into one another. These volcanoes are generally older than the volcanoes of the lava-capped plateau and hence represented a barrier to the flow of flood basalt from the west. At the same time they represented a barrier to the movement of relatively young alluvial sediments from the east.

The original topography and drainage pattern prior to development of the Questa Tailings Facility is shown in Figure 2-3. The only two perennial streams in the study area are the Red River and Cabresto Creek. Both streams drain the western slopes of the Sangre de Cristo Mountains before entering the alluvial plain. Cabresto Creek flows into Red River just to the east of the village of Questa (Figure 2-3). The Red River enters the Red River Gorge two miles west of Questa and eventually drains into the Rio Grande. Peak flows in the Red River and Cabresto Creek are observed during snowmelt in the Sangre de Cristo Mountains (May and June).

The tailings impoundments were constructed in two deeply incised arroyos which run in a southwesterly direction towards the Red River valley (Figure 2-3). These arroyos drained the eastern slopes of the Guadalupe Mountains and the alluvial plain to the north. However, runoff from the Guadalupe Mountains and the alluvial plain is very low owing to the low precipitation in the area and the high permeability of the volcanics in the Guadalupe Mountains and surfical sediments in the alluvial plain. Hence the arroyos were likely dry during extended periods of time with intermittent stream flow only during intense summer thundershower activity producing short-duration, high peak floods.

2.3 Hydrology and Surface Water Quality

The hydrology of the area covered by the Questa Tailings Facility has been studied for the design of the East and West Drainage Ditches (also referred to as 'Diversion Ditches') (Vail, 1975). The location of the East and West Drainage Ditches, and their respective sub-watersheds are shown in Figure 2-3. Most of the drainage reporting to the lower portion of the west ditch is from the steep eastern slope of the Guadalupe Mountains. This mountainous drainage area extends from 7560 to 8667 feet a.s.l. with an average ground slope of 15%. The upper end of the west drainage ditch collects runoff from approximately 1100 acres of relatively flat, alluvial plain with generally a herbacious ground cover and soil types with fairly good hydrological characteristics (Vail, 1975). Approximately 320 acres of mountaineous land with characteristics similar to that along the lower portion of the west ditch, drains through the alluvial plain to the uppermost end of the ditch (Figure 2-3).

The drainage area of the East Ditch covers approximately 1060 acres, most of which lies between elevations of 7520 and 7800 feet a.s.l. (Figure 2-3). This drainage area is similar to the alluvial plain areas draining to the west ditch. The overall ground slope to the East Drainage Ditch is less than 2%.

Although both drainage areas contain a number of small arroyos, there is no major drainage channel in either area and a large section of the alluvial plain above the West Drainage Ditch does not have a defined drainage system (Figure 2-3). Early maps of the area show an irrigation canal ('Sunshine Canal') which apparently diverted flow from Cabresto Creek into the Sunshine Valley to the north (Figure 2-3). This irrigation canal has been abandoned, however, many years ago (Vail, pers. comm.).

According to isopluvials published by the U.S. Weather Bureau, the maximum 24 hour precipitation that can be expected in the drainage area once in every 100 years is 2.8 inches (Vail, 1975). Probable maximum 24 hour precipitation rates for other time periods are listed in Table 2.2.

Table 2.2.

Peak 24 hr Rainfall Rates for Drainage Area of Questa Tailings Facility (from Vail, 1975).

Return Period (in years)	**24 hour precipitation (in inches)**
2	1.2
5	1.6
10	1.8
25	2.1
50	2.4
100	2.8

The total runoff and peak rates of discharge from these two drainage areas have been computed based on procedures developed by the Soil Conservation Service (SCS) (Vail 1975). The total direct runoff from various portions of the drainage area was estimated to range from 0.45 to 1.2 acre inches per acre for the 1 in 100 year 24 hr storm event (Vail, 1975). The time it takes for runoff to travel from the hydraulically most distant part of the watershed area to the discharge point during a storm event was estimated to be in the order of 1.6 hours (Vail, 1975). Peak discharges for the 1 in 100 year precipitation event (2.8 inches) were estimated to be about 2070 cfs for the West Drainage Ditch and 450 cfs for the East Drainage Ditch (see also Appendix F).

Red River stream flows have been monitored by the U.S. Geological Survey at the Questa Ranger Station (just upstream of the confluence of the Red River with Cabresto Creek) from 1913 to the present (85 years). The drainage area above the Questa gauging station extends over 113 square miles of steep sided river canyon and high mountain country where precipitation occurrence and rainfall intensity are much higher than at the tailings pond drainage area. The highest peak instantaneous flow recorded at the Questa gauging station was 886 cfs suggesting that the peak flows estimated for the drainage areas of the east and west diversion ditch are very conservative (see Appendix F).

There is very little ‘baseline’ data available on water quality of the Red River (or other streams in the study area) pre-dating the development of the Questa Tailings Facility. At any rate, such baseline data would be of limited value only, since the water quality of the Red River has likely changed during the 30 years of tailings operation. Increased land use of the Red River watershed due to population growth, development of the region as a tourist destination, and other activities upstream of the Tailings Facility have all likely contributed to increases in suspended and dissolved solids to the Red River over those years. In addition long-term precipitation patterns and decrease in basin yield due to changes in vegetation may have caused possible water quality changes (Vail, pers. comm.). The impact of the Questa Tailings Facility on surface water quality is better evaluated by comparing present-day stream water quality upstream and downstream of the tailings impoundments (see Section 3.1.7).

2.4 Geology

Figure 2-4 shows the surficial geology of the study region. At the regional scale four major geological units have been identified (Scott Vail, 1987):

- recent alluvium (al): surficial alluvial deposits mostly derived from the Sangre de Cristo Mountains to the east;
- Servilleta flood basalt (svb), olivine bearing; grouped as upper (sbu) and combined middle and lower (sbl) members;
- volcanic flows of Guadalupe Mountain (gv); lobate dacite flows and olivine andesite; and
- old alluvium (al_{SF}): conglomerate, sandstone, and siltstone; mostly derived from mountains to the east.

The young, surficial alluvial sediments are exposed in the eastern parts of the study region (Figure 2-4). Older alluvial sediments are found at greater depths throughout the study region, typically interbedded with the andesite basalt flows of the plateau. These old 'Santa Fe sediments' are exposed on the canyon walls of the Rio Grande and the (lower) Red River (Winograd, 1959). The alluvial sediments beneath the valley are estimated to be about 3000' thick (McKinlay, 1956). However, the sediments deposited since the last period of volcanic activity thin out toward the west, and, near the contact with the eastward dipping lava flows, they are only a few feet thick.

The surficial alluvial sediments are composed of materials ranging in size from clay particles to cobbles 8 inches in diameter. Usually the alluvial sediments are unsorted, but locally they are fairly well sorted, and contain lenses of gravel, sand, or clay. Owing to the large range in possible degrees of sorting and coarseness of the alluvial sediments, the permeability of this material varies greatly. The old alluvial sediments located at greater depths are much less permeable than the surficial sediments and have to be considered aquitards at the regional scale (Dames and Moore, 1987).

The Servilleta flood basalts extend from near the ground surface to a depth of a few hundred feet over much of the plateau area west of the Guadalupe Mountain and along the Rio Grande and Red River gorges (Figure 2-4). These basalt flows were derived largely from molten lavas of low viscosity; hence they were able to spread out over the plateau in tabular sheets, often of large extent. The individual basalt lava flows are generally less than 50 feet thick and are locally interbedded with thin strata of volcanic ash. The sheets were cut by numerous vertical fractures, which formed during cooling of the lava. The rapid chilling of the tops and bottoms of individual flows, and later erosion, resulted in a rugged contact between the lava strata.

The permeability of the Servilleta flood basalts depends largely upon the extent of its fracturing and the bedding contacts of different flows, which act as high permeability layers. Vesicles do not seem to be an important medium for groundwater movement through the lava. Although small portions of a lava flow are commonly impermeable, the lava flow as a whole is capable of transmitting large quantities of groundwater (high formational permeability).

The lobate flows of the Guadalupe Mountains (gv) are exposed only in vicinity of the Guadalupe Mountain (Figure 2-4). However, at greater depths, they reach as far west as the Rio Grande canyon (note outcropping of Guadalupe volcanics near Cerro Chiflo and Big Arsenic Springs, Figure 2-4). The volcanic formations of Guadalupe Mountain rest on the Santa Fe alluvial deposits. The elevation of the top of the Santa Fe sediments beneath Guadalupe Mountain has not been ascertained; however, it probably is a few hundred feet beneath the water table.

The volcanic activity of Guadalupe Mountain has emplaced a variety of volcanic lithologic types including dacites, colluvial and surge breccias, rhyodacite and occasional cinder beds. Probably very few of the rock units are continuous over the study area. Bed orientations and thicknesses are chaotic, and units can not be easily correlated over any great distance (Dames and Moore, 1987). Fracture densities and orientations, which control groundwater flow in this area, appear to vary widely. Indications of high volcanic rock permeability have been observed in the vicinity of the Guadalupe Mountains (e.g. South Pass Resources, 1993; Dames and Moore, 1987).

A series of northwest to southeast trending faults, referred to here as the Red River Fault Zone, bisects the area along the southwestern toe of the Guadalupe Mountain complex (see Figure 2-4). West of the fault zone, the Santa Fe sediments have been uplifted. East of the Red River Fault Zone, the rock units are down-dropped several hundred feet relative to the west of the zone. An exception to this condition can be found in the Big Arsenic Springs area (Figure 2-4) where a lobate dacite flow followed and filled a paleo-valley (possibly an ancestral Red River valley) at a depth that is now a few hundred feet below the top of the Santa Fe sediments (Vail, 1993).

The eastern section of the Questa Tailings Facility was entirely constructed on recent alluvial sediments, whereas the western sections were constructed partially on alluvial sediments and partially on volcanic rocks of the Guadalupe Mountains (Figure 2-4). Beneath the tailings facility the basalt flows from the Guadalupe Mountains gradually dip eastward, interfingering and underlying the recent alluvial sediments. Further details on the local geology at the tailings site are provided in Section 2.5.2 (Site Hydrogeology).

2.5 Hydrogeology and Groundwater Quality

2.5.1 Regional Hydrogeology

The groundwater conditions differ significantly between the piedmont alluvial plains to the east and the Guadalupe Mountain area and the lava-capped plateau to the west. Surficial alluvial sediments form the principal aquifer(s) in the eastern parts of the study region (Figure 2-5). Shallow groundwater in the alluvial sediments in the study area typically occurs under water table conditions. The gradients under which the groundwater moves through the alluvial sediments range from approximately 0.01 to 0.04 feet/foot, or 50 to 200 feet to the mile (Winograd, 1959).

In the vicinity of Cerro, and southward towards Questa, the water table is typically 60 to 160 feet below ground surface, depending on local topography. Most irrigation and water supply wells in this area are completed in the surficial alluvium of recent age (less than 300 feet below ground surface). The specific capacity of these wells is typically less than 20 gpm per foot of drawdown (Winograd, 1959).

In the western parts of the study region, the volcanics form the principal aquifer (Figure 2-5). In the volcanics, groundwater movement is controlled by fracture permeability, lava flow-boundary permeability and to a lesser extent vesicular permeability (Dames and Moore, 1987). Beneath

Guadalupe Mountain and further to the west, groundwater in the volcanic aquifer occurs under water table conditions. However, where the volcanics are overlain by alluvial sediments of appreciable thickness (i.e. east of the Guadalupe Mountain) groundwater is often confined (Winograd, 1959). Owing to the high formation permeability of the volcanics, hydraulic gradients are typically much lower than in the alluvial sediments. Dames and Moore (1987) estimated gradients of approximately 0.0036 feet/foot, or 19 feet to the mile, in the Guadalupe Mountain area.

The water table in the volcanic aquifer(s) is typically several hundred feet below ground surface. The only two water supply wells presently completed in the deep volcanic aquifer(s) are operated by the Bureau of Land Management in the "Rio Grande Gorge Wild and Scenic River Area". One well is located at the BLM's headquarters and the other one is located at the Chiflo Campground. Both wells produce approximately 30 gpm and operate on a pressure-demand basis (Dames and Moore, 1987). A pump test conducted in a test hole completed in the deep volcanics at the toe of Molycorp's tailings Dam No. 4 indicated a specific capacity of approximately 250 gpm per foot of drawdown (South Pass Resources, 1993).

The interaction of shallow groundwater flowing in the sediments of the piedmont alluvial plains and the deep groundwater flowing in the volcanic aquifer(s) is of special importance for evaluating the groundwater flow conditions at the Questa tailings site. It is commonly observed that the water table in the alluvial sediments is over 100 feet higher than in the underlying volcanics (e.g. Winograd, 1959; South Pass Resources, 1993). The downward movement of groundwater is retarded by a confining layer of lower permeability material, consisting either of an alluvial silt or clay bed or the upper portion of the lava flow where the fractures have been filled with clay, sand and gravel (Winograd, 1959). This confining layer causes the great head differential between the upper alluvial aquifer and the deeper volcanic aquifer. Groundwater moves through this confining layer recharging the deeper volcanic aquifer below. The absence of springs at the surficial contact of the alluvial sediments and the volcanics, plus the similarity in chemical composition of the water in the volcanics to that in the alluvial sediments, are further evidence that water from the sediments moves into the underlying volcanics (Winograd, 1959).

Perched conditions, i.e. shallow groundwater flow on top of low permeability clay lenses and/or layers resulting in a zone of aeration, occur locally within the alluvial sediments but are not considered important at the regional scale (Winograd, 1959). The perched water conditions in the vicinity and down-gradient of Dam No. 1 are, however, very important in that they control the flow paths and mixing of the tailings pond seepage and the natural groundwater (see Section 3.2.5 and 3.2.6).

Groundwater in the study area generally moves from areas of higher elevation, i.e. recharge areas at the base of the Sangre de Cristo Mountains, to those of lower elevations, i.e. discharge areas along the Rio Grande and the Red River (Figure 2-5). The groundwater initially moves in a westerly direction through the alluvial sediments, which underlie most of the area receiving recharge, and drains eventually into the underlying, permeable volcanics. The Guadalupe Mountain complex evidently does not represent any barrier to flow and groundwater continues to move in a southwesterly direction beneath this mountain complex (Dames and Moore, 1987; see Figure 2-5).

Groundwater flow down-gradient of the Guadalupe Mountain is controlled primarily by hydraulic properties of volcanics (in particular lobate dacite flows from the Guadalupe Mountain complex) and by the sedimentary Santa Fe Formation (Dames and Moore, 1987). East of the Red River Fault Zone the water table is in very permeable volcanics and groundwater is discharging at natural discharge points in and adjacent to the Rio Grande and the Red River (Figure 2-5).

West of the Red River Fault Zone, however, the Santa Fe sediments are uplifted and placed in the flow path of the regional groundwater system. Owing to their low permeability the Santa Fe sediments act as an aquitard restricting groundwater flow from volcanic aquifers east of the fault zone to the Rio Grande and the lower 2 miles of the Red River (Dames and Moore, 1987).

An exception is the dacite filled paleo-channel within the Santa Fe sediments, which emerges at the Big Arsenic Springs complex. The dacite has a relatively high permeability and appears to be an avenue of higher flow through the Santa Fe sediments (Figure 2-5). This condition explains the presence of the approximately 18 cfs of groundwater discharge in the Big Arsenic Spring complex (Scott Vail, 1987).

The western flank of the Sangre de Cristo Mountains is thought to be the principal area of groundwater recharge in the study region. The Rio Grande and the Red River gorges are the principal areas of groundwater discharge. Both, groundwater recharge and discharge rates in the study region have been estimated by various authors.

Precipitation in the study area ranges from 14 inches or less below 8,000 feet of elevation to over 30 inches in higher elevations. However, only a small percentage of this precipitation will actually recharge the aquifers. McAda and Waseolek (1987) estimated that the annual recharge from percolation of precipitation in the Espanola Basin (immediately to the south of the study region) is no more than 0.28 inches per year in those areas covered by the Santa Fe Group formation.

Most of the recharge to the groundwater probably occurs from ephemeral and perennial streams running off the Sangre de Cristo Mountains (and related irrigation ditches), which upon leaving their mountain courses and entering the plateau area, lose much of their flow to permeable alluvial sediments. Other sources of recharge are leakage from arroyo flood flows, and infiltration of water pumped for irrigation. Most recharge is to the groundwater body in the alluvial sediments. Recharge to the volcanics occurs predominantly though leakage from the overlying alluvial sediments. Vail estimated that the total recharge to the study region is in the order of 50 cfs (Vail, 1988).

Groundwater discharge in the study region is predominantly through natural springs into and near the Rio Grande and the Red River. The spring flows have been estimated directly and indirectly using accretion measurements (during low flow periods) in these rivers. Dames and Moore (1987) provide a comprehensive review of springs flows and river accretion measurements. The results of their review are shown in Table 2.3

At the regional scale, the groundwater system appears to be in relative equilibrium (Dames and Moore, 1987). No major changes in spring flows and/or static water levels have been observed in the volcanics and alluvial aquifers as a result of pumping (for irrigation) and/or seasonal recharge. Only shallow wells show seasonal variations in water levels corresponding to seasonal recharge.

Table 2.3.
Summary of Accretion to Rio Grande and Red River (after Dames and Moore, 1987).

	Total Accretion	*Estimated groundwater contribution from study region*
Rio Grande		
Cerro Chiflo to Red River Fault Zone	22 cfs	11 cfs from east
Red River Fault Zone to Confluence	23 cfs	18 cfs from Big Arsenic Springs Complex plus 2 cfs from east
Subtotal	**45 cfs**	**31 cfs**
Red River		
Questa to Fish Hatchery	18 cfs	12 cfs from north
Fish Hatchery to Red River Fault Zone	10 cfs	7 cfs from north
Red River Fault Zone to Confluence	5 cfs	2 cfs from north
Subtotal	**32 cfs**	**21 cfs**
TOTAL	**77 cfs**	**52 cfs**

2.5.2 Site Hydrogeology

Molycorp Inc. has commissioned several field investigations since 1989 to evaluate the impact of tailings seepage on the water quality of the local aquifers. In 1993, five monitoring wells were installed down-gradient of the tailings impoundments by South Pass Resources Inc. (SPRI). The results of this field investigation are summarized in SPRI (1993). In 1994, four extraction wells and an additional monitoring well were installed down-gradient of the impoundments (SPRI, 1995). In the fall of 1997, an additional set of monitoring wells and extraction wells was completed under the supervision of Souder, Miller and Associates (SMA, 1997). During each field investigation, selected wells were pump tested to obtain estimates of aquifer transmissivity.

In the following section we summarize the results of these field studies as they relate to the hydrogeology at the study site. For a discussion of the impact of the Questa Tailings Facility on the local groundwater system the reader is referred to Section 3.1.5 (Seepage Interception

System) and Section 3.1.5 (Groundwater Monitoring). For a more detailed interpretation of the field investigations the reader is referred to the cited literature.

Figure 2-6 shows an idealized cross-section running perpendicular to the two arroyos (parallel to the Red River) downgradient of the tailings facility. The exact location of the section line (and the various boreholes) are shown in Figure 3-14. Figure 2-6 illustrates the site geology and local groundwater flows. Table 2.4 summarizes the results of pump or bail tests conducted on selected wells to obtain estimates of aquifer transmissivity.

As a first approximation, the local groundwater system can be divided into an upper (shallow) aquifer system (above an elevation of ~7200 ft) and a lower (deep) aquifer system (below an elevation of ~7200 ft). The two aquifer systems may be characterized as follows:

- the shallow aquifer system consists of a complex mixture of recent alluvial sediments, ranging from coarse, permeable sand and gravel units to very low permeable clay layers (see Figure 2-6 and Table 2.4) resulting in very high spatial heterogeneity at the local scale; these alluvial and alluvial/lacustrine sediments contain thin layers of silt and clay which extend laterally (in a north-south direction) up to several hundred feet (see Photo 13);
- groundwater in the shallow aquifer system preferentially moves in permeable sand and gravel units of limited extent; it is difficult to isolate distinct aquifer units at this scale (note that SPRI has postulated the presence of an upper and lower aquifer separated by a middle aquitard; however, the lateral extent of these units is difficult to trace in the existing borehole logs); shallow groundwater is typically perched, flowing on top of silt and clay layers and gradually 'cascading' downward into deeper soil horizons (Figure 2-6);
- groundwater flow in the shallow aquifer system is predominantly in a south-southwesterly direction discharging in various springs at or near the Red River (e.g. Big Springs including Questa Springs); some shallow groundwater percolates downward and into the deeper aquifer system (leakage);
- the deep aquifer system consists of deep alluvial sediments in the eastern parts and volcanic rocks from the Guadalupe Mountains in the western parts of the study area (beneath the Dam 4 arroyo) (Figure 2-6); the basalt flows from the Guadalupe Mountains gradually dip eastward, interfingering and underlying the recent alluvial sediments beneath the Dam 1 arroyo (Figure 2-6); the volcanics have a very high secondary permeability (e.g. MW-11, Table 2.4) and act as a drain for shallow groundwater flowing above in the shallow alluvial sediments (Figure 2-6);
- groundwater flow in the deep aquifer system is predominantly in a southwesterly direction discharging in various springs in the Red River Gorge (much of this flow is collected in the warm water supply for the Fish Hatchery; see Section 3.2.7); deep groundwater moves through permeable sand and gravel layers of the deep alluvial sediments and fractures and bedding planes in the volcanics; the deep aquifer system appears to be unconfined with a water table near or below the level of the Red River (Figure 2-6);
- groundwater flow in the shallow aquifer system is influenced by seasonal recharge with seasonal water level fluctuations in the order of 1-2m; groundwater flow in the deep aquifer

system is at steady-state, i.e. seasonal variations in observed water levels are minor (in the order of 10-20 cm).

Note that the observed heads in the shallow aquifer system are many tens of feet higher than in the deep aquifer system (compare e.g. water levels in EW-4 and MW-14 to those in EW-2 and MW-12, Figure 2-6). The difference in permeability of shallow alluvial sediments and the units in the deep aquifer alone can not explain these very high vertical gradients. It is believed that shallow groundwater flow is locally perched due to the presence of silt/clay lenses and layers maintaining such a high head differential.

Note also that the local stratigraphy is complicated by a set of two (possibly more) faults (Figure 2-6). Vail (1987) mapped a northeast trending high angle fault along the east flank of the Guadalupe Mountains). This fault appears to follow the arroyo, now largely covered by the tailings behind Dam No. 4 (Figure 2-5). Field reconnaissance suggests that the fault block to the east has moved relatively downward (SPRI, 1995). East of this fault line, the basalt flows of the Guadalupe Mountains are exposed at the surface covered only by a thin veneer of soil derived from weathering of the local volcanics (Figure 2-6).

A second high angle fault line runs along the center of the northeast trending arroyo, now largely covered by the tailings behind Dam No. 1 (Figure 2-6). The borehole logs suggest that the volcanic unit has been displaced downward to the east of this fault line (SPRI, 1993). This fault line acts as sharp boundary between different stratigraphic units (Figure 2-6).

Note that the borehole data and field exposures are concentrated in a narrow band to the south of Dams No. 1 and No. 4. It is believed, however, that the structure and lithologic units, particularly the basalt unit, extend northward beneath the tailings pond facility and southward at least to the Red River (SPRI, 1993).

2.5.3 Groundwater Quality

The earliest records of groundwater quality in the study area are published in Winograd (1959). He noted that the groundwater quality in the area was good to excellent with low hardness (less than 100 mg/l $CaCO_3$) and low concentrations of sulfate (~20 mg/l), fluoride (<1.2 mg/l) and total dissolved solids (TDS<160 mg/l). Furthermore, it was observed that the quality of groundwater in the shallow alluvium and the deep volcanics was nearly the same.

These early measurements were later confirmed by sampling groundwater in a number of wells and springs upgradient or out of the flow path of tailings seepage from the Questa Tailings Facility (e.g. Dames and Moore, 1987). Table 2.5 lists water quality parameters for those wells with natural ambient groundwater quality in the study area (after Vail, 1993). The natural groundwater in both the shallow and deep aquifers has a near-neutral pH with low concentrations of dissolved solids (140-150 mg/l TDS). The water is generally soft with most of its hardness derived from calcium carbonate. Sulfate concentrations in the natural groundwater are about 20 mg/l and ambient concentrations of molybdenum are below the detection limit (Table 2.5).

Table 2.4.

Results of Pump Tests near Tailings Facility.

Borehole	Aquifer Material	Method	Transmissivity g/d/ft	Transmissivity m^2/s	Saturated Thickness (ft)	Hydraulic Conductivity $g/d/ft^2$	Hydraulic Conductivity cm/s	Reference
MW-7a	sandy gravel	Cooper - recovery	2,500	3.6E-04	10	250	1.2E-02	
MW-10	gravelly sandy clay	Cooper - drawdown(1)	9	1.3E-06	50	0.18	8.5E-06	SPRI, 1993
	w/ thin layers of	Cooper - recovery(1)	2	2.9E-07	50	0.04	1.9E-06	
	sandy gravel	Specific Capacity Test (1)	51	7.3E-06	50	1.012	4.8E-05	
MW-11	volcanics	Cooper - drawdown	1,932,000	2.8E-01	56	34,500	1.6E+00	SPRI, 1993
		Cooper - recovery	784,000	I.IE-01	56	14,000	6.6E-01	
		Specific Capacity Test	383,700	5.5E-02	56	6,852	3.2E-01	
EW-2	sandy gravel	Cooper - drawdown	2,600	3.7E-04	30	87	4.1 E-03	SPRI, 1994
		Cooper - recovery	27,000	3.9E-03	30	900	4.2E-02	
EW-3	gravelly clay and	Cooper - drawdown	4,400	6.3E-04	15	293	1.4E-02	SPRI, 1994
	clayey gravel	Cooper - recovery	2,200	3.2E-04	15	147	6.9E-03	
EW-5A	sand w/ gravel	Cooper - drawdown(1)	5,793	8.3E-04	30	193	9.1 E-03	SMA, 1997
EW-5B	gravelly sand; silty g	Cooper - drawdown(1)	70,026	1 .OE-02	30	2,334	1.1E-01	
EW-5C	silty, gravelly sand	Cooper - drawdown(1)	1,082	1.6E-04	30	36	1.7E-03	
EW-5D	silty sand	Cooper - drawdown(1)	43	6.2E-06	25	2	8.1 E-05	

Notes:

(1) maximum drawdown was not reached

Table 2.5

Ambient Natural Groundwater Quality

WATER SOURCE	LOCATION Sec	Twp	Rng	AGENCY	DATE	SPEC. COND. umhos	TDS mg/l	pH units	SO4 mg/l	CALCIUM mg/l	MAG-NESIUM mg/l	CHLORIDE mg/l	FLOURIDE mg/l	IRON ug/l	MANGANESE ug/l	MOLY-DENUM ug/l	ZINC ug/l
Big Arsenic Springs	a	28	12	USGS	10-07-80	228	161	8.2	22.0	18.0	4.8	6.9	---	<10	2	<10	---
Big Arsenic Springs	8	28	12	USGS	08-20-82	220	159	7.9	22.0	20.0	5.1	6.8	1.2	4	3	---	13
Big Arsenic Springs	8	28	12	EID	01-13-83	226	162	7.5	23.7	18.0	5.7	8.0	---	---	<10	---	<50
Big Arsenic Springs	8	28	12	EID	07-23-84	---	160	---	24.8	16.3	5.6	6.0	---	<50	<10	<50	<50
Big Arsenic-North Springs	8	28	12	EID	01-13-83	229	163	7.5	23.7	19.4	5.4	8.0	---	---	---	<10	<50
Big Arsenic-Meadow Springs	8	28	12	EID	01-13-83	192	163	7.5	23.7	19.4	5.4	8.0	---	---	<10	---	<50
Big Arsenic-Meadow Springs	8	28	12	EID	11-08-84	---	154	---	29.6	22.4	7.8	6.3	1.2	<100	<50	<10	<50
Big Arsenic-Meadow Springs	8	28	12	EID	05-30-85	---	165	---	24.5	24.0	8.3	8.6	---	110?	<50	<10	<10
Big Arsenic-High Springs	8	28	12	EID	11-08-84	---	---	---	---	21.6	3.9	---	1.08	480?	<50	<10	---
Big Arsenic-High Springs	8	28	12	EID	05-30-85	247	170	---	24.5	11.2	20.0	6.8	---	<50	<50	<10	---
Chiflo Springs				EID	05-30-85	218	---	---	26.6	22.5	17.6	7.0	---	---	---	---	---
BLM Visito Center Well	9	28	12	USGS	08-20-82	220	156	7.9	20.0	19.0	5.0	7.0	1.2	7	3	---	48
BLM Chiflo Wells	9	28	12	USGS	08-20-82	220	158	8.0	23.0	19.0	5.2	6.9	1.3	3	10	---	97
Mottle Spring-Red River	9	28	12	USGS	08-19-82	220	---	7.5	---	---	a - -	---	---	3	8	6	<3
Warm Spring-Red River	9	28	12	EID	02-21-84	---	164	---	21.7	24.0	5.9	9.7	---	---	<10	---	<100
MC Guadalupe Well 4 (Average of 7 samples)	22	29	12	MC	12-87	---	167	7.5	50.1	20.5	4.9	8.7	1.1	5	2	<2	150
MC Guadalupe Well 5 (Average of 5 samples)	33	29	12	MC	ii-as	---	167	---	18.8	20.4	5.4	7.6	1.1	3	14	<2	40
ALLUVIUM WELLS																	
Top of World Farm	35	1	74		1955	217	136	7.7	8.8	24	5.7	5.0	0.8	---	---	---	---
Anderson Well	16	12	30		1954	194	---	7.2	---	---	---	4.5	---	---	---	---	---
Carter Farm	24	12	30		1954	190	---	---	43	36	2	18	---	---	---	---	---

2.6 Soils, Vegetation and Wildlife

2.6.1 Soils

Soils in the area of the tailings facility prior to operation of the ponds have been identified from the 1976 Soil Survey of Taos County. The soil descriptions indicate conditions prior to placing of tailings. Figure 2-7 indicates the location and soil types by abbreviation. In addition, the information is important to the closure of the facility because borrow areas for covering the tailings are located in and around the tailings ponds. Identification and descriptions of the soils allow for planning of the final reclamation of the site. The descriptions of the various soils in the area have been verified informally by staff at Molycorp, based on their experience with the borrow areas at the tailings facility.

There are three soil types identified at the tailings facility that make up the majority of the site. Three additional soil types occur in a much smaller area at the tailings. The three major soil types are identified as 1) Sedillo-Silva Association (SED); 2) Fernando Cobbly Loam (FaC); and 3) Rock Outcrop-Raton Complex (RRE). The minor soil types are the Fernando Clay Loam (FfC), Manzano Clay Loam (MnC), and Silva Loam (SmB). The soil descriptions are summarized below, with only the major components of a unit discussed and focusing on characteristics that are important to its use as a cover material. For complete descriptions of the soil classifications, refer to the Soil Survey of Taos County.

Sedillo-Silva Association: The Sedillo is a very gravelly loam and makes up about 55% of the association and is found on side slopes in the region. The Silva loam makes up about 25% and is found on ridge crests. Because of the location of each type, it is anticipated that the Sedillo soil is the most likely to be used for cover material in this association. Also making up this association are Orthents and Manzano, Fernando, and Hernandez soils (each at 5%). The Sedillo soil is well drained with an effective rooting depth of 60 inches *in situ*. When the soil is classified by layers (which is lost during the use of the material as cover) the top 5% is very gravelly loam, 13% is very gravelly clay loam and the remaining 82% (to 60 inches) is very gravelly sandy loam. The available water capacity ranges from low to moderate. The Silva soil is loam and clay loam with a similar rooting depth.

The Fernando Cobbly Loam is found on alluvial fans at the base of mountains and formed in mixed alluvium. Included in the mapping units are Fernando loam (10%), Hernandez soils (15%) and Rock Outcrop (5%). The soil is generally cobbly loam (5%), loam and clay loam (33%) and loam (62%). The effective rooting depth is a minimum of 60 inches *in situ*. Cobbles and gravel cover 15 to 35% of the surface. The available water capacity is high and the soil is noted to be suitable for juniper and pinon.

The last major soil type in the area, the Rock Outcrop-Raton Complex is unlikely to be used for cover material. It includes areas of rock outcrop and Raton very stony silt loam intermingled. Included in this association are Orthents and Stunner soils which make up 15% of this complex. The rock outcrop consists of folded, broken and exposed basalt flows. The Raton soil is shallow, only 18 inches deep, and formed in the residuum of basalt and in mixed eolian sediment. The top four inches is very stony silt loam and the lower 14 inches is very stony clay. The effective rooting depth is 18 to 20 inches *in situ* and it is suitable for woodland growth. However, because of the shallow soil and stony nature of the complex, it is unlikely to be cost effective to use this material as a cover material.

The minor soil types are considered those which occur at the tailings facility in lower percentages relative to the three major soil types previously discussed. The Fernando Clay Loam is a deep, well-drained soil that formed in alluvium on alluvial fans. Individual areas are 5 to 40 acres in size. About 15% of the unit are small areas of Silva and Hernandez soils. The surface layer is generally brown clay loam about 5 inches thick. The subsoil is brown silty clay loam about 14 inches thick and the remaining depth to 60 inches is made up of light brown silt loam. The soil may be somewhat calcareous, has an effective rooting depth of at least 60 inches, and the available water capacity is high. The soil has medium potential for use as habitat for openland and rangeland wildlife.

The next soil type is Manzano Clay Loam, which is formed in mixed alluvium along arroyo channels and range in size from 5 to 160 acres. There are some areas of gravelly soils and a few areas of intermingled Caruso and Tenorio soils (up to 15%). The surface 10 inches is generally brown clay loam, with about 33 inches of dark brown clay loam and the remaining 37 inches is brown clay loam. The available water capacity is high and the effective rooting depth is at least 60 inches. The dominant vegetation *in situ* is blue grama, big sagebrush and western wheatgrass. This soil has moderate potential for use as rangeland wildlife.

The last soil type in the region is the Silva Loam. This soil formed in mixed alluvium and eolian sediment on upland fans and ridges. Included in this soil are Fernando and Sedillo soils, which make up about 10% of the type. The top 8% is typically brown loam, the next 42% is brown clay loam and the remaining 50% to 60 inches is pink clay loam. The effective rooting depth is at least 60 inches and available water capacity is high.

2.6.2 Vegetation

The pre-existing vegetation prior to establishment of the tailings ponds has been determined indirectly. By examination of air photos (prior to 1965), talking to long-time residents of Questa and looking at the soils and topography in the area, the vegetation in the area has been identified as primarily pinon-juniper woodland in combination with sagebrush. The bottom of the arroyos were mainly grasses with some woody vegetation. As further confirmation of the pre-existing vegetation descriptions, the ecosystems surrounding the Questa tailings facility are of the same two types, the sagebrush ecosystem and the pinon-juniper ecosystem. A general description of the two ecosystems follows and are summarized from recognized descriptions of range and forest ecosystems (Eyre 1980, Garrison et al. 1977).

The sagebrush ecosystem (Photo 22) generally occupies plains and plateaus derived from lava flows, ancient lakebeds and broad basins of alluvium. The length of the frost free season ranges from 80 to 120 days with precipitation ranging from 5 to 12 inches, although some areas with as much as 20 inches of precipitation are found. The site is dominated by sagebrush (*Artemesia spp.*) and other shrubs may make up a part of the community. Sagebrush is also found as the only shrub with the understory made up of wheatgrasses, fescues, bromes, etc. The soil types are generally Aridosols, may have no pedogenic horizons and are typically low in organic matter.

Animals which generally occupy the sagebrush ecosystems include mule deer (winter use primarily), gophers, coyotes, jackrabbits, and rats. Bird populations are generally low during the breeding season with an average of 25 pairs for 100 acres. Major influent birds include red-tailed hawk, Swainson hawk, owls, and eagles.

The pinon-juniper woodland (Photo 21) is considered a climax community found in areas characterized by low precipitation, low relative humidity, hot summers with high evaporation rates and clear weather with intense sunlight. This type is often flanked by desert shrub (e.g., sagebrush) communities. Generally, the pinon-juniper type occupies the rocky or rough terrain, while sagebrush or other species occupy the gentle portions. Soil types associated with pinon-juniper woodlands include Aridosols with pedogenic horizons and moderate to low organic matter.

Some species found in association with pinon-juniper, particularly in well-developed (12 inches) soils include big sagebrush, western wheatgrass, blue grama, cliffrose, bitterbrush and Indian ricegrass. As the canopy closes, or on soils with low water holding capacity, grass production is reduced, shrubs spread out and the closure of canopy may eventually eliminate the understory.

Animals associated with pinon-juniper woodlands include mule deer, coyote, bobcat, and elk may be locally important. Also found are the wood rat, cliff chipmunk, jackrabbit, porcupine and gray fox among others. Some of the birds found in the pinon-juniper ecosystems include gray titmouse, Woodhouse's jay, red-tailed hawk, pinon jay, and rock wren.

2.6.3 Wildlife

Wildlife occurrence and use of the area was described as part of the site assessment completed to meet requirements under the New Mexico Mining Act. The site assessment included both the tailings facility and the mine site. The information from that site assessment is summarized for this report (1994 Molycorp – Mining Operation Site Assessment, ENSR Consulting and Engineering). A wide variety of animals have been noted in and around the tailings facility. It is not expected that usage of the area prior to tailings placement was different from what is seen surrounding the area currently. The general descriptions of wildlife use of pinon-juniper woodlands and sagebrush communities are consistent with the descriptions for this site.

Mule deer may use habitats near and particularly west of, the tailings ponds and the elk use patterns typically parallel mule deer, and elk have been spotted west of the tailings ponds. Bobcat, coyote, gray fox, raccoon, and ringtail have been found within the tailings ponds. Black bear and mountain lion are limited in numbers but have been reported just west of the tailings ponds. Small mammals include white-tailed jackrabbit, Ord's kangaroo rat, deer mouse and chipmunk.

In 1986, 133 avian species were recorded near the tailings facilities. Raptors are found throughout the area and are represented by species such as the red-tailed hawk, American kestrel, great-horned owl, and saw-whet owl. Amphibians and reptiles found in the area included the western spadefoot toad, leopard frog, collard lizard, great plains skink, and prairie rattlesnake. Threatened or endangered species in the area include the bald eagle and whooping crane. Wintering bald eagles are known from the upper Rio Grande Gorge to the west of the tailings ponds. The whooping crane may potentially pass through the area during migration but is not expected to use the habitat.

2.7 Roads and Land-use

The site where the tailings impoundments are located was made up of two large arroyos draining towards the Red River. The presence of the arroyos limited the uses of the site. There was no known agricultural use of the area, although it was probably used for some sheep and/or cattle grazing. It is expected that wildlife in the area made use of the two arroyos. There were no maintained roads at the site, and it is believed that if any roads existed they were primitive roads or dirt tracks.

3.0 Tailings Impoundment Development

The description of the Questa Tailings Facility is subdivided into historic development (Section 3.1) including all developments until the spring of 1998, and future development (Section 3.2).

3.1 Historic Development

3.1.1 Dams, Diversions, Structures and Buildings

3.1.1.1 Dams

The locations of the dams that have been constructed to develop the Questa Tailings Facility are shown on Figure 3-1. As they currently exist they comprise three impoundment systems:

i) The first system is located in Section 36 and currently consists of Dams 1 in the south, Dams 1C, 1B, and 2A on the east and a separator dyke between this impoundment and that for the Dam 4 complex on the west.

ii) The second system is located in Section 35 and consists of Dam 4 in the south, Dam 3A in the north and a discontinuous containment dyke along the west.

iii) The third system, also in Section 35, consists of Dam 5A in the south and impounds against Dam 3A. This system is currently receiving tailings.

In addition to these dams, a low earth dam was constructed as a water control dam just below the toe of Dam 4. This dam and its reservoir are referred to as ‘Pope Lake’ (Photo 3; see Figure 3-20 for location).

All the dams have been designed, constructed and operated under the permitting control and regulatory overview of the New Mexico State Engineer. Construction and operation have been in accordance with the designs and specifications as permitted. Regular dam inspections have been performed by New Mexico Registered Professional Engineers in accordance with the National Dam Safety Act. Deficiencies identified during inspections and operation, and any concerns expressed by the State Engineer, have been addressed and remediation or repairs made as appropriate. There are currently no outstanding issues or concerns remaining to be dealt with.

Dam 1 Complex

Dam No. 1 was designed by Dames and Moore in 1965 for the foundation and geotechnics (Dames and Moore, 1965) and by Western Knapp Engineering Division of Arthur G. McKee & Company for the layout and specifications (Western Knapp, 1965). Dam 1 was constructed in 1966 as an earthfill dam across an arroyo as shown in Photo 1. It contains a blanket and chimney drain and was raised by downstream construction using earthfill in stages from its original crest elevation (El) of 7460 to El of 7500 (see Figure 3-2). The last raising from El 7500 to El 7525 was by upstream construction using earth fill. Historic details of construction and dam operation are summarized in Section 3.1.2.1. The dam includes a 120 wide toe berm (see Photos 1 and 5) installed in 1981 which was required for stability. Initially water was decanted from the tailings impoundment through two vertical, lined concrete penstocks to a horizontal decant conduit. It was lined with a 24 inch diameter culvert sleeve installed in the concrete conduit, a few years after construction. This conduit was abandoned and plugged with approximately 20 feet of concrete in the early 1970s.

In 1975, “Old” Dam 1C was constructed of cycloned sand 650 feet upstream of Dam 1 to El 7560. To provide containment along the east side, next to the diversion ditch, Dams 1B and 2A were constructed to El 7560 using earth fill as shown in Figures 3-3 and 3-4A/B.

In 1981 “New” Dam 1C was constructed at its present location (see Figure 3-2) to its present elevation of 7584 (Photo 1). This ‘new’ dam replaces the old dam, which is contained within the tailings deposited behind “New” Dam 1C. The new dam was designed to achieve appropriate static and dynamic stability criteria. It incorporates a chimney and blanket drain and includes a downstream berm to provide adequate stability and provide for future downstream raisings (Figure 3-2).

Dams 1B and 2A were raised at the same time to the same elevation, as shown on Figures 3-3 and 3-4. Dam 1B was raised with earthfill by downstream construction and includes a chimney and blanket drain, and a downstream stabilizing/downstream construction berm. Prior to raising Dam 2A, a cycloned tailings dam had been constructed inboard of the dam and the tailings immediately upstream from the dam were excavated to allow for the construction of the raised Dam 2A as illustrated in Figure 3-4. Chimney and blanket drains were installed.

The separator dyke between the impoundments in Sections 35 and 36 had been constructed of earth fill. In 1991 the State Engineer queried the stability of the divider dyke. Following an investigation of the dyke stability, the dyke was stabilized by installing a downstream berm (Geocon 1991).

Dam 4 Complex

Dam No. 4 (originally referred to as “Dam 2”) was designed in 1974 by Dr. B. Hoare, later of Geocon and Hoare (Hoare, 1971). The initial embankment of Dam 4 was constructed in the arroyo in Section 35 in 1971 to El 7460 (Photo 6). It was constructed of earthfill and incorporates a chimney and blanket drain as shown on the typical cross-section on Figure 3-5. Seepage through the embankment is controlled by an upstream asphalt membrane. Subsequent raisings have been substantially constructed by centerline construction methods. There have been some changes in construction concept, which led to changes in the location and nature of the chimney and blanket drain as shown on Figure 3-5. For the most recent raise to El 7520 there has also been a change of material for the seepage cut-off to a high density polyethylene (HDPE) geomembrane.

Dam 3A is an earth fill dam constructed in 1973 to El 7532. It served to retain tailings placed behind Dam 4 from flowing further north and west (Figure 3-1). With the placement of the tailings which is currently occurring behind Dam 5A, this dam will cease to function as a dam and it is not considered further here.

Dam 5A Complex

Dam No. 5A was constructed in 1990 in the old west decant channel on the north side of Dam No. 3A (see Figure 3-1 and Photo 7). It was made of earth fill and reached an elevation of 7525'. It was raised in 1996 to El 7545 as a zoned rockfill dam as shown in section on Figure 3-6. Tailings are currently being placed in the impoundment formed by this dam (Photo 8).

3.1.1.2 Diversions

The hydrology and drainage of the site, prior to dam construction, is described in Section 2.2. With the development of the tailings dams, the flow from the upstream catchment had to be diverted around the tailings impoundments. In 1973 a drainage ditch was constructed to divert water around the west side of the impoundments (Vail 1975). The run-on water to the eastern (Dam 1) arroyo was also diverted to this ditch. With the development of the expanded tailings structures in 1975 the diversion ditch at the toe of Dams 1B and 2A were filled in and new diversion facilities were needed. A comprehensive hydrology analysis was performed (Vail 1975) and the current West and East Drainage Ditches designed and installed at the location shown on Figure 3-1 at that time. Typical sections through the east and west drainage ditches (also refered to as diversion ditches) are shown on Figure 3-7. Both ditches were designed to pass the one in one hundred year frequency storm over the entire catchment basin, with three feet of freeboard (see Appendix F for more detail).

During their more than 20 years of operation, no flow has been observed in the west diversion ditch. Only minor flows have been observed in the east diversion ditch and this appears to be associated with irrigation water discharges to the catchment rather than storm water flows. Field inspection of the ditches indicate that there is little evidence of either side slope or channel erosion (see Photo 2).

3.1.1.3 Structures

The only significant structures on the tailings dam complex are associated with the water decant and discharge channels. The original decant conduit under Dam 1 was plugged and abandoned. Tailings water discharge, for most of the facility life, has been along the western decant channel. This is a channel, which has been excavated into soil and rock along the western perimeter of the Dam 4 impoundment (Photo 13). Each of the tailings ponds behind Dams 1 and 4 were discharged to this decant channel via decant structures. In earlier years the decant channel discharged over the right abutment of Dam 4 to Pope Lake and its downstream drainage. With the requirement that process water be treated prior to discharge it has been necessary to install a concrete weir in this channel. Here water flow (if it exceeds discharge standards) is transferred into a 12 inch diameter steel pipe which conducts flow to the ion exchange plant (Photo 3). The upper part of the decant channel has been blocked by the construction of Dam 5A, and is no longer required.

Discharge from Pope Lake (Outfall 001) is through a concrete weir with a head gate.

3.1.1.4 Buildings

Two permanent buildings are on site; the administration building and the ion exchange plant building.

The administration building is a one-story 12 ft by 30 ft cinder brick building with a cement floor which serves as a change house, lunch room, office and storage building. This building is located on the east side of the impoundment on Section 36. It has washroom facilities which drain to a septic tank.

The ion exchange plant is a 260 ft by 150 ft by 40 ft high structural steel building with a concrete floor. It contains primarily steel tanks, pipes, pumps and storage bins for reagents. It is located adjacent to Pope Lake at the location shown in Photo 3 (see also Figure 3-20). Electrical power is 3 phase 440 Volt. There are no PCBs in the facility. It has washroom facilities draining to a septic tank.

In addition to the above buildings there is a temporary contractors building which is being removed.

3.1.2 Tailings Deposition and Characterization

The tailings have been deposited into the tailings impoundments by a variety of discharge methods and from varying locations. An understanding of the discharge methods and history is required to develop a 'model', which describes the nature and variability of the tailings through the tailings impoundments.

During initial placement behind Dam 1 the discharge was made from the north end of the impoundment resulting in a beach forming at the northern end of the impoundment which sloped towards a tailings pond which formed in the south against Dam 1. Typical tailings beach slopes vary between 1 to 1.5% near the discharge to less than 0.5 % near the pond. At the pond edge the tailings profile would typically steepen to about 5%. As the tailings flow down the beach the tailings solids settle out and are deposited on the beach. The coarsest tailings (sands) are deposited near the discharge point while the finest fraction (slimes or fines) are carried to near the pond. This beach and pond formation is characteristic of all beached deposits in the Questa tailings impoundments. Tailings pond water was decanted from the Dam 1 pond through the decant conduit. Since the tailings pond was initially against the Dam 1 embankment this resulted in the accumulation of a substantial depth of fine tailings adjacent to the dam. This served to 'blind off' the permeable foundation alluvial deposits reducing foundation seepage.

When the discharge conduit was abandoned and the west decant channel was developed it was necessary to "move" the tailings pond to the west perimeter of the Dam 1 impoundment. This was achieved by discharging tailings from the Dam 1 embankment and from the east side of the impoundment perimeter from a series of spigots (small pipe discharges) to develop beaches from these locations. The beaches, sloping to the north from Dam 1, and to the west from the east perimeter resulted in the tailings pond being 'driven' the central-west location from which it could decant to the west. As the pond was driven to its new location it would result in the formation of tailings fines (or slimes) deposits at its moving location. A deep deposit of slimes developed at the new location of the pond against the west perimeter. The initial slimes deposit against Dam 1 was covered by a thick deposit of tailings sands. These deposits of sands and fines were observed (as expected) in the borehole samples recovered during the tailings investigation program discussed below.

The sand beaches drain rapidly and are trafficable to construction equipment (see Photo 9). The slimes beaches are very soft with low shear strength and cannot be accessed when wet and saturated.

At various stages during the development of the impoundment there were variations in the discharge methods. For example, during the initial raising of the Dam 1 complex above El 7520 a set of cycloned dams (Old Dam 1C and Dam 2B) were constructed inboard of the subsequent final dams (New Dam 1C and 2A). During cycloning the sands are separated from the fines in cyclones and deposited in a steep cone (typically 3:1 to 5:1 side slopes) to form a dam. The fines are deposited upstream of the sand retention dams or in other dam reservoirs (such as Dam 4). The fines fraction forms a beach as previously described for total tailings. Cyclone sand berms were also developed across the tailings impoundments to serve as separator dykes to allow the impoundments to be operated as separate areas. Tailings were spigotted into these management areas from perimeter discharge points to produce beaches which would allow the tailings pool to be maintained at a desired location adjacent to the western perimeter from which discharge could be effected. The total quantity of tailings placed by cycloning methods is a relatively small portion of the total tailings.

For a more detailed understanding of the nature and distribution of tailings the following review of the deposition history and subsequent modeling of the deposit was required.

3.1.2.1 Deposition History

In late October 1996, representatives of Robertson GeoConsultants Inc. (RGC) and Steffen Robertson and Kirsten (U.S.) Inc. (SRK) visited the Questa mine site to gather data to reconstruct the history of tailings deposition at the mine. The depositional history was constructed from drawings, maps and production reports (Table 3.1), in conjunction with results from the drill sampling program undertaken in December 1996 (SRK Report No. 09208.04/2, January, 1997a), and was reported in RGC Report No. 036006/1 (October, 1997). A summary of the tailings depositional history is provided herein.

Table 3.1
Yearly Tailings Production.

YEAR	PRODUCTION (TONS)	PERCENTAGE OF TOTAL PRODUCTION
1966	2 945 793	3.07
1967	3 935 784	4.11
1968	3 889 384	4.06
1969	4 320 755	4.51
1970	5 286 225	5.52
1971	6 483 109	6.77
1972	5 327 827	5.56
1973	5 304 236	5.54
1974	5 812 258	6.07
1975	6 067 467	6.34
1976	6 238 184	6.51
1977	5 175 000	5.40
1978	4 380 000	4.57
1979	5 130 000	5.36
1980	5 110 000	5.34
1981	3 101 000	3.24
1982	shut down	-
1983	1 183 000	1.24
1984	3 878 000	4.05
1985	4 357 538	4.55
1986	730 690	0.76
1987	shut down	-
1988	shut down	-
1989	1 054 384	1.10
1990	3 363 787	3.51
1991	2 700 641	2.82
1992	shut down	-
1993	shut down	-
1994	shut down	-
1995	shut down	-
1996	started up 10/96	
1997		
TOTAL	95 775 062	

Mining operations at Questa have consisted of both open pit and underground operations and, due to the fluctuating price of molybdenum, were intermittently halted for relatively short periods of time. The open pit mine started in 1965 and was active until 1983 after which mining activities progressed underground. The underground has been operated from 1982 to the present time, with intermittent closures in 1982, from 1987 to 1988, and from 1992 to 1996.

There are three main zones in the tailings facility as shown in Figure 3-1. Initially, tailings were deposited behind Dam 1 in Section 36. After 1971, as the facility was expanded, tailings were also placed behind Dam 4 in Section 35. Tailings are currently being placed behind Dam 5A, also in Section 35.

The following is a chronological description of the deposition of tailings within the Questa Tailings Facility.

<u>1965</u>

Open pit operations commenced.

<u>1966</u>

Dam No. 1 (Section 36) was constructed of earth fill material to an elevation of 7460'. It was raised to 7520' in 1969-1970 and further raised to its present elevation of 7525' in 1971. All tailings were deposited behind this dam until 1971.

<u>1969</u>

A northern confinement dam, in Section 36, was constructed of cycloned tailings to an elevation of 7520', it was named Dam No. 2.

<u>1970</u>

A small 10' dam, Dam No. 3, was constructed at the north end of Section 35; it was breached shortly afterwards.

<u>1971</u>

Dam No. 1 was raised to 7525', and Dam No. 4 (Section 35) was constructed to 7440'. From this time on, the tailings were split and deposited behind both dams from 1971 until 1991.

Internal berms were also constructed in this year, located in Section 35, north of Dam No. 4. Berm #1 (southern-most berm) and berm #2 (northern-most berm) are both seen in a 1976 airphoto. In 1985, berm #1 was covered with tailings and berm #2 was still active. In the 1991 airphoto, berm #2 was almost completely covered.

<u>1973</u>

Dam No. 3A, on the west side of Section 35, was built to an average elevation of 7532'. It was lower on the west end and higher on the east end of the dam.

A temporary impoundment, shown on a 1973 design drawing, located between the two large tailings areas, was built for tailings deposition during times of major construction. This area was referred to on a work sheet as the Rice Paddy and is referred to here as such. Its elevation was approximately 7550', the holding capacity was estimated at 890,000 tons; therefore, at 18,000 tpd, this represented approximately 3 months of deposition. The tailings here are contemporaneous with tailings deposited in Section 36 between 1973 and 1974.

<u>Pre-1974</u>

Tailings were also deposited in the "work area" behind Dam No. 1A; they are contemporaneous with tailings deposited behind Dam No. 1 in the time period between 1966 and 1967, prior to Dam No. 1 being raised to 7484', and are approximately 65' deep. This area was covered when the east diversion ditch was constructed around 1974.

<u>1975</u>

Dam No. 1B was constructed of earth fill to an elevation of 7560' and is a perimeter dam located upstream of Dam No. 1 running parallel to the east diversion ditch.

Dam No. 2A was constructed of earth fill to an elevation of 7560' when property was acquired north of Dam No. 2. Deposition of tailings north of Dam No. 2 occurred from various locations along Dam No. 2A, usually for days or hours at a time. It is approximated that deposition in this area occurred intermittently between 1975 and 1985, contributing to approximately 70 to 80' of tailings near the dams.

"Old" Dam No. 1C was also constructed in 1975, it was made of cycloned tailings and was located approximately 650' north of, and parallel to Dam No. 1. It reached an elevation of 7560'.

<u>1980</u>

Dam No. 2B, a cycloned tailings dam, was built in the area just in front of Dam No. 2A to an elevation of 7580'. It was subsequently covered when Dam No. 2A was raised to an elevation 7584' in 1981-1982. The area north of Dam No. 2 was covered in the 1986, and the 1991 airphoto shows established vegetation on the area.

<u>1981-1982</u>

"New" Dam No. 1C was built from earth fill material. It was stepped back from (south of) "old" Dam No. 1C, and raised to its present elevation of 7584'.

Underground operations commenced.

<u>1983</u>

Open pit operations ended.

<u>1984</u>

The tailings inspection report reported a 50:50 split in the tailings deposition between Section 36 and Section 35, it is believed to be more of a 60:40 split in the long term, the larger amount being deposited in Section 36.

<u>1986-1989</u>

No tailings were discharged between February 28, 1986 and October 12, 1989.

<u>1990</u>

Dam No. 5A was constructed in the old west decant channel on the north side of Dam No. 3A. It was made of earth fill and reached an elevation of 7525' and was designed to be raised to an elevation of 7540'. Deposition behind Dam No. 5A commenced in March 1991 and continued until January 1992.

<u>1992-1996</u>

No tailings were discharged between January, 1992 and October, 1996. An interim soil cover was placed on the tailings in Sections 35 and 36.

<u>1996</u>

Deposition of tailings re-commenced in mid October, 1996 behind Dam No. 5A.

<u>1997-present</u>

Current deposition is behind Dam No. 5A.

The chronological study of tailings deposition at Questa was undertaken in order to determine where boreholes should be located for sample collection for the geochemical studies in order to intersect tailings representative of every year of tailings production. Four borehole locations were selected (Figure 3-8). Borehole 1 (BH1) was located to transect the tailings deposited between 1966 and 1970 which represents the oldest tailings produced during open pit operations as well as surface tailings exposed to atmospheric oxidation for the greatest period of time. The second and third boreholes (BH2 and BH3) were located in original valleys so as to intersect the entire cross section of tailings deposition in each of the two impoundments, from 1971 to 1991 for BH2 and from 1966 to 1991 for BH3. The fourth borehole was also located overtop of an original valley in an area predominantly comprised of slimes.

A graphical representation of the estimated year of deposition for those tailings sampled from each of the four boreholes is provided in Figure 3-9. Together, samples from these boreholes are believed to be representative not only of every year of tailings production at Questa, but also of each of the tailings types and grain sizes, andesites, aplites and slimes (see Section 3.1.2.2 below). Figure 3-10 is a comparison of the number of samples collected for each year of production and the total tonnage of tailings produced during each year. From this figure it can be seen that although the sampling program was biased with respect to older tailings and surface tailings, every year of tailings deposition is represented by the samples collected. A total of 463 tailings samples varying in weight between 2 and 25 lbs depending on the sampling technique used (Table 3.2), have been collected since February, 1996 to represent 25 years of tailings production at Questa, or approximately 96 million tons of tailings. According to Levinson (1980), a simple statistical formula used in exploration geochemistry to determine the number of class intervals needed to represent a certain number of samples is given by:

$[k] = 10 \times \log_{10}N$

Where [k] is the number of intervals within the population and N is the number of samples. In this case, the number of class intervals is known and is equal to the number of years of deposition, i.e. 25 (from 1966 to 1991). Using this equation then, the number of samples that would statistically be represented by 25 intervals (years) would be given by:

$\log_{10}N = [k]/10$

$\text{Log}_{10}N = 25/10$

N = 316 samples.

The actual number of tailings samples collected is 147% of the statistically representative number of samples and is therefore considered to be representative of the entire chronology of tailings deposition at Questa.

Levinson also recommends the ideal amounts of each sample, for fine grained, relatively homogenous materials such as tailings, is approximately 500 grams (~ 1 lb). Therefore, the size of tailings samples collected at Questa is considered to be more than adequate. These statistical conclusions are supported by statistical analysis of certain geochemical parameters (i.e. NP, AP and metals concentrations) and are discussed in greater detail in Appendix C.

The sampling program was designed for the physical and geochemical characterization of the tailings which was intended to determine the present and long term acid generating potential of the tailings. Therefore the bias was towards older and surficial tailings, as mentioned above. This sampling design was conservative in that those tailings subjected to the longest period of natural oxidation, and those tailings most susceptible to atmospheric oxidation and therefore acid generating potential were more heavily sampled. The results of the physical and geochemical characterization are presented in detail in the following section.

Table 3.2.
Summary of Tailings Sample Collection.

Sample ID	Date Collected	Weight	Method of Collection	Comments
T-l to T-24	February, 1996	2 to 5 lbs each	excavated with a shovel and placed in clean plastic bags	21 samples in total.
VC1- to VC6-	February, 1996	1 foot to 9 foot intervals collected	collected with a vibracore drill rig (with 10 foot length hollow barrel) and placed in clean plastic bags	depths of up to 26.5 feet sampled. 21 samples in total.
BH1- to BH4-	December, 1996	1 foot intervals or 5 to 50 foot composites	collected using an AP2000 reverse circulation hammer drill rig, samples placed in clean plastic bags in 5 gallon buckets	BH1 to 180 feet; BH2 to 135 feet; BH3 to 128 feet; BH4 to 180 feet. 402 samples in total.
T-25 to T-32	December, 1996	approx. 10 to 25 lbs each	excavated with a shovel and placed in 5 gallon buckets	sampled to extend surface sampling coverage. 9 samples in total.
97-T-l to 97-T-7	May, 1997	approx. 2 to 5 lbs.	excavated with a shovel and placed in clean plastic bags	geotechnical and geochemical testing. 7 samples in total.
T4(1)(2)T5(1)(2)(3), T3/971-6 Comp, 1341197-l	quarterly samples for first 3/4 of 1997			fresh tailings samples. 3 samples in total.

3.1.2.2 Physical Characterization Studies

A total of 32 tailings samples were analysed for standard grain size analyses (ASTM D422) to characterize the spatial distribution of the tailings at the surface of the impoundments according to size fraction. Only those tailings samples collected from the near surface were selected for analysis. Figure 3-8 shows the sampling locations of the various near-surface tailings samples. These tailings samples had been originally collected from 1995 to 1997 for geochemical and hydrological testing (see SRK, 1997a; RGC 1997a). The grain size analyses of most of these samples were performed in February of 1998 in the SRK Denver laboratories. The laboratory results are summarized in Appendix H.

The tailings were subdivided into three classes:

i. *coarse tailings* with <50% fines content (where fines constitute silt and clay sized particles with a grain diameter smaller than 0.075 mm (# 200 mesh));

ii. *intermediate tailings* with 50%< fines content <80%; and

iii. *fine tailings* with >80% fines.

The spatial distribution of these tailings classes in the tailings impoundments behind Dam No. 4 and Dam No. 1/1C was inferred using these laboratory results, surface topography (indicating beaches), current extent of surface ponding and our general understanding of the operation of these tailings impoundments.

The estimated relative coverage of the coarse, fine and intermediate tailings in the two impoundments is shown in Table 3.3. It is seen that both tailings impoundments show very similar coverages of the three tailings classes. The coarse tailings dominate with about 2/3 of the total surface area. The fine tailings comprise only about 12% of the present tailings surface area. The estimate of fine tailings coverage is considered conservative (high) in that all currently ponded areas were assumed to be underlain by fine tailings (very few samples were available in the pond areas).

It should be noted that the ‘fine tailings’ of the Questa impoundment are not as fine as observed elsewhere as a result of the overall coarse grind of the ore. According to the USCS classification the ‘fine tailings’ of the Questa impoundment are classified as silt (ML) with typically only about 30% clay (<0.002 mm) (see Appendix H). The strength of the ‘beach’ material is a good indicator of the materials on the beaches. A person is able to walk out onto the sandy coarse and intermediate tailings beaches almost to the current pond edge (Photos 10 and 11). It has also proven possible to cover these areas with alluvial cover materials using conventional scraper equipment.

Table 3.3.

Relative Coverage of coarse, intermediate and fine tailings.

Tailings Impoundment	Surface Area (in ha)	Relative Coverage by Tailings Class (in %)		
		coarse tailings (<50% fines)	intermed. tailings (50%<fines<80%)	Fine tailings (>50% fines)
behind Dam Nos. 1/1C	119	65%	23%	12%
behind Dam No. 4	102	61%	27%	12%
TOTAL	221	63%	25%	12%

3.1.2.3 Geochemical Characterization Studies

a) Investigation and Sampling

Initial geochemical characterization of the tailings, consisting of field and static tests, took place from the fall of 1995 until the spring of 1996 and was reported in SRK Report 09208.04, “Questa Tailings Disposal Facility Assessment of Acid Generating Potential” (March, 1996). Subsequent geochemical characterization of the tailings was undertaken from the winter of 1996 until the fall of 1997, and consisted of extensive sampling as well as field tests and laboratory based static and kinetic tests. Fieldwork performed for sample collection for this stage of tailings characterization was described in SRK Report No. 092008.04/2, “Questa Tailings Disposal Facility Drilling Report and Preliminary Cover Modeling Interim Report” (January, 1997). Phase I of the investigation presented the field test results and the initial results of static testing and was presented in SRK Report 09211/1, “Questa Tailings Disposal Facility, Geochemical Testing, Interim Report” (June 30, 1997). Phase II of the geochemical investigations included additional static testing and subsequent kinetic tests and were reported in SRK Report No. 09211/2, “Questa Tailings Facility Geochemical Testing, Final Report” (November 4, 1997).

The objectives of the program were to:

- Characterize the current state of weathering and the prevailing geochemical condition of the tailings throughout the facility;
- Assess the mineralogical behavior of the tailings;
- Determine the overall future potential for acid generation or acid neutralization of the tailings;
- Assess the potential for localized zones with net acid generating characteristics;

- Estimate rates of sulfide mineral oxidation reactions in the tailings;
- Identify potentially soluble constituents that may be present in the tailings or may be generated from oxidation; and,
- Identify possible solubility controlling mineral phases that may control constituent concentrations in the tailings pore water.

Numerous samples of the tailings (463 in total) have been collected through the various stages of the geochemical investigation in order to achieve the above objectives. A summary of the samples collected from the tailings impoundments, dates collected and methods of collection, is provided in Table 3.2. All sample locations are shown in Figure 3-8.

In addition, as part of an ongoing program being carried out under Molycorp's Discharge Plan 933, weekly samples of current tailings are collected at the mill. These samples are then composited into a single sample for each quarter and submitted for analyses of metals concentrations and acid generation potential. Molycorp reports these results to the NMED on a regular basis. Those results that were available have been included in the joint SRK-RGC tailings investigation.

b) Background

The Questa Tailings Facility has been in operation since mining commenced in 1965 and is planned for closure in about 2020. The mining history and depositional history of the tailings, as discussed in the previous section, are intimately related. The variability in the geochemical composition of the ore zones that have been mined at Questa has resulted in moderately different (geochemically) tailings types within the tailings facility. Ore has been mined from either andesite or aplite host rocks. At any one time a mixture of the two ore types was mined with the relative proportions varying from predominantly aplite to predominantly andesite. The mineralogy of the two rock types is somewhat similar except that the andesites have a lower silicate content and higher concentration of mafic (dark) minerals. The andesites at Questa also have a slightly higher sulfide content than the aplites. These mineralogical differences are reflected in the tailings and formed the basis for tailings identification in the field.

Tailings can also be differentiated based on grain size (e.g. sands versus slimes). This physical characterization is relevant for understanding the physical behavior of the tailings including permeability and drainage rates and air and oxygen entry and oxidation potential. Since most of the tailings are produced from mixtures of aplite and andesite ore, a classification based on the relative abundance of minerals characteristic of each rock type is more descriptive of the tailings geochemical characteristics. Aplite and andesite tailings are tailings identified as predominantly tailings from aplite or andesite ore respectively.

During milling, lime is added to maintain a relatively high pH. The high pH of the tailings prevents bacterially catalyzed oxidation of sulfides from occurring. During active placement of the tailings in the impoundment, the tailings beaches are continually covered with fresh, high pH tailings. This effectively prevents any rapid surface oxidation and maintains alkaline pH values as long as the tailings remain saturated. At depth, oxidation is limited by the limited penetration of oxygen both during and after tailings are discharged in the impoundment. Therefore, tailings oxidation is generally limited to surficial exposures after discharge ceases.

Throughout the tailings depositional history, mining operations were occasionally shut down due to the fluctuating prices of molybdenum. Therefore, interim layers within the tailings were sometimes exposed to air and oxidation for some time (years) prior to the restart of deposition of successive layers of tailings. Some oxidation would have occurred in these layers. The time period for which interim surfaces were exposed to weathering is short compared to the time period that the existing surface tailings were exposed to oxidation (from 6 to more than 25 years). Therefore, the effect of oxidation in these layers is considered to be minimal and inferences of long term oxidation trends and geochemical changes in the tailings can best be made from examination of current near surface tailings samples.

c) Results

The results of the geochemical characterization of the tailings were presented in detail in various reports (SRK 1996, SRK 1997b and SRK 1997c) and are summarized in Appendix C. The testing program included:

- Paste pH and Conductivity Measurements;
- Mineralogical Characterization (including petrography and X-ray diffraction analyses);
- Total Metals Concentrations;
- Acid Base Accounting;
- Leach Extraction Tests;
- Enhanced Peroxide Oxidation Tests;
- Humidity Cell Tests; and,
- Geochemical Speciation Modeling.

A summary table listing the number of samples subjected to each of the above tests is provided in Table 3.4. A discussion of the interpretations and implications of these results as pertaining to the Revised Closure Plan for the Questa Tailings Facility is presented in Appendix C and the primary conclusions are as follows.

d) Conclusions

The conclusions from the static testing program can be summarized as follows:

Static tests are conducted to characterize the mineralogy and geochemistry of the tailings and indicate whether or not there is a ‘potential’ for a sample to generate net acidity and metal production. These tests define the balance between the acid generating minerals (sulfides) and acid consuming minerals (predominantly carbonates) in a sample. These tests provide a preliminary and approximate means of classifying the acid generating potential of tailings. Those samples for which static test procedures indicated uncertainty with respect to acid generating potential were typically further characterized by kinetic test methods (see below).

Sampling

The Questa tailings are geochemically similar mixtures of aplite and andesite tailings. The purpose of the sampling program was to obtain representative samples from throughout the impoundment so that the geochemical nature and variability of the tailings could be determined. The 463 tailings samples collected are considered to be statistically representative of the entire tailings facility. Subsets of these samples were subjected to various testing procedures as shown in Table 3.4.

Mineralogy

The mineralogical composition of the tailings consists predominantly of quartz, plagioclase feldspar, potassium feldspar and biotite with lesser amounts of chlorite, amphibole, calcite and sulfide minerals. The sulfide minerals include pyrite, sphalerite, chalcopyrite and molybdenite with trace amounts of galena, covellite and pyrrhotite. Minor amounts of fluorite and muscovite are also present in the tailings, along with traces of magnetite, apatite, and secondary minerals of gypsum, iron-oxyhydroxides and possibly native sulfur.

The minerals that are considered potential sources of acidity and dissolved metals are pyrite, chalcopyrite, molybdenite and sphalerite. Very minor alteration of pyrite and chalcopyrite were detected in some of the samples (5 of 10 samples) characterized by mineralogical analysis. These samples also contained excess calcite and had near neutral paste pH values indicating acid production is effectively neutralized. One sample showed slight dissolution of molybdenite.

The minerals that likely contribute to the laboratory neutralization potential, determined using a concentrated strong acid, include calcite, biotite, plagioclase feldspar and minor clay. Of these calcite is the most important since it is currently buffering the porewater in the tailings to near neutral values.

Table 3.4.
Summary of Testing at Various Investigation Stages.

Testing Method	Number of Samples Tested			
	Acid Generating Potential Assessment (SRK 1996)	Geochemical Testing Program Phase I (SRK 1997b)	Geochemical Testing Program Phase II (SRK 1997c)	Gechemical Speciation Modeling (SRK 1997c)
STATIC TESTS				
Paste pH	42	402		
Paste Conductivity	42	402		
Acid Base Accounting	42	36	10	
Metals Concentration by ICP	12	14		
Petrographic/XRD	A	6		
Leach Extraction	18	16	7	5
KINETIC TESTS				
Humidity Cells			9	8
modified NAG test			5	

Current acidity condition

The Questa tailings are currently **not** acid generating, the pH of the tailings is consistently near neutral for all samples (surface and at depth).

Moderate conductivity measurements in the borehole samples indicate that, although the pH is near neutral, ongoing oxidation is occurring in the exposed tailings and those immediately beneath the present cover. The results also indicate a significant decrease in the rate of oxidation with time.

Solute quality

Leach extraction tests indicated that readily soluble constituents associated with the tailings include Al, Ca, Mg, Mn, Mo, K, Na, Sr, and SO_4. The primary "contaminants" (i.e. elements with concentrations greater than those defined by the New Mexico groundwater standards) occurring in the tailings leachate are F, Mn, Mo and SO_4.

Potential for acid generation

Acid/base accounting (ABA) tests are typically used as an initial screening of a sample's potential to generate acid. The test involves the determination of neutralization potential (NP) and acid generation potential (AP) both in kg $CaCO_3$ equivalent per tonne. Theoretically, when the NP and AP are equal (i.e. 1:1 ratio), the system should be balanced and no acid generation should occur. In practice a 1:1 ratio is not always sufficient. The exposure and reactivity of the alkali minerals and the sulfides may be unequal. If the sulfides are preferentially exposed and more reactive than the alkali, then an increased ratio of NP to AP is required to ensure that there is sufficient exposed alkali to react with the exposed oxidized sulfides. Technical guidelines such as the B.C.Acid Mine Drainage Task Force Report "Draft Acid Rock Drainage Technical Guide" have quoted an NP/AP ratio of 3:1 as being the 'cut-off' between acid consuming and uncertain acid generating potential materials. This value was first derived as a guideline for waste rock characterization where sulfide minerals that contribute to the AP are often typically well and preferentially exposed on joints whereas the neutralizing minerals are locked up in calcite veinlets or host materials and not accessible to neutralize the acidic pore waters. There is also a great variability in the NP:AP ratio through a waste rock dump. Thus a dump with an average NP:AP ratio of 3:1 may well have significant zones with ratios that are substantially less than this. Tailings, as a result of the blending, mixing and grinding of the ore, are finer grained and homogenous relative to waste rock. The neutralizing minerals are exposed, available, and located near to oxidation sites (sulfides). Therefore neutralization in tailings is much more effective than in waste rock. NP/AP values above 1.5 are considered to be likely acid consuming. This value was used for initial classification of the Questa tailings. The validity of this assumed cut-off value was checked by performing kinetic tests on samples with NP:AP ratios greater and less than 1.5:1 as discussed below.

Based on the distribution of all the samples tested for acid/base accounting (ABA), using a defining NP/AP ratio of 1.5, approximately 80% of the tailings were initially characterized as acid consuming, 14% were considered uncertain, and 6% were considered to be potentially acid generating. The predominantly andesitic tailings have higher sulfide-sulfur contents and a higher potential to generate acid than the slimes tailings or aplite tailings.

If static testing results only are considered, then the following conclusion may be reached. Isolated very localized thin layers of net acid generating potential exist if alkalinity controls are not provided by alkali leachates from overlying layers of tailings. These potentially acid generating layers are predominantly on or near the current tailings surface, and are a result of unusual conditions of mining immediately prior to mill shut down. Overall, the tailings deposit is strongly net acid consuming. Any potential acidity generated in these shallow layers (should it occur) would be neutralized in underlying acid consuming tailings. Future burial of these surface tailings by additional acid consuming tailings will render the overall mass of tailings non-acid producing.

The conclusions from the kinetic testing program can be summarized as follows:

Kinetic tests were conducted to increase the understanding of kinetic controls on potential acid generation, particularly for samples classified, from static tests, as potentially acid generating or uncertain. They were also performed to help determine the weathering characteristics of representative samples and resultant leachate water quality with time. The results of the kinetic tests were used to re-interpret (validate) the preliminary assessment of the potential for acid generation deduced from the static testing. These tests are also used to estimate oxidation rates of sulfides. Laboratory based kinetic tests such as humidity cells are designed to approximately simulate field conditions, but with enhanced conditions of temperature and humidity to somewhat accelerate oxidation and observe the long term kinetic performance of the tailings.

Potential for acid generation

Enhanced peroxide oxidation tests (also referred to as Net Acid Generation Tests, or NAG tests, see Miller, 1997) use a strong oxidant (peroxide) to kinetically accelerate the oxidation process. In a sense they are ‘rushed’ kinetic tests. The test determines if there is sufficient alkalinity kinetically available to neutralize all the acidity generated when the reactive sulfides are all rapidly oxidized by the strong oxidant. Samples, which will buffer to pH values greater than 4.5, are considered acid consuming.

Five enhanced peroxide oxidation tests were performed on samples characterized as potentially acid generating or uncertain based on ABA results to validate the use of an NP/AP ratio of 1.5:1. The NP:AP ratios for these samples ranged from 1.67 to 0.64. The results indicated that three of five samples tested (NP:AP’s = 1.67, 1.11and 0.64) would in fact be acid consuming, only one sample (NP:AP = 1.37) would be classified as potentially acid generating with low capacity and one sample (NP:AP = 1.14) would remain in the “uncertain” area. Based on the kinetic results, the approximate percentages of acid consuming and acid generating tailings given above would be refined to approximately 90% acid consuming, 7% uncertain and 3% potentially acid generating (low capacity). These results indicate that the ‘cut-off’ in NP/AP ratio for classification potentially acid generating for the Questa tailings of 1.5 to 1 is conservative.

Nine humidity cell tests were conducted on samples with NP:AP ratios ranging from 4.2 to 0.42. The leachate from these cells maintained long term pH values between 7.8 and 8.2. Thus alkalinity release from the dissolution of calcite in the humidity cells is rapid (compared to natural rates of oxidation), and buffers the leachate pH to above 7.0. This indicates that neutralizing carbonates are readily accessible to buffer acidity produced by natural sulfide oxidation.

An advantageous situation exists at Questa because the entire tailings facility has been exposed to surface oxidizing conditions for at least 6 years and a substantial area of tailings (22 acres) for more than 27 years. The tailings impoundments are of themselves 'large humidity cells', or a huge field based kinetic test. The surface tailings at Questa, which have been most susceptible to oxidation processes, have remained grey in color and are consistently circum-neutral with respect to pH. They are net acid consuming and, in terms of kinetics, have been so for 27 years.

Oxidation rates and conditions

The overall oxidation rates for the tailings were calculated to be between approximately $2x10^{-8}$ and $9x10^{-9}$ kg $O_2/m^3/s$. These rates are low compared to rates reported in the literature.

The preference of oxidation of the primary sulfide minerals is estimated to be as follows:

Pyrite/pyrrhotite > molybdenite > sphalerite > arsenopyrite.

Conclusions based on <u>geochemical modeling</u> can be summarized as follows:

Geochemical modeling was performed to enable estimates to be made of the likely quality of tailings pore water (seepage) that will develop in the field as a result of on-going sulfide oxidation in the tailings. Modeling was based on the chemical analyses of the tailings solutes (from static testing) and leachates (from the kinetic testing) and was performed using standard modeling codes such as MINTEQA2 (Allison et al., 1991) to evaluate water quality over the long term. Predictions made, based on the results of the geochemical modeling, were in part done by and reviewed by J. Chapman, a specialist in solution chemistry, and are presented in detail in Appendix D.

Leachate quality

The possible solubility controlling mineral phases, that may be limiting the release of metals from the tailings under field conditions, include basaluminite and possibly alunite (Al), barite (Ba), celestite (Sr), fluorite (F), iron oxy-hydroxides (Fe), rhodochrosite (Mn), otavite (Cd), cerrusite (Pb), malachite (Cu) and gypsum (Ca, SO_4).

Although sulfate pore water concentration is controlled by the formation of gypsum, the presence of magnesium in solution results in sulfate concentrations exceeding typical gypsum equilibrium conditions. Sulfate concentrations in the medium and long term are expected to be in the order of 3,000 mg/L.

No solid phase control was indicated for molybdenum, but in conventional water treatment technology, molybdenum is coprecipitated from solution with ferric oxy-hydroxides. Molybdenum solubility may be controlled in the field by the formation of oxy-hydroxides which were identified by petrographic analysis. Secondary solubility controlling phases for molybdenum were not included in the MINTEQA2 database. However, there appears to be a solubility controlling mechanism as indicated by the leach extraction test concentrations. Molybdenum concentrations in the pore water are expected to be in the order of 5 to 6 mg/L.

Oxidation Rates and Conditions

It is reasonable to determine the rate of oxidation from sulfate release from the humidity cells. This rate is not expected to increase in the moderate to long term.

Diffusion calculations indicate that oxygen diffusion through a soil cover is inversely controlled by the moisture content of the cover. Diffusion is also controlled, to a lesser extent, by cover thickness. A cover thickness of 2 to 3 feet at a moisture content of 20 percent is anticipated to be less effective than a 1 foot cover with a moisture content of 25 percent.

e) Interpretation

The distribution of the ABA results, together with the kinetic behavior of the tailings, suggest that the Questa tailings are predominantly acid consuming. There may be rare, localized thin layers of tailings which, in isolation, could be potentially acid generating. However, the potential for acid generation in such localized layers, sandwiched between layers of acid consuming tailings is very low. Any minor amounts of acidic leachate, should it develop in such a localized thin layer, would be neutralized by the excess neutralization potential in underlying layers through which seepage would migrate. The overall tailings deposits are net acid consuming and the expected leachate quality is given in Table 3.5.

Table 3.5.
Calculated Tailings Pore Water Chemistry.

PARAMETERS (mg/L)		NEAR SURFACE SAMPLES (ABOVE 20FT)					SAMPLES FROM DEPTH (BELOW 20 FT)				
		T-24B	T-I 3	vc-3, IO-15	average	std. dev.	BHI-135	BH1-40	BH3-69	average	std. dev.
Aluminum	Al^{+3}	0.04	0.07	0.07	0.06	0.02	0.12	0.13	0.06	0.10	0.04
Antimony	Sb^{+3}						0.020	0.020		0.020	0.000
Arsenic	As^{+3}	0.010			0.010		0.010		0.020	0.015	0.007
Barium	Ba^{+2}	0.005	0.005	0.233	0.081	0.132	0.264	0.005	0.272	0.181	0.152
Cadmium	Cd^{+2}	0.007	0.007	0.006	0.007	0.000			0.007	0.007	
Calcium	Ca^{+2}	330	317	277	308	28	270	321	291	294	25
Carbonate	CO_3^{-2}	256	149	203	203	54	125	76	212	138	69
Chromium	Cr^{+2}	0.113			0.113						
Copper	Cu^{+2}	0.18	0.11	0.11	0.13	0.04	0.08	0.08	0.08	0.08	0.00
Fluorine	F'		2.1	2.4	2.3	0.2	2.3	1.7	2.0	2.0	0.3
Iron	Fe^{+2}	0.113	0.113		0.113	0.000	0.081			0.081	
Lead	Pb^{+2}	0.356			0.356						
Magnessium	Mg^{+2}	488.5	270.0	263.5	340.7	128.1	175.7	56.1	110.0	113.9	59.9
Manganese	Mn^{+2}	5.10	1.57	0.45	2.37	2.43	4.12	4.51	4.47	4.37	0.21
Mercury	$Hg2^{+2}$		0.006		0.006						
Molybdenum	Mo^{+6}	15.24	43.77	85.29	48.10	35.23	47.93	4.42	21.42	24.59	21.93
Nickel	Ni^{+2}	0.451			0.451			0.077		0.077	
Potassium	K^{+1}	108.6	203.7	374.2	228.80	134.57	241.8	163.4	360.2	255.14	99.05
Selenium	Se^{+6}	0.040			0.040		0.039	0.008	0.015	0.021	0.017
Silver	Ag^{+1}								0.317	0.32	
Sodium	Na^{+1}	29.70	48.09	198.75	92.18	92.74	288.52	69.20	140.26	165.99	111.90
Strontium	Sr^{+2}	11.05	10.42	8.41	9.96	1.38	8.07	6.22	9.14	7.81	1.48
Sulfate	SO_4^{-2}	2614	2266	3083	2654	410	2940	1610	2285	2278	665
Zinc	Zn^{+2}	1.80	0.45	0.22	0.83	0.85	0.08	0.08	0.31	0.16	0.13
TDS (calculated)		3862.18	3312.56	4496.22	3890.32	592.33	4104.07	2312.77	3436.81	3284.55	905.31
pH(measured)		7.1	7.3	7.3	7.23	0.12	7.5	7.5	7.2	7.40	0.17

3.1.3 Interim Covers

Following the shutdown of tailings operations in the early 1990s the drying of the tailings beaches resulted in wind erosion and dust from the tailings beaches. To control such dusting a program of interim cover placement was implemented. This comprised the placement of 9 inches of alluvial gravel material onto the tailings beaches (see Photo 12) followed by the establishment of vegetation on these covers (Photo 14). The tailings surface between Dam 1 and Dam 1C had been capped in a similar manner prior to 1974 (Photo 16). The extent and timing of cover placement over the beaches between 1992 and 1998 is shown on Figure 3-11. The table insert on that figure summarizes the areas and time of cover placement.

The coarse sand beach areas are accessible to construction traffic shortly after placement (see Photo 9). The intermediate beach areas require some desiccation prior to allowing construction equipment to travel on them but have also proven to be readily accessible to heavy construction equipment such as scrapers (see Photo 10).

The placement of the interim cover provides an excellent 'full scale field trial' which demonstrates the constructability, cost and performance of this cover type.

The cover material is alluvial gravels borrowed from the impoundment area and typical of the extensive deposits of this nature available locally. The gravel content of the cover material renders it very effective for the long term control of both wind and water erosion (Photo 15). The small clay content gives sufficient cohesiveness to prevent dust erosion and the gravel content provides physical protection from both forms of erosion. The problem with dust has been entirely eliminated with the placement of these interim covers. No evidence of water erosion has been observed on the covers over the 6 years of their existence. The success of the relatively modest re-vegetation program that has been implemented is readily apparent (see Photos 14 to 20).

3.1.4 Tailings Water Treatment and Discharge

Each of the tailings ponds behind Dams 1 and 4 were discharged to a decant channel via decant structures. In earlier years the decant channel discharged over the right abutment of Dam 4 to Pope Lake and its downstream drainage (Outfall 001). With the requirement that process water be treated prior to discharge it has been necessary to install a concrete weir in this channel. The weir provides a means of regulating the pond elevation, provides additional settling of the tine solids and maintains, if required, a steady head for the feed along a 12 inch diameter steel pipe into the ion exchange plant (see Figure 3-20 for location of Pope Lake and IX plant).

The ion exchange water treatment plant (IX building) was constructed alongside Pope Lake In 1983 (Photo 3). Figure 3-12 shows a flow diagram outlining the principle of the ion exchange system for treatment of tailings process water.

The feed solution is adjusted to a low pH (3.5 to 4.0) using acid reagents. The feed then flows into the ion exchange column and moves upflow through four stages and overflows through a resin trap and into a tails tank. Overflow from the tails tank flows to a baffled launder where powdered lime is added by one or two screw feeders connected to the lime storage silo to control the pH of the tail solution to between pH 6.0 to 9.0 prior to it being discharged into Pope Lake. Discharge from Pope Lake (Outfall 001) is through a concrete weir with a head gate.

When the resin in the first stage of the column becomes loaded with molybdenum (approximately 2 days for 4000 gpm or 16 days at 500 gpm) the feed is stopped and the resin is exchanged and eluted using a sodium hydroxide solution. Precipitation of the molybdenum from the pregnant eluate is accomplished by the addition of calcium chloride. The precipitate is transferred onto a Vacuum Pan Filter and the filter cake is loaded into drums and disposed of.

3.1.5 Seepage Interception System

Over the last 25 years a seepage interception system, consisting of shallow drains and extraction wells, was progressively developed downgradient of Dam 1 in order to intercept seepage originating from the tailings impoundments. Figure 3-13 shows the location of the various components of the present interception system.

The first seepage barriers (seepage barriers #1 and #2) were installed in 1975. Seepage barrier #1 consists of a series of shallow trenches, excavated to a clay layer, backfilled with sand and plugged with two feet of tamped earth, along the western side slopes of the Dam 1 arroyo (Figure 3-13). These shallow drains intercepted small seeps originating from the tailings, which were deposited during that time behind Dam 4. This seepage flows along permeable sand and gravel beds on top of clay layers in the alluvial sediments. All intercepted seepage from these drains drained by gravity into the common collector pipe and through Outfall 002 into the Red River (Figure 3-13). These shallow drains dried up once sufficient tailings had been deposited to effectively seal the alluvial ridge, which represents the natural embankment for the tailings in the eastern portion of the Section 35 Tailings Area.

Seepage barrier #2 (called 002 in earlier NPDES permits) consists of a 15-20 feet deep, 14 feet wide and 200 feet long trench excavated across the center of the Dam 1 arroyo (Figure 3-13). The trench was backfilled with five feet of fine alluvial material as seal on the downstream side, four feet of rock drain and five feet of suitable filter material on the upstream side. Seepage is collected in a perforated drain pipe embedded in the rock drain, and flows by gravity into a 10” collector pipe and through Outfall 002 into the Red River (Figure 3-13). This seepage barrier appears to be very effective and currently intercepts much of the shallow seepage originating from the Section 36 Tailings Area (behind Dam 1) (see below).

In the late 1970s, seepage barrier #3 (called 003 in earlier NDPES permits) consists of a 10-20 feet deep, 10 feet wide and 50 feet long trench excavated across a side valley to the west of the arroyo below Dam No. 1 (Figure 3-13). Drain construction is similar to that of barrier #2 with a PVC seal on the downstream side, and backfill consisting of rock material and suitable filter material on the upstream side. This barrier collects shallow seepage originating from the tailings behind Dam 4. It runs by gravity in a 10” diameter pipe to the common collector pipe and flows through Outfall 002 into the Red River.

An additional seepage barrier (#3a) excavated a few hundred feet downgradient (to the east) in the mid 90's (see Figure 3-13) did not collect any seepage suggesting that the original barrier #3 is quite effective in intercepting shallow seepage flowing within this side valley.

In 1996, an additional seepage barrier (#2A) was installed in the Dam 1 arroyo several hundred feet south of seepage barrier #2 (Figure 3-13). This seepage barrier #2A (also called 002A) consists of a trench excavated to clay (at about 20 feet depth), backfilled with 10 feet of gravel and 10 feet of earth material. An 8" diameter perforated pipe collects seepage at the base of the backfilled trench. The collected seepage flows by gravity into a pump sump from where it is pumped to a manhole where it joins the common collector pipe and flows through Outfall 002 into the Red River (Figure 3-13).

Water quality sampling of the intercepted seepage at Outfall 002 indicated that the network of interceptor drains is very effective in collecting tailings seepage with elevated concentrations of soluble oxidation products such as sulfate, TDS and molybdenum. For example, sulfate concentrations for the intercepted seepage are in the order of 800 to 900 mg/l (compared to 20 mg/l in the unimpacted groundwater) suggesting that about 70% of all intercepted shallow seepage comprises tailings seepage (see Appendix A for more details). In 1993 the total flows intercepted by the seepage interception system were about 260 gpm (0.6 cfs) (Vail, 1993). In the fall of 1997, just prior to pumping from the extraction wells, the interception rate had dropped to about 200 gpm (0.45 cfs) (Molycorp, unpubl. data), presumably as a result of reduction in seepage from the tailings impoundment due to the mine and mill closure from 1992 to 1996 and interim cover placement on the tailings impoundment.

A series of extraction wells were installed in the mid-90s to collect additional seepage not intercepted by the shallow interceptor drains. In the fall of 1994, four extraction wells were installed in the Dam 1 arroyo downgradient of Dam 1 (EW-1 to EW-4, see Figure 3-13). All four extraction wells were constructed using 8" PVC casing and screen. Table 3.6 provides further installation details of these extraction wells. These extraction wells were monitored for three years prior to installing pumps and piping to connect them to the interception system (see below). The water quality monitoring indicated that EW-1, EW-3 and, to a lesser extent EW-4, intercept groundwater impacted by tailings seepage, i.e. with elevated sulfate and TDS concentrations (see Section 3.1.6). The groundwater intercepted in the deep extraction well EW-2 showed no signs of tailings seepage with soluble oxidation products such as sulfate at ambient background levels (see Section 3.1.6).

In the fall of 1997, a series of four shallow extraction wells were installed at the toe of Dam 1 (EW-5A to 5D, see Figure 3-13). All four extraction wells were constructed using 4" PVC casing and screen. Table 3.6 provides further installation details of these extraction wells. Initial water quality sampling in these wells indicated that the shallow seepage intercepted represents predominantly seepage from the tailings impoundment (sulfate concentrations ranging from 900-1200 mg/l; see Section 3.1.6 on Groundwater Monitoring for more details)

After completion of the installation of the EW-5 extraction well series in September 1997 all eight extraction wells were fitted with submersible pumps and the discharge lines were hooked up to the existing seepage interception system (Figure 3-13). The pumping rate in any given extraction well is controlled by the size of the pump installed. In order to protect pumps from running dry pump operation is controlled automatically by using Coyote switches. These switches turn off the pump as soon as the pump does not pump water and restarts the pump after a chosen time interval during which the water levels in the well are allowed to recover (Souder, Miller & Associates, 1997). Flow meters were installed on the extraction wells in order to measure pump rates. Table 3.7 summarizes the pumps installed and provides recent estimates of flows intercepted by various components of the interception system (March 1998). Note that the deep extraction well EW-2 is no longer pumped because it intercepts deep, unimpacted groundwater. Molycorp is planning to use this well in the future for monitoring purposes only.

The total seepage flow intercepted with the existing interception system is about 260 gpm (or 0.58 cfs) as of March 1998. Assuming for the moment no seasonal fluctuations in seepage, the addition of the eight extraction wells would have increased the total rate of intercepted seepage by about 30% (from about 200 gpm to 260 gpm). The data also suggest that pumping of the extraction wells reduced the amount of shallow seepage intercepted in the seepage barriers #2 and #2A located further downgradient. In particular EW-5A intercepts significant flows of shallow tailings seepage (Table 3.7) which is flowing in very permeable units of alluvial sands and gravels beneath the toe of Dam 1.

Current trends of water quality in monitoring wells located downgradient of the seepage interception system (e.g. MW-1, MW-2 and MW-12) suggest that the seepage interception system is effective in protecting groundwater downgradient of the Questa Tailings Facility (see Section 3.1.6). In addition, water quality monitoring of the Red River and near-by springs has shown that there is no significant impact on surface water quality (see Section 3.1.7). Molycorp will re-evaluate the seepage collection and extraction system after a period of one year as outlined in the Discharge Plan 933. If the existing seepage interception system is not adequately protecting downgradient groundwater quality within state standards, Molycorp will upon NMED's approval, upgrade its existing collection and extraction system or add additional seepage barriers and/or extraction wells.

Table 3.6

Summary of Installation Details for Extraction Wells

Well No.	Ground Elevation (feet **a.s.l.)**	Total Depth (feet **b.g.s.)**	Screened Interval (feet)	Well Completed In	Reference
EW-1	7313'	157	57-83	basalt/basalt gravel	SPRI. 1995
EW-2	7300'	214	104 – 114 120-132 151 – 185	sandy gravel sandy gravel, gravelly sand, clay basalt gravel in clay	**SPRI. 1995**
EW-3	7317'	104	62-77	sandy clay/clayey gravel	**SPRI. 1995**
EW-4	7280'	58	42-58	clayey gravel	**SPRI. 1995**
EW-5A	~7318[2]	50	15-45	sand w/ gravel; sandy and gravelly clay	Souder, Miller & Associates, 1997
EW-5B	~7318[2]	50	15-45	gravelly sand; silty gravel, silt w/ clay	Souder, Miller & Associates, 1997
EW-5C	~7332[2]	59.4	24-54	silty, gravelly sand; silty gravel	Souder, Miller & Associates, 1997
EW-5D	~7347[2]	43	37.7 – 12.7	silty sand; silty gravel	Souder, Miller & Associates, 1997

Notes:

1. taken from Vail, 1997
2. estimated from topographic map

Table 3.7

Seepage Interception System - Summary of Collection System

and Estimated Flows Intercepted.

Component	Collection System		Estimated Flow (in GPM)
	Pump Model	**Pump Rating**	
Seepage barriers #1	gravity drainage		dry[1]
Seepage barrier #2	gravity drainage		135[4]
Seepage barrier #2a	Grundfos SP4” – ¾ HP	30 GPM	17[2]
Seepage barrier #3	gravity drainage		11[2]
EW-1	Grundfos SP4” – 1 HP	20 GPM	14[3]
EW-2	Grundfos SP4” – 1 HP	20 GPM	not pumped
EW-3	Grundfos SP4” – ½ HP	20 GPM	7.5[3]
EW-4	Grundfos SP4” – ½ HP	20 GPM	2[3]
EW-5A	Grundfos SP4” – 2 HP	60 GPM	7.5[3]
EW-5B	Grundfos SP4” – 2 HP	60 GPM	61[3]
EW-5C	Grundfos SP4” – ½ HP	20 GPM	2.4[3]
EW-5D	Grundfos SP4” – ¾ HP	20 GPM	not pumping[3]
TOTAL	-	-	**257[3]**

Notes:

1. no flow observed in fall 1997 during construction of new discharge lines
2. measured by Molycorp staff in early March, 1998
3. measured by Souder, Miller & Associates on March 1-3, 1998 (SMA, 1998)
4. discharge pipe under water; flow estimate from water balance of interception system

3.1.6 Groundwater Monitoring

Over the last twenty years of tailings operation, a total of 19 monitoring wells were installed down-gradient of the Questa Tailings Facility to monitor groundwater quality. Figure 3-14 shows the location of the various monitoring wells. Table 3.8 summarizes relevant installation details of these monitoring wells.

Little is known about the oldest monitoring wells (MW-A to MW-C) which are located immediately below the toe of Dam No. 1 (Figure 3-14). These very shallow wells were likely installed to monitor the effectiveness of the underdrain system of Dam No. 1. The shallowest well, MW-C, appears to be completed entirely within the underdrain layer of Dam No. 1. All three monitoring wells are listed as required sampling points for the groundwater monitoring program under the current discharge permit DP 933. However, only MW-A produces reliable water quality data (Table 3.8).

In 1979, a series of six monitoring wells (MW-1 to MW-6) were installed to monitor groundwater quality at the Questa Tailings Facility. MW-1 to MW-4 are located in the arroyo below Dam 1 (Figure 3-14) whereas MW 6 is located northeast of the Section 36 Tailings Area (approximately 3000 ft north of the village of Questa). The monitoring well MW-5 is lost (location unknown). Only very simplified geologic descriptions of the borehole cuttings are available and the screening intervals are unknown (Table 3.8). All six monitoring wells are listed as required sampling points for the groundwater monitoring program under the current discharge permit DP 933.

Table 3.8

Summary of Installation Details for Monitoring Wells

Well No.	Ground Elevation (feet a.s.l.)	Total Depth (feet)	Screened Interval (feet b.g.s.)	Well Completed In	Reference	Comments
MW-A	7310[1]	40	unknown	unknown	Molycorp, unpub. data	well not capped
MW-B	7312[1]	15	unknown	unknown	Molycorp, unpubl. data	not sufficient yield for sampling
MW-C	7314[1]	20	unknown	drain layer of Dam 1	Molycorp, unpubl. data	well plugged (overgrown)
MW-1	7283[1]	117	unknown	volcanics; volcanics and gravel	GeoWest Group, 1993	
MW-2	7279[1]	80	unknown	clay (and gravel?)	GeoWest Group, 1993	
MW-3	7298[1]	52	unknown	gravel and clay	GeoWest Group, 1993	
MW-4	7358[1]	102	unknown	gravel and clay	GeoWest Group, 1993	
MW-6	N/A	101	unknown	N/A	GeoWest Group, 1993	east of Section 35 Tailings Area (background well?)

Notes:

1. taken from Vail, 1997
2. estimated from topographic map
3. screening interval unknown

Table 3.8 (cont'd)

Summary of Installation Details for Monitoring Wells

Well No.	Ground Elevation (feet a.s.l.)	Total Depth (feet)	Screened Interval (feet b.g.s.)	Well Completed In	Reference	Comments
MW-7A MW-7B MW-7C	7318'	146	78-88 104 – 114 132 - 142	gravelly clay; sandy gravel gravelly clay sandy gravel; gravelly sands	SPRI, 1993	 casing collapsed not sufficient yield for sampling
MW-8	7372'	225	180-220	basalt; volcanic conglomerate	SPRI, 1993	plugged
MW-9A	7306'	147	33-43	clayey gravel; gravelly clay	SPRI, 1993	
MW-9B	7306'	147	115-145	clayey gravel; gravelly clay	SPRI, 1993	not sufficient yield for sampling
MW-10	7352'	129	94 – 124	clayey gravel; gravelly clay	SPRI, 1993	
MW-1 1	7343'	249	207 – 247	clayey gravel; gravelly clay	SPRI, 1993	
MW-12	7280'	234	203 – 234	basalt and gravel	SPRI, 1995	
MW-13	~7350[2]	229	212 - 222	basalt	SMA, 1997	
MW-14	~7340[2]	64	39 - 59	sand; gravel w/ clay; sandy clay	SMA, 1997	

Notes:

1. taken from Vail, 1997
2. estimated from topographic map

In the fall of 1993, the monitoring wells MW-7A to MW-11 were installed under the supervision of South Pass Resources Inc. (SPRI, 1993). MW-7A to 7C, MW-8 to MW-9 were completed at different depths in the alluvium of the arroyo below Dam No. 1 (Figure 3-14). Only MW-7A and MW-9A, however, yield sufficient water for sampling. The other wells do not yield water and/or the casing has collapsed preventing adequate groundwater sampling (Table 3.8). MW-10 was completed in the alluvial soils at the foot of the alluvial ridge to the southeast of the Section 36 Tailings Area (Figure 3-14). MW-11 was completed in the deep volcanics just south of Dam No. 4 (Figure 3-14). In the fall of 1994, an additional monitoring well (MW-12) was completed in the deep alluvium/volcanics of the Dam 1 arroyo under the supervision of South Pass Resources Inc. (SPRI, 1995). All monitoring wells installed by SPRI, with the exception of the destroyed MW-8, are listed as required sampling points for the groundwater monitoring program under the current discharge permit DP 933.

In the fall of 1997, two more monitoring wells were installed south of the Questa Tailings Facility under the supervision of Souder, Miller & Associates (SMA, 1997). MW-13 was completed in the deep volcanics immediately to the south of the Section 35 Tailings Area at the toe of Dam No. 4 (see Photo 6). MW-14 was completed in the shallow alluvial soils at the foot of the alluvial ridge to the southeast of the Section 36 Tailings Area (Figure 3-14).

As of the fall of 1996 all functional monitoring wells are being sampled quarterly and the samples are being analysed for field parameters, general chemistry and metals as outlined in the Discharge Permit 933 (see Appendix G for a complete listing of all quarterly groundwater monitoring data). Prior to this quarterly sampling, those monitoring wells existing at the time were also sampled once each in the fall of 1993 and 1994 (Appendix G). No data were available on earlier groundwater quality monitoring in those few monitoring wells installed prior to 1993.

Figures 3-15A to 3-15C show the sulfate, molybdenum and TDS concentrations observed over the last five years in several monitoring wells located downgradient from the Questa Tailings Facility. Figure 3-14 shows the location of these monitoring wells and Table 3.8 summarizes their screening depths. The groundwater monitoring indicates that seepage from the Questa Tailings Facility has resulted in a significant increase in the concentration of sulfate, molybdenum and total dissolved solids (TDS) in the shallow (perched) groundwater immediately downstream of the Section 36 Tailings Area in the Dam 1 arroyo) (see e.g. MW-A; MW-7A in Figures 3-15A to C). In contrast, the deep groundwater flowing beneath the Section 36 Tailings Area (in mixed layers of alluvium and volcanics) shows virtually no increases in those constituents (see e.g. MW-12 in Figures 3-15A to C).

The seepage pattern in the Dam 1 arroyo is further illustrated in Figure 3-16. Figure 3-16 shows an illustrative cross-section along the Dam 1 arroyo from the tailings impoundment south to Embargo Road. Also shown are recent sulfate concentrations observed in monitoring wells and extraction wells (prior to pumping of extraction wells in September 1997), in seepage barriers (in March 1998) and in boreholes drilled to the base of the tailings (in December 1996; RGC; 1997a).

The observed sulfate concentrations suggest that shallow seepage is dominated by tailings pore water with sulfate concentrations in the order of 900-1200 mg/l (Figure 3-16). The very steep vertical hydraulic gradients and aquitard layers evident from borehole logs suggest that this shallow seepage is perched, flowing along layers of silty clay and clayey silt within the alluvial sediments. Near-by outcrops and cuts in the alluvial sediments indicate that these aquitard layers consist of thin but horizontally extensive lenses of very fine sediments likely deposited behind debris dams of coarser alluvium (see Photo 13). With distance from the tailings impoundment, the tailings pore water gradually percolates downward, 'cascading' from one silt/clay lens to the next, as illustrated in Figure 3-16. In the process, the tailings seepage is mixing with more and more natural groundwater flowing at greater depths in various perched aquifer layers. The observed sulfate concentrations in these perched aquifer layers are quite variable, due to variable proportions of natural groundwater and tailings seepage. Nevertheless, they are typically lower than those of the shallow seepage (see Figure 3-16).

The tailings seepage has virtually no impact on the water quality of the deep groundwater flowing at depths of >100 feet below ground surface (Figure 3-16). The observed sulfate concentrations in this deep, semi-confined aquifer are very close to ambient background concentrations (~20 mg/l) also observed upgradient of the tailings facility (see Section 2.5). Any tailings seepage possibly entering this deep aquifer is effectively diluted in the deep groundwater flows.

Figure 3-16 illustrates the effectiveness of the seepage interception system currently operating below Dam 1. The seepage barriers and the shallow extraction wells (EW-5 series) intercept the majority of tailings seepage as shallow seepage. Any tailings seepage, which is not intercepted by the shallow interceptor drains and wells, and percolates downward and mixes with natural groundwater in deeper perched layers, is extracted using the deeper extraction wells.

The time trends of sulfate, molybdenum and TDS indicate that the water quality in the groundwater downstream of the Questa Tailings Facility has stabilized over the last five years, or is declining (see Figures 3-15A to 3-15C). This observation is consistent with the contention that tailings seepage is controlled by tailings process water presently stored in the tailings pore volume (see Section 4.6). The drainage of tailings process water has stabilized and is reduced as a result of the inactivity of tailings discharge to the tailings areas immediately behind Dams. 1 and 4. There has been no apparent increase in soluble oxidation products (from oxidation of the unsaturated tailings on the beaches) entering the groundwater system.

The significant decline in soluble oxidation products observed in MW-4 (downgradient of embankment Dam 1B) over the years clearly indicates that the contribution of tailings seepage from the beaches behind Dam No. 1B has declined, very likely due to a decline in the phreatic surface (see Figure 3-15A to 3-15C).

The only consistent, albeit small, increase in all oxidation products (sulfate, molybdenum and TDS) during the five year monitoring period was observed in the deep volcanic aquifer downgradient of the Section 35 Tailings Area (MW-11, see Figure 3-15A to 3-15C). This small increase is most likely a result of the start-up of operation in 1996 (tailings discharge behind Dam 5A). This small increase in soluble oxidation products appears to have stabilized over the last year.

Note that some monitoring wells show significant seasonal variations in water quality (e.g. MW-A; MW-1) while others show very little seasonal change (e.g. MW-7A). The seasonal variations in groundwater quality may be caused by:

i. seasonal variations in natural groundwater flows receiving tailings seepage (in particular in very shallow perched aquifers fed predominantly by recharge during spring and late fall);

ii. seasonal variations in tailings seepage flow (higher flows due to wetting fronts reaching the base of the tailings impoundment); and/or

iii. seasonal variations in water quality of tailings seepage leaving at the base of the tailings impoundment (e.g. flushing of oxidation products during passage of a wetting front).

In our opinion the first factor, seasonal variations in shallow groundwater flow, is likely the dominant factor causing the observed seasonal variations in water quality in some monitoring wells.

3.1.7 Surface Water Monitoring

During operation of the Questa Tailings Facility tailings process water ponding in the impoundments is typically decanted, treated if necessary, and discharged into the Red River using Outfall 001 (see Section 3.1.4). In addition, all tailings seepage intercepted downgradient of Dam 1 is also discharged into the Red River using Outfall 002 (see Section 3.1.5). Finally, any tailings seepage not intercepted and mixing with the groundwater flowing beneath the tailings impoundments (in particular below Section 35 Tailings Area) also discharges into the Red River (see Section 2.5). This implies that the Red River is the only surface water receiving tailings process water and tailings seepage.

In April 1993, Vail Engineering conducted a water quality survey along the Red River between the State Road 522 highway bridge and the Red River Fish Hatchery (Vail, 1993). The primary objectives of this survey study were:

i. to assess the impact of tailings seepage on Red River water quality; and

ii. to estimate the amount of tailings seepage entering the Red River (via springs and groundwater) along specific reaches of the river.

Figure 3-17 shows the various sampling locations of this survey. A total of 20 samples were analysed for field parameters, sulfate, and twelve other parameters (see Table 3.9 for description). The Red River was sampled at six selected locations, springs and field drainage in the fields south of Dam No. 1 were sampled at four locations, and five samples were taken from springs flowing into Red River along and at the head of the Red River Gorge (Figure 3-17). In addition, samples were taken from the cold water and warm water supply of the State Fish Hatchery, and from the Outfall 002 (Figure 3-17).

Table 3.9
Summary of Red River Water Quality Survey

'Sample Point	Description	Red River				Springs and Drainage			
		Temp. (°C)	SO_4 (mg/L)	TDS (mg/L)	Mo ' (mg/L)	Temp. (°C)	SO., (mg/L)	TDS (mg/L)	Mo ' (mg/L)
1	R/R Below Highway Bridge	8.3	119	255	<.03				
2	Spring N. Side R/R					10.5	92	247	<.03
3	Field Drainage to R/R 500'E. of 002					11.2	92	246	0.20
4	Field Drainage to R/R 450'E of 002					17.8	172	648	<.30
5	R/R 300'E of 002	9.1	118	240	<.03				
6	Outfall 002					9.7	840	1764	1.80
7	Field Drainage 74'W of 002					10.1	228	727	0.20
8	R/R above Questa Spring	9.8	141	268	<.03				
9	Near Questa Springs SE of Conc. Box					7.8	504	1094	<.03
10	Near Questa Springs End of Old Pipe					7.1	210	576	<.03
11	R/R 500'W of Questa Springs	10.3	138	269	<.03				
12	Spring - N. Side R/R Sta. 47+20					15.3	115	271	<.03
13	R/R Sta. 47+70 Above Hatchery	10.5	128	259	<.03				
14	Spring S. Side R/R Sta. 36+80					16.9	126	304	<.03
15	Spring N. Side R/R Sta. 36+40					16.4	20	145	<.03
16	R/R Sta.	I I	129	247	<.03				
17	Hatchery Inlet Cold Water					8.3	80	176	<.03
18	Hatchery Inlet Warm Water					15.8	63	284	<.03
19	Seep Water in Irrigation Ditch Above 002 Line X @ Road					10.5	660	1304	<.03
20	Molycorp Drain Below Culver Above Ditch					8.9	790	1702	1.70

• Dissolved Molybdenum Concentration

Table 3.9 summarizes the observed temperature, sulfate, dissolved molybdenum, and total dissolved solids (TDS) for these sampling points. A complete listing of all water quality parameters for these sampling stations is provided in Appendix I. The data indicate that the water quality of the Red River is not affected negatively by tailings seepage from the Questa Tailings Facility. Sulfate and TDS concentrations rise only very slightly in the reach immediately to the south of the Dam 1 arroyo (Table 3.9) whereas molybdenum in the Red River remains below the detection limit throughout the entire study reach (Table 3.9).

Figure 3-18 shows the sulfate concentrations in the Red River as a function of distance below the highway bridge. It is seen that the sulfate concentrations in the Red River remain nearly unchanged except for immediately downstream of three known point sources:

i. Outfall 002 where intercepted tailings seepage (840 mg/l SO_4) is discharged into the Red River at a rate of about 0.6 cfs;

ii. Fish Hatchery cold water supply (80 mg/l SO_4) with an estimated discharge of 2.7 cfs; and

iii. Fish Hatchery warm water supply (63 mg/l SO_4) with an estimated discharge of 10.0 cfs.

Immediately downstream of Outfall 002, the sulfate increases slightly due to the discharge of intercepted tailings seepage with elevated sulfate concentrations. This slight increase in sulfate concentration, however, is compensated further downstream by (i) accretion of groundwater in the Red River Gorge, and (ii) the discharge of the water supply from the Fish Hatchery, both of which have sulfate concentrations lower than those of the Red River (Figure 3-18). Note that the Fish Hatchery water supply consists of groundwater, which would naturally discharge into the Red River upstream of the Fish Hatchery. The cold water supply consists of shallow groundwater intercepted in the alluvial soils to the east of the Dam 1 arroyo (Figure 3-17) and has a water temperature varying from 8-10º Celsius (Vail, 1993). The warm water supply comprises groundwater discharging in numerous springs west of the upper end of the Red River Gorge (Figure 3-17). The warm water springs emanate from the volcanic formations predominantly along the northern side of the gorge and have a temperature of about 16ºC (Vail, 1993).

The observed sulfate loadings to the Red River were used to estimate the contribution of tailings seepage to the Red River (Vail, 1993). In this analysis it was assumed that tailings seepage, groundwater and Red River water mix completely. It was further assumed that tailings seepage and groundwater not impacted by tailings seepage, have a sulfate concentration of 840 mg/l and 20 mg/l, respectively, and that sulfate behaves conservatively during mixing (Vail, 1993). Here we summarize mixing calculations to estimate the overall contribution of tailings seepage to the Red River. For a more detailed treatment of the subject the reader is referred to Vail (1993).

The total accretion (of groundwater and tailings seepage combined) to the Red River in the study reach was about 20.3 cfs during the time of sampling (Vail, 1993). Based on the observed increase in the sulfate loading along this reach (66.3 cfs x 117 mg/l - 46 cfs x 119 mg/l = 2283 cfs x mg/l; Vail, 1993), the average sulfate concentration of the accretion flow was about 112 mg/l sulfate (i.e. 2283 cfs x mg/l / 20.3 cfs).

The proportion of tailings seepage to the overall accretion flows to the Red River was estimated using the following equation:

$$X_{seepage} = (C_{accretion} - C_{GW}) / (C_{seepage} - C_{GW})$$

where $X_{seepage}$ is the fraction of tailings seepage in accretion flow and $C_{accretion}$,C_{GW} ,and $C_{seepage}$ are the sulfate concentrations in accretion flow, groundwater (not impacted by tailings seepage), and tailings seepage, respectively. Using the assumed sulfate concentrations for the various mixing components the contribution of tailings seepage to the Red River on April 12, 1993 was about 2.3 cfs (or 11% of total accretion flow). This leaves about 18 cfs of accretion flow to the Red River from natural groundwater flows, which is consistent with earlier estimates of accretion to the Red River in this reach (by natural groundwater flows) reported by Winograd (1959) and other earlier studies summarized in Dames and Moore (1987).

Note that the estimate of tailings seepage (2.3 cfs) includes seepage from the Section 35 Tailings Area (behind Dam Nos. 4 and 5A as well as from the Section 36 Tailings Areas (behind Dam 1). It is believed that a significant portion of the total tailings seepage (likely >0.8 cfs) originates from the currently active tailings pond behind Dam No. 5A where tailings process water is seeping directly into the very permeable volcanics.

The accuracy of the above estimate of tailings seepage depends on the uncertainty in the input parameters, in particular measurements of stream flow and sulfate concentrations of tailings seepage. According to the USGS, the stream flow data during the sampling period were rated as 'good', i.e. within 10% of the true value 95% of the time (Vail, 1993). The resulting uncertainty in the estimate of tailings seepage is in the order of 13% (i.e. ranging from 2.0 cfs to 2.6 cfs). The sulfate concentration of tailings seepage is also known to vary from 800 mg/l (for tailings process water) to as high as 1200 mg/l (observed in shallow seepage extracted in EW-5 series). The resulting estimates of tailings seepage range from 1.8 cfs to 2.4 cfs.

Molycorp has continued to monitor the water quality in the Red River and near-by springs on a regular basis since completion of the first survey in April 1993. Red River water quality surveys of similar scope were undertaken in November '93, February '95 and November '95. In the fourth quarter of 1995, the number of stations sampled for full water quality was reduced to seven springs located downgradient of the tailings impoundments. These stations are: Questa Springs Surface Discharge (#9), Questa Springs Old Discharge Pipe (#10), First Creek below Pope Creek (#12), South Side Spring (#14), Spring near Concrete Collection Box (#15), Hatchery Cold Water Supply (#17), and Hatchery Warm Water Supply (#18). Spring water samples taken at these stations are now being analysed quarterly for field parameters, general chemistry, and metals as outlined in the Discharge Plan 933. Molycorp has continued to monitor the remaining stations of the Red River survey for field parameters on a voluntary basis. The results of the surface water quality monitoring from 1993 to the present (field parameters and sulfate) are summarized in Appendix I.

Figure 3-19 shows the sulfate concentrations in selected springs located downgradient of the Questa Tailings Facility from 1993 through to the present (February 1998). The water quality of the 'Questa Springs' (#10) and Fish Hatchery cold water supply is representative of that of groundwater flowing beneath the Section 36 Tailings Area in the shallow alluvium (see Figure 3-17). The water quality of the Fish Hatchery warm water supply is representative of that of groundwater flowing beneath the Section 35 Tailings Area in the deep volcanics (see above). It is seen that the sulfate concentration in these spring flows remained very stable (Fish Hatchery supply water), or has been slightly decreasing (Questa Springs), over the five year monitoring period (Figure 3-19). These water quality trends are consistent with those observed in the monitoring wells located downgradient of the Tailings Facility (see Section 3.1.7). They support the earlier conclusion that the system has reached an apparent 'steady-state', i.e. the loading of soluble oxidation products from the tailings facility into the groundwater system and ultimately to the Red River is currently stable, if not declining.

3.2 Planned Development – Future Operations

3.2.1 Dams, Diversions, Structures and Buildings

3.2.1.1 Dams

As for construction to date, future dam construction and permitting will be under the control of the State Engineer. Provision is required for a total of 82 million tons of tailings at an annual production rate of 3.5 million tons for a further 23.5 years of operation, from from the date of recommencement in 1996, till 2020. A conceptual development plan was developed by Geocon-Hoare (1975) which provides for capacity in excess of this tonage. This included the development of conceptual dam raising sections but not of detailed designs.

A number of new technologies are being investigated which may be advantageous for the future development of the Questa tailings impoundments. These include technologies such as 'dry stacking' and barge mounted pumped discharge systems. The following description of dam raisings is what is anticipated at this time. Alternative development strategies may be proposed in the future when the benefits and requirements of these alternative technologies have been established.

Figure 3-20 illustrates the final elevations of tailings impoundment development which provides for the required tailings volume, and achieves a suitable surface profile for reclamation and closure. Initial placement of tailings will be in the Dam 5A and Dam 4 complexes, which will be developed into one system. This complex will be expanded to the north, but within the limits of the western diversion ditch. On closure the only dam that will exist for this complex is Dam 4. The divider berms between the various impoundment areas will be low berms, typically no more than 10 ft high, and will not retain water pools. This complex is able to store 75 million tons of tailings to the elevations indicated at an average dry tailings density of 88lbs per cubic foot. This complex will serve to store tailings until about 2017. At that time the Dam 1 complex will be developed. This will require the raising of Dam 1C as well as 1B and 2A. A low berm will separate this complex into two areas. For the final dam elevations shown, the dam complex has capacity for up to a further 5 years of tailings deposition, for a total additional capacity of 86 million tons.

The conceptual designs for the dam raisings for Dams 4, 1C, 1B and 2A are shown on Figures 3-2 to 3-6. Dam 4 will be raised to El 7465 by centerline methods similar to the most recent raisings (Figure 3-5). The remainder of the raisings to El 7585 will be by upstream construction. The HDPE geomembrane liner and the chimney and blanket drains will be extended as shown on the figure. Dam 1C will be raised to El 7600 by a centerline raise and thereafter to El 7620 by upstream construction as shown on Figure 3-2. Dams 1B and 2A will be raised to 7560 by centerline construction and then to El 7620 and 7625 by upstream construction a shown on Figures 3-3 and 3-4. The chimney and blanket drains will be extended as shown on the figures.

3.2.1.2 Diversions

There will be no changes to the diversion structures.

3.2.1.3 Structures

It is anticipated that the western decant channel will be replaced by a barge mounted pump decant system. The western decant channel will therefore be abandoned, including the contained structures, and will be buried by tailings.

3.2.1.4 Buildings

The current buildings will remain and no new buildings are proposed.

3.2.2 Tailings Deposition and Characterization

3.2.2.1 Placement Plans

Tailings placement will continue to be primarily by spigot discharge from the perimeter of each tailings deposition area. Discharge will be managed to achieve beaches which slope towards a pond located close to the discharge, as shown on Figure 3-20. The low berms between the operating areas will be constructed using cycloned sand or earthfill. To allow for the final drainage plan to discharge from east to west to the western diversion ditch, and for a general slope from the north to the south across the tailings impoundments it will be necessary to develop the northern tailings areas first and progress to the south.

To restrict the tailings area being operated at any one time, and avoid the potential for dusting, the tailings complex has been divided into 6 areas, each of about 200 acres (Figure 3-20). The tailings impoundments will be developed so that no more than two of these areas are being operated at the same time; one under active discharge and one under preparation, standby or remediation. Dust control will be provided on all beaches by allowing for the spigoting of additional tailings to wet dry beaches.

3.2.2.2 Characterization and Monitoring

Physical Characterization

No change in ore type or processing methodology is anticipated. Hence, no change in the resulting physical characteristics of future tailings is expected.

Acid Generation Potential of Future Tailings

The tailings characterization work described above was based on the tailings that have been produced to date. An assessment was also made of the geochemical characteristics of tailings that will be produced in the future. Future mining will extract ore, which has the same host rock types and the same genesis as the previously extracted ore. The molybdenum grade of future ore is also very similar to that previously mined. There is, however, potential for the mix of host rock to differ as a result of different mining methods and changes in the percentages of the different host rock types. This potential was evaluated as follows.

Prior to 1983 all mining was by open pit methods. During open pit mining, each shovel loads a particular rock type (which depends on the rock type occurring in the bench it is loading from). There is therefore the potential for all the shovels that are loading ore to be located in a particular rock type (Andesite or Aplite). During block caving, the cave develops through a variety of rock types, and ore is drawn simultaneously from a number of draw points drawing ore from a variety of locations and rock type combinations. Thus the ore from block caving is expected to be a more blended mixture than is ore from open pit mining. All other things being equal, there is less potential for a concentration of ore with high sulfide and low neutralizing potential with tailings from underground mining, than from open pit mining.

To evaluate the combination of rock types (and hence mixtures) that have been mined in the past, Questa mine prepared geologic sections through zones previously mined by open pit methods as well as the zones currently being mined and which will be mined in the future. These Zones are shown on Figures 3-21 to 3-23. Estimates were then made of the percentages of Aplite, Andesite and Mixed Volcanic rock that have and will be mined in each zone. The results are summarized in Table 3.10. From this table the following may be observed:

Between 1965 and 1981 approximately 82 million tons of ore was mined by open pit methods with an average composition of 65% Aplite, 30% Andesite and 3% Mixed Volcanics. With the development of the underground mine to mine the SW Orebody, the mix of host rock types changed for the mining period 1983 to 1992 to 33% Aplite, 65% Andesite and 2% Mixed Volcanics. This change in host rock type is reflected in the changes in AP values and in the NP:AP ratio, however the tailings remain net acid consuming. A total of about 15 million tons of tailings were produced from the mining of the SW Orebody. On restarting the mine in 1996, mining commenced in an extension of the SW Orebody and the mix of rock types in the railings remain the same. The 3.4 million tons of ore from this zone will produce feed for the mill until about 2001. Prior to 2001 the "D" Orebody will be developed. This orebody comprises approximately 27% Aplite, 70% Andesite and 3% Mixed Volcanics. Thus it is very similar to the

SW orebody in composition and the geochemical characteristics are expected to be essentially similar.

Thus it is anticipated that future tailings will also be acid consuming with geochemical characteristics similar to that produced to date.

Table 3.10

Tons Mined and Milled at Questa (Period 1965 to Feb. 1998)

Source	Tons (MM)	Aplite (%)	Andesite (%)	Mixed Volc. (%)
Open Pit	82.23	65	30	5
SW Orebody	15.16	33	65	2
SW Extension	3.39	33	65	2
TOTAL	100.78	57.8	38	4.2
Future Mining (“D Orebody”)		27	70	3

Monitoring

Questa currently samples tailings on a weekly basis and produces a composite from these samples each three months for ABA testing. This monitoring allows the geochemical characteristic of the tailings to be monitored and would provide an early warning of any changes in characteristics, should these unexpectedly occur. The results from this monitoring to date indicates that tailings from the SW Extension Orebody is net acid consuming with NP:AP ratios as expect

3.2.3 Interim Covers

Inactive tailings areas which will remain inactive for extended periods will be covered by placing interim covers on the coarse and intermediate beach areas as has been practiced during the recent mine closure. Interim cover placement will be 9 inches of alluvial gravel placed by scraper and revegetated. The experience with the placement of current interim covers well demonstrates the technical feasibility and success of such covers.

3.2.4 Tailings Water Treatment and Discharge

Molycorp will continue to treat tailings process water during future operation of the Questa Tailings Facility using the IX plant if the decant water does not meet discharge requirements.

3.2.5 Seepage Interception System

Molycorp will re-evaluate the seepage collection and extraction system after a period of one year as outlined in the Discharge Plan 933. If the existing seepage interception system is not adequately protecting downgradient groundwater quality within state standards, Molycorp will upon NMED's approval, upgrade its existing collection and extraction system or add additional seepage barriers and/or extraction wells.

3.2.6 Groundwater Monitoring

Molycorp will continue to sample all functional monitoring wells quarterly during future operation of the Questa Tailings Facility and analyse the samples for field parameters, general chemistry and metals as outlined in the Discharge Permit 933

3.2.7 Surface Water Monitoring

Molycorp will continue to monitor water quality in the seven springs located downgradient of the tailings impoundments, and specified in the Discharge Plan 933, during future operation of the Questa Tailings Facility. These springs will be sampled quarterly and analysed for field parameters, general chemistry, and metals as outlined in the Discharge Plan 933.

4.0 REVISED CLOSURE PLAN

The Revised Closure Plan has been divided into series of eight individual plans:

1. Surface shaping plan
2. Buildings and clean-up plan
3. Cover placement plan
4. Drainage plan
5. Revegetation plan
6. Groundwater interception plan
7. Monitoring and maintenance plan
8. Post closure land-use plan

Each of these is described in the following sections. While separated into individual plans, they have been integrated to form the overall Revised Closure Plan. While the Revised Closure Plan provides considerably more detail and technical support for the various elements of the closure plan, the principal measures of the closure plan are essentially similar to, and consistent with the measures described in the previously submitted closure plans of 1995 and 1997.

4.1 Surface Shaping Plan

Historic and Planned Development of the tailings impoundments have been described in Sections 3.1 and 3.2. It is an objective of this development to achieve a final surface topography of the tailings impoundments (on closure) which lends itself to reclamation with a minimum of surface reshaping. The requirement for the development of such a surface has been described in Section 3.2. By implementing such development, the tailings impoundments are expected to achieve (approximately) the shape and contours shown on Figure 4-1 at the time of final closure.

The proposed surface contour plan after closure:

i. Effectively fills the entire area contained within the east and west diversion channels;

ii. Provides a surface that drains from northeast towards the southwest;

iii. Achieves final pond locations at the western boundary of the individual impoundments zones;

iv. Develops pond elevations above the level of the downstream drainage channel;

v. Develops gentle sloping beaches of limited length towards the individual ponds.

vi. Provides a surface that can be reclaimed with additional earthworks and reshaping only for the drainage from the ponds.

The ponds will be drained and breached by constructing drainage channels through western embankments (Figure 4-1) and installing spillway structures as discussed in the Drainage Plan (Section 4.4). This will allow the entire tailings surface to be drained so that no water is impounded on the tailings surface. The resulting shape is a series of 5 shallow sloping 'fans' of tailings beach extending outwards from the five spillway structures in each of the five impoundment zones (Figure 4-1). Note that zones 1 and 2 may be combined to achieve a single fan and pond discharge.

In practice it will be necessary to locate the final pond a short distance in from the western embankment. This distance will be minimized by 'driving' the pond as close to the western embankment as possible as each impoundment zone is completed. To provide drainage from the lowest point of the 'pond' through the embankment will require the excavation of an open channel drain from the low point in the pond through the embankment. The depth and profile for this drain will take into account potential additional settlement of the tailings (particularly the tailings fines underlying the pond) which may occur, post closure. Evaluation of such settlement can be made only once the impoundment approaches closure and the detailed settlement characteristics of the tailings under the pond (particularly recent deposits) are known.

In addition to the earthworks required for the drainage channels from the pond areas it will be necessary to do minor reshaping and contouring for the riprap lined drainage swales shown on Figure 4-1. The design of these swales is described in Section 4.4. The earthworks shaping will be done using a grader for the trafficable beach zones and using a light backhoe, operating off the cover material in the fine tailings (or drained pond) zones.

Apart from the construction of the drainage channels and swales no additional re-shaping of the final tailings surface or embankments are proposed. The dams and dikes will be closed-out with their current and future developed shapes and profiles. These dam and dike slopes are typical of the characteristic slopes associated with the arroyos in which the impoundments have been constructed.

Two areas of minor earthworks will be required. The first is the breaching of the 'Pope Lake' embankment once Pope Lake reservoir is no longer required. This will involve the removal of a portion of the Pope Lake embankment down to bedrock to allow the free flow of any water that may in future be discharged to below Dam No 4 through the western diversion channel. The breach will have side slopes of 3 horizontal to one vertical and a bottom width equivalent to that of the western diversion channel (see Figure 3-7). The second is the removal of the present culvert and fill over the eastern diversion channel at the location of the access road to the top of the Dam 1B. Material removed from these excavations will be applied to the top of the impoundments dams as cover material.

4.2 Buildings and Clean-up Plan

Only two buildings will require removal on closure: the administration/change house building and the IX water treatment plant.

The one story administration building and change house located east of Dam 1B at the entrance to the site will be demolished, including the concrete floor and foundations, and the building rubble transported to and disposed of in a permitted landfill at the Questa mine site.

The water treatment plant is a metal clad steel structure containing mainly pumps, piping, and metal tankage, as described in Section 3.1.4. There are no PCB's. This facility will be maintained and operated, as necessary, until treatment of tailings surface or ground water is no longer required. Minor quantities of reagents in the form of sulfuric acid and caustic soda may remain on termination. These will be sent to the mine and mill for use, if these remain in operation, or will be disposed of using the services of a licensed waste disposal company. To the extent practical the building, cladding, tankage, pumps and reverse osmosis units will be disassembled and sold. The remaining metal scrap will be transported to the Questa mine site to be consolidated with the much larger volume of mine and mill scrap metal and sold or disposed of with mine/mill scrap. The concrete floor and foundations will be broken up and it, and any building rubble, will be transported to and disposed of in a permitted landfill at the Questa mine site.

Following removal of the buildings the construction area will be graded to a smooth surface. Where required, 9 inches of alluvial fill will be placed and the disturbed area re-vegetated in accordance with the re-vegetation method used for re-vegetation of the tailings cover.

In addition to removal of the two buildings the site will be cleaned up to remove all tailings delivery piping and any concrete or timber cribs that were used to support the tailings lines. Concrete and timber will be transported to and disposed of in a permitted landfill at the Questa mine site. Tailings piping will be sold off as second hand piping or scrap. Any remaining scrap metal will be transported to Questa mine for consolidation with the much larger volume of mine and mill scrap.

4.3 Cover Placement Plan

The purpose of the final cover is to:

i. provide for physical stabilization of the tailings (i.e. control surficial erosion and/or dust emission);

ii. provide for chemical stabilization of the tailings (i.e. minimize oxidation of the tailings and/or movement of oxidation products into the aquatic environment); and

iii. support vegetation and a beneficial land-use.

The design of a cover system, including type of cover material(s) and cover thickness, should take into account all site conditions including the tailings characteristics (e.g. potential for tailings oxidation), the surrounding environment (e.g. potential for environmental impact due to release of oxidation products; available cover materials) and climatic conditions. The interim cover on the Questa tailings impoundments has demonstrated that it can well achieve the objectives of (i) and (iii) above. The extent to which alternative covers could achieve (ii) chemical stabilization had to be investigated.

As outlined in the tailings characterization sections (Sections 3.1.2 and 3.2.2) the tailings deposits contain process water (in the tailings pore space) with moderately elevated levels of sulfate, molybdenum and TDS. This process water would drain from the tailings, over time, regardless of what form of cover is placed. The tailings also contain sulfides that will oxidize over time, producing oxidation products, primarily gypsum (calcium sulfate) and metal hydroxides. While the tailings are not acid generating (as discussed in Section 3.1.2) there will be leaching of the gypsum and, at lower concentrations, of the hydroxides and some salts. Water quality values for such leachate have been estimated as discussed in Appendix D. It is necessary to, not only ensure that the surface and groundwater quality is protected to achieve New Mexico state standards, but also to use best practice and technology to minimize any increase in salt and metals loading to such waters. To this end the cover design should seek both to achieve state standards and minimize leaching. In the following section we briefly review several alternative cover types and evaluate their suitability for use at Molycorp's tailings facilities near Questa. The alternatives evaluation is followed with a description of the proposed method of cover placement (Section 4.3.2) and an assessment of the performance of the selected cover (Section 4.3.3). Finally, a verification test program is outlined that will aid in optimizing the design of the selected cover prior to closure (Section 4.3.4).

4.3.1. Alternatives Evaluation

Control of migration of soluble oxidation products into the environment can be done in one of three ways:

i. control of oxidation, preventing the formation of the leachable oxidation products; or

ii. if oxidation can not be prevented, limiting the infiltration of water into the tailings, thereby limiting the amount of soluble oxidation products which are leached and transported to ground or surface waters; and

iii. if leaching cannot be prevented adequately, then the leachate seepage can be intercepted and collected.

Molycorp currently has an interception and collection system in place to intercept and collect seepage containing predominantly process water draining from the tailings facility. The alternatives investigation focussed on determining what the effect may be on requirements for continued interception (to protect groundwater) if covers of different types and thicknesses were installed. The objective was to determine which particular cover type would best protect groundwater.

Surface water quality is not at issue since the surface run-off from above the tailings cover would not have been in contact with the tailings.

Four basic cover types were considered:

i. a water cover, which would serve to prevent oxidation;

ii. a ‘conventional low permeability’ complex cover to limit infiltration;

iii. a capillary barrier cover which is effective in dry climates to limit infiltration; and

iv. a storage cover which takes advantage of the low precipitation, high evapotranspiration climatic conditions at Questa to minimize infiltration.

In addition to considering the technical merits, and the availability of local borrow materials for each of these cover types, the consequences and benefits of having a very effective infiltration limiting cover was investigated using the modeling described in Section 4.6.2. This modeling demonstrates that there are only very small, if any, benefits from a very efficient infiltration barrier.

Water Cover

Here the tailings are submerged under water, typically by flooding the tailings impoundment or relocating the tailings in an alternative storage basin (such as an open pit). The water cover dramatically reduces the potential for air to move into the tailings hence providing excellent protection against future oxidation of the tailings (e.g. Davé et al., 1997). However, there may be problems with physical stability of the tailings (many tailings dams were not designed to be flooded), and with land use.

A water cover is not a viable option for the Questa Tailings Facility for three reasons. First, the tailings dams were not designed to be flooded permanently and would have to be reconstructed at extremely high cost. Second, there is no readily available source of water to flood the impoundment. Significant volumes of water would be needed to flood the tailings impoundments and maintain flooded conditions during the summer months (high evaporation rates). The supply of surface water is limited and in high demand for irrigation purposes. Third, the flooding of the tailings will increase seepage through the tailings beaches, flushing out stored oxidation products and causing increased contaminant loads to the receiving groundwater.

Low Permeability Cover

A conventional infiltration limiting cap typically consists of a low-permeability (clay or geosynthetic membrane) layer, in combination with a number of other layers. This type of cover requires additional suction break and protective soil layers to minimize deterioration of the low permeability layer by dessication, frost action, erosion, animal burrowing and/or plant rooting. A complex cover of several layers and considerable depth (4 to 5 feet thick) results. If the low permeability layer must also serve as an oxygen barrier then additional constraints apply. For example clay layers must remain saturated and geosynthetics must be replaced when they age and deteriorate. Rodent (prairie dog) and ant burrowing through the existing (gravelly) cover at the site is extensive (see Photos 14 and 15) and indicates the likelihood of disruption of any engineered low permeability cover layers.

The low permeability cover was not considered a viable option as a final cover for the Questa Tailings Facility for two reasons. First, there are no local sources of clay available (in the quantities required). Thin layers of silts occur in the predominantly coarse, gravelly, alluvial valley fills. These silts would make marginal quality low permeability layers and their recovery from between the thick gravel beds would have a very high cost and would result in large environmental impacts of dust and noise near the village of Questa. If a complex cover of four feet thickness was placed over the 1200 acres of impoundment this would require eight million cubic yards of cover material – a substantial mine in its own right. Second, there is serious concern regarding the long-term integrity of such a cover system under the local climatic conditions. The dry, continental climate at the site would likely result in cracking of the low-permeability clay layer in response to air-drying and/or freeze/thaw cycles (see e.g. Morris and Stormont, 1997).

Considering the cost and environmental impact of borrowing and transporting such materials to the site and the concerns with respect to long-term stability of the cover system this cover type was not selected for the site.

Capillary Barrier Cover

A capillary barrier effect is created when a fine material layer is placed on top of a coarse material layer. Under unsaturated conditions the hydraulic conductivity of the coarse material is much lower that that of the fine-grained material preventing any downward movement of soil moisture from the upper soil layer. This phenomenon ceases when the fine material layer is close to full saturation and the interface suction approaches zero. The capillary barrier cover significantly reduces water flux into the tailings as long as the entire cover profile remains unsaturated (e.g. Aubertin et al., 1997). However, it does not prevent the flux of oxygen into the tailings unless provisions are made to keep the soil moisture content of the fine (silt) layer near saturation.

For the climatic conditions at the Questa Tailings Facility, additional thick protective layers would likely be required to prevent the desiccation cracking, root and animal burrowing penetration of the upper silt layer which would result in rapid infiltration particularly during high rainfall events. In addition, the capillary break effect can be expected to deteriorate with time due to animal burrowing which would tend to mix the finer and the coarser material (see Photos 14 and 15 for examples of such animal burrowing activity at the site). Finally, as previously indicated, there are no local sources of fine cover material available (in the quantities required).

In light of the cost and environmental impact of borrowing and transporting such materials to the site and the concerns with respect to long-term effectiveness of the cover system this cover type was not considered appropriate for the site.

Storage Cover

A storage cover consists of one or several soil layers, which are designed to maximize root penetration and soil moisture storage. This type of cover relies entirely on the process of evapotranspiration by the plants to control deep seepage. The storage cover has to be designed in such a way that all incoming infiltration during the dormant season can be stored within the root zone. Note that the root zone is not limited to the cover layer but may extend into the upper layers of the tailings. In this case, the cover material would primarily serve as a medium for initiating plant growth and to avoid wind and water erosion of the tailings.

The climatic conditions at the Questa site favor the design of a storage cover for construction of a permanent cover. This cover type can be constructed entirely from local material without material screening simplifying construction and thus greatly reducing construction costs. Because it utilizes the upper tailings as part of the 'cover' storage system, the depth of cover can be quite small and yet remain very effective. In addition, this cover type has the lowest risks with respect to long-term integrity. Its function is not affected by desiccation cracking, frost effects, or penetration due to root and burrowing animal activity. In fact long-term performance is expected to increase as the vegetation matures and the potential for evapotranspiration is maximized. The concept of a storage cover was used to design a final cover for the Questa tailings facility. In Section 4.3.3 the effects of infiltration through this form of cover are evaluated and comparisons are made with more and less efficient infiltration limiting cover systems to demonstrate the relative insensitivity of the groundwater quality to cover type.

The adoption of a storage cover, being as, or more, beneficial than a 'traditional' low permeability cover in dry climates is consistent with the findings of other research workers (see e.g. Morris and Stormont, 1997).

4.3.2 Cover Placement

Cover placement methods will differ to cater for differences in the surface shear strength and therefore trafficability of the tailings surface.

Cover placement on the trafficable beach areas of the tailings will be placed using the same methods that have been used to date for placing the interim covers, i.e. using scrapers. The short haul to alluvial gravel adjacent to the tailings impoundment makes this a relatively economic method of cover placement. Scraper use allows accurate placement of shallow but consistent layer thickness.

During periods when an impoundment zone will be inactive for a number of years, an interim cover, such as the current interim cover, will be placed over the beach zones. During such interim periods the pond zones will remain flooded (as per current practice).

On final closure, for areas of fine tailings where ponding has prevented evaporation and desiccation, the pond will first be drained. This will be achieved by excavating a trench to the pond edge and installing a pump to pump water to the treatment plant prior to discharge. The dewatered pond area will then be allowed to dry and desiccate. During desiccation the upper crust of tailings gains shear strength (see Photo 11). Once desiccation has occurred to a level sufficient to support a light dozer on low pressure tracks, the cover layer will be advanced over the fine tailings areas. Cover material will be dumped using trucks some distance from the edge of the advancing cover and then pushed to the edge to advance the cover by the dozer. To further improve safety and working conditions the dozer will operate only on the cover material as it is advanced. The cover on which the dozer operates also serves to spread the point load of the dozers. The minimum thickness for safe operation of the dozer depends on the strength gain that has occurred in the desiccated tailings. This strength can be determined using a field shear vane for testing the tailings strength ahead of cover advance. The placement of a slightly thicker cover (18 inches instead of 9 inches) would reduce the strength gain required prior to cover placement. In the interest of conservatism it is assumed that the average cover thickness over the tailings fines area (shown on Figure 3-8) will be 18 inches. In practice this may vary from 9 to 36 inches to suit conditions at time of placement. The greatest depth is likely to occur at the lowest point where it will take longest for desiccation to develop.

The five impoundment zones will become available for reclamation over a period of several years (about 5) prior to terminal closure. These will be covered progressively as they become available. Prior to placing cover on the fine tailings area of the first pond to be reclaimed a geotechnical investigation and design will be completed to define the rate and methods of cover advance. The drainage, desiccation, cover placement and re-vegetation practices can be developed and demonstrated during the reclamation of the first fine tailings area

The entire Questa valley, north, south and east of the tailings impoundment is comprised of gravel alluvium. Thus there are ample sources of borrow material of the same characteristics as the interim cover materials. These are also the same materials as have been used for the construction of the Questa embankments and which will be used for the future raisings of the embankments. Most of these borrow areas are located north of the current impoundment over which future tailings expansion will occur. Since many of the current borrow pit areas will be worked for borrow material for the construction of the future raisings it is premature at this time to perform a borrow pit investigation. Such an investigation will be performed during the last five years of tailings impoundment operations at which time it will be known what the final impoundment plan is and where residual borrow is available with the minimum of additional land area disturbance.

4.3.3 Cover Performance

The final cover to be placed onto the tailings at closure must meet the following objectives:

i. control dust from exposed tailings;

ii. avoid surficial erosion of exposed tailings;

iii. support a vegetative cover; and

iv. control movement of water through the tailings (seepage) in the long-term.

The placement of a cover of alluvial gravel provides a very effective control of both dust and water (sheet flow) erosion. The slightly clayey, sandy gravel, that comprises the typical alluvial soils used for the cover material (see Photo 15), has sufficient gravel that deflation by wind is effectively prevented. Any tendency for deflation by removal of the fine particles results in the exposure of a surface ‘armouring’ or ‘desert pavement’ of coarse gravel, which resists further deflation. The slightly clayey nature also helps to bind the material and to resist both wind and water erosion. Since placing the interim covers on the exposed beaches of tailings, the dust problem that was previously encountered in the town of Questa has been eliminated. As vegetation establishes, the wind ground velocity during wind events is yet further reduced. The current interim cover, even without a mature vegetation cover, well demonstrates the effectiveness of the proposed final closure cover and no further performance evaluation is proposed in this regard.

An inspection of the interim cover shows that there is no evidence of surface erosion by water of the interim cover (see Photos 14 and 16). This is due to the following factors (i) the dry climate; (ii) the naturally low run-off from such a gravelly cover; (iii) the uniform and gentle slopes of the hydraulically placed beaches; (iv) the relatively small areas over which flow can accumulate and concentrate; and (v) the natural erosion resistance of the gravelly cover material. The development of a mature vegetation cover will yet further improve the erosion resistance of the cover by providing shelter from raindrop energy and binding the cover soil. The final closure plan also provides for the installation of erosion resistant drainage channels (see Drainage Plan; Section 4.4.2) to break up the catchment areas and further reduce the potential for concentrated water flow on the cover itself. No further performance evaluation is proposed in this regard.

The performance of such an alluvial storage cover, with respect to controlling infiltration into, and therefore seepage out of the tailings, is more difficult to quantify in the field. For evaluation purposes, the cover flux through the existing and alternative storage covers, constructed from locally available alluvial soils, was estimated using an unsaturated flow model (see Section 5.0; RGC 1997a). In the following, we briefly summarize the findings of this study.

Figure 4-2 illustrates the conceptual model used for modeling a storage cover. The typical cover profile consists of a single layer of alluvial soil (say 9 inches) overlying sandy (or fine) tailings. At the soil surface, precipitation (rain and/or snow) may infiltrate into the soil profile as long as the rate of precipitation is less than the saturated hydraulic conductivity of the cover material. Next, the water percolates downward through the cover material and into the tailings. As it moves through the root zone, some, if not all, of the water is taken up by the plant roots and transpired back into the atmosphere. Some water, in particular close to the soil surface, is also evaporating and leaving the soil profile as water vapor.

The removal of soil moisture via evaporation and transpiration was simulated by specifying potential rates of evapotranspiration (RGC 1997a). It was assumed that shrub vegetation is well established on the cover with a well-developed root zone of 1 m thickness. An active root zone depth of 1m is considered conservative for a mature semi-arid shrub community (RGC 1997a; see also Section 2 of this report). Note that much of the root zone is actually located within the tailings. In other words the tailings themselves were assumed to be an integral part of the “storage cover”. The entire soil profile modeled here was assumed to be unsaturated with the water table (if any) well below the upper ~10m of the soil profile.

Any soil moisture not taken up by the plant roots (in particular during the winter months) will gradually percolate deeper into the tailings profile and eventually will become “net infiltration”, i.e. water which will move through the tailings and emerge as seepage at the base of the tailings. Note, however, that the plant roots are able to create upward hydraulic gradients drawing soil moisture from deeper in the profile back up into the root zone. The exact depth of the zone of influence for evapotranspiration depends on soil conditions, transpiration rates (plant type), and climatic conditions (RGC 1997a).

The infiltration and seepage through a layered soil column (cover material over tailings) was modeled using the finite element code SWMS_2D (Simunek et al., 1994). The material properties (characteristic curves of moisture content and hydraulic conductivity) were taken from laboratory measurements of these parameters using representative samples of alluvial cover and tailings material (RGC, 1997a). Historic records of precipitation and pan evaporation, observed at representative weather stations, were used to model the climatic conditions at the site (RGC, 1997a). The length of the growing season was varied to evaluate the sensitivity of this parameter on cover performance. A detailed description of the numerical methods and modeling assumptions is provided in RGC (1997a).

A total of five different cover scenarios were evaluated (see RGC 1997a):

- 9 inch (0.23 m) thick coarse alluvial cover on sandy tailings (“Run 1”);
- 9 inch (0.23 m) thick coarse alluvial cover on fine tailings ("Run 2”);
- 18 inch (0.45 m) thick coarse alluvial cover on sandy tailings (“Run 3”);
- 36 inch (0.90 m) thick coarse alluvial cover on sandy tailings (“Run 4”); and
- 18 inch (0.23 m) thick coarse alluvium over 6 inch (15.25) thick fine alluvium (silt) on sandy tailings (“Run 5”).

Each cover scenario was evaluated using 1984 climate data (“average year” with 13.8” precipitation) as well as using climate data for 1993 (i.e. an “exceptionally wet year” with 19.3” precipitation). Those simulations using the 1993 weather data are considered “worst-case” scenarios.

All cover scenarios studied showed a similar seasonal pattern with predominantly infiltration and storage of water in the soil profile during the late fall and winter months and a gradual depletion of this stored water as a result of evapotranspiration during the spring and summer months. Figure 4-3 illustrates this seasonal response of a storage cover using the example of a 9 inch thick alluvial cover on sandy tailings for 1993 (with intermediate length of growing season). Shown are the simulated cumulative atmospheric fluxes in and out of the soil profile, i.e. actual infiltration and actual evapotranspiration, respectively. The difference between these two fluxes is the net atmospheric flux, with fluxes into the soil profile being positive and fluxes out of the profile being negative (Figure 4-3).

The final net atmospheric flux (at the end of the year) is a surrogate for cover performance. A positive cumulative net flux indicates that more water has infiltrated than could be given off as evapotranspiration. It is conservatively assumed that any positive net atmospheric flux at the end of the year equals “net infiltration”, i.e. water that has infiltrated passed the root zone and into the deeper tailings profile (RGC 1997a).

The net atmospheric fluxes for the five simulated cover scenarios are summarized in Table 4.1. The cover modeling results may be summarized as follows (see Table 4.1):

- the final net flux (or “net infiltration”) is greater through a storage cover placed on sandy tailings than through an equivalent cover placed on fine tailings (c. Runs 1 and 2);

- the final net flux is significantly greater for an exceptionally wet year (1993) than for a year with typical annual precipitation (1984) (both in absolute as well as relative terms);

- the length of growing season is a critical parameter in cover performance; simulated net atmospheric fluxes (for the exceptionally wet year) range from about 3.8 inches for a short growing season to –0.1 inches for a year-round growing season;

- the thickness of the alluvial cover does not significantly influence cover performance; net atmospheric fluxes calculated for 9”, 18” and 36” thick alluvial covers showed no significant differences neither for average (1984) nor for exceptionally wet conditions (1993) (c. Runs 1, 3 and 4); and

- the placement of a low permeability silt layer between the alluvial cover and the tailings improves the cover performance only marginally (c. Runs 1 and 5).

Several additional model runs were performed to evaluate the sensitivity of the model results to various input parameters (see RGC 1997a for details). This sensitivity analysis suggested that the climate and vegetation data are generally more critical to the performance of the storage cover than the material properties and thickness of the alluvial cover layer.

Particular attention was paid to the root zone depth of the vegetation growing on the storage cover. Sensitivity runs were performed for the case of an 18 inch thick alluvial cover on coarse tailings with a root zone depth ranging from 0.5m to 2.5m (RGC 1997a). Figure 4-3a shows the simulated net infiltration rates (“cover flux”), expressed as a percentage of total annual precipitation, versus root zone depths. For a typical range in root zone depth of 2 to 3 feet, the cover flux through the proposed storage cover is expected to range from 20 to 13 % of annual precipitation (Figure 4-3a).

Table 4.1

Summary of Cover Modeling Results

It was concluded from the cover performance analysis, that the thickness of the alluvial cover placed on the tailings is not an important factor in cover performance in terms of reducing net infiltration. It was further concluded that there appeared to be little benefit in placing a composite cover layer with low permeability alluvial silt onto the tailings, considering the small reduction in cover flux versus concerns about the long-term integrity of this low permeability silt layer. Based on the cover performance analysis, it was recommended that a 9 inch thick alluvial cover be placed onto the tailings after final closure of the tailings impoundments (RGC, 1997a). The long-term average net infiltration through this type of cover was estimated to range from about 0.4 inches to 1.1 inches for the fine and coarse tailings, respectively.

It was recommended to conduct a field program to measure the performance of the existing alluvial cover in-situ (RGC, 1997a). Such a test program could be used for model calibration allowing confirmation or refinement of the final cover design well ahead of the tailings facility closure.

4.3.4 Verification Test Program

Experience with the extensive placement of interim covers over the tailings provides the excellent verification for many of the issues that are typically of concern when designing new covers. Field observations and predictive modeling suggest that a nine inch thick alluvial soil cover will meet all four objectives for final closure, i.e. control of dust; control of surficial erosion; establish a mature shrub vegetation; and reduce net infiltration into the deep tailings profile. The first two objectives have been clearly demonstrated in the field (see Section 4.3.3). Hence no further verification of these cover objectives is proposed with respect to dust control and control of surficial erosion.

With respect to plant growth, field evidence is available from those tailings areas which have been covered in the past (typically areas with coarse and intermediate tailings). The good growth of shrub vegetation on the interim cover, in particular in the Dam 1 area (see Photos 16-18), which was covered in the mid 1970s, strongly suggests that a nine inch thick alluvial cover is sufficient to support a mature shrub vegetation. In fact, it is expected that the establishment of a mature shrub vegetation on the final cover will be significantly faster since the re-vegetation plan includes planting of woody plants and possibly the addition of soil amendments (see Section 4.6). (The present shrub vegetation invaded naturally from the surrounding areas without additional seeding, planting or soil amendments). While the experience with re-vegetation clearly demonstrates the natural propensity for the proposed cover/tailings system to develop and support naturally invading species, a revegetation test plot program will be performed to evaluate the effectiveness of the proposed, ‘assisted’ revegetation plan for the final cover over coarse as well as fine tailings. This revegetation test plot program is outlined in more detail in Section 4.3.4.1.

The greatest uncertainty with respect to cover performance lies in the estimation of net infiltration rates through the storage cover system. The cover performance modeling indicated that the predicted net infiltration rates are sensitive to climate and vegetation data and, to a lesser extent, the material properties of the tailings and cover materials (see Section 4.3.3). A cover test plot study will be conducted to measure such data in-situ and calibrate a soil-atmosphere model for final design evaluation. This cover test plot study is outlined in more detail in Section 4.3.4.2.

4.3.4.1 Revegetation Test Plot Program

The revegetation test plot program will be conducted prior to closure in order to refine and provide further evidence of the soundness of specific aspects of the revegetation plan. This will allow for optimizing the establishment and growth of the vegetation in order to meet the goal of developing a self-sustaining ecosystem.

The revegetation test plot program is designed to meet the following objectives:

i. to provide further evidence that 18 inches of cover over the fine tailings is adequate for the establishment and growth of vegetation.

ii. to evaluate the potential of additional species for the revegetation of the tailings ponds.

iii. to evaluate the potential benefit, both short and long term, of the addition of organic matter to the site prior to establishing plants or the addition of fertilizer to the plantings within the three year post-planting period.

iv. to demonstrate the time necessary to establish woody plants in the plant communities described in the revegetation plan (Section 4.5).

v. to demonstrate the indicators of success for final closure certification.

The following studies have been designed to meet the test program objectives. A general outline of the studies that will be conducted is provided.

Objective (i): Provide further evidence that 18 inches of cover over fine tailings is adequate.

Several test plots will be installed to examine the effects of cover depth over fine tailings on plant establishment and growth. In addition, the effects of adding organic matter or fertilizer will be evaluated as well as response to these treatments by individual species.

The following treatments will be used in this study. Cover depth will include 18 and 27 inches of soil over fine tailings. The organic matter/fertilizer treatments will include the following three levels: (1) no addition of organic matter/fertilizer (control), (2) the addition of organic matter at or prior to planting, and (3) fertilizer applied one and two years post-planting or seeding. Species to be evaluated will include two tree species, three shrub species, three grass species and two forb species for a total of 10 species evaluated.

Responses to be measured and evaluated include seed germination, transplant survival, growth and density. Measurements will be taken annually for a minimum of three years. Evaluations will include destructive sampling to examine root development after three and five years. Monitoring of this study is expected to extend for a minimum of five years but could extend to closure if necessary.

Objective (ii): Evaluate the potential of additional species for the revegetation of the tailings ponds.

Several test plots will be installed as a species screening trial, and those species that perform well in this trial could be added to the planting mixes when appropriate. The addition of species to planting mixes will increase the diversity at the site. The study will be placed on an area that is covered with nine inches of soil over tailings (coarse or intermediate tailings). Species to be tested include tree, shrub, grass and forb species. Tree and shrub species will be transplanted and grass and forb species will be seeded. Specific species to be evaluated are yet to be finalized but include some of those listed on the species list in the revegetation plan (Section 4.5).

Responses to be measured and evaluated include seed germination, transplant survival, growth and density. Measurements will be taken annually for a minimum of three years. Evaluations will include destructive sampling to examine root development after three years. Monitoring of this study is expected to extend for a minimum of five years but could extend to closure if necessary.

Objective (iii): Evaluate the potential benefit, both short and long term, of the addition of organic matter prior to establishing plants, or the addition of fertilizer to the plantings.

Several test plots will be installed to examine vegetative establishment as affected by the addition of organic matter or fertilizer. The study will also evaluate species responses to these treatments. Placement of the study will be on an area of coarse or intermediate tailings with nine inches of cover. The three levels of treatment for the addition of organic matter or fertilizer include no amendment or fertilizer (control), the addition of organic matter prior to or at planting, and fertilizer application one and two years post-planting. In addition, 10 species will be evaluated for establishment and growth responses to the treatments and will include two tree species, three shrub species, three grass species, and two forb species.

Responses to be measured and evaluated include seed germination, transplant survival, growth and density. Measurements will be taken annually for a minimum of three years. Evaluations will include destructive sampling to examine root development after three and five years. Monitoring of this study is expected to extend for a minimum of five years but could extend to closure if necessary.

Objectives (iv) and (v): Demonstrate the time necessary to establish woody plants in the plant communities described in the revegetation plan, and to demonstrate the indicators of success for final closure certification.

While the studies listed above will also provide information on these objectives, it is worthwhile to design a study focusing on these two objectives. On an area covered with nine inches of soil, the four plant communities described in the revegetation plan will be planted. Planting will be as described in the revegetation plan, the only exception may be the use of more hand planting because of the area of the trial plot compared to the entire tailings impoundment.

Responses to be measured and evaluated include seed germination, transplant survival, growth and density. Initial measurements will be taken annually for a minimum of three years. Evaluations will include destructive sampling to examine root development after three years and subsequently as necessary. Monitoring of this study will extend for at least fifteen years in order to demonstrate the indicators of success for final closure. Monitoring measurements such as growth, survival, cover and production in grass/forb areas will be on an annual basis from years five to fifteen.

The revegetation test plot program will be implemented following the approval of the revised closure plan. The design of the various test plots (size, number of replicate plots etc.) will follow standard plant research techniques. The studies will be evaluated using appropriate statistical methods and procedures. When necessary the studies will be designed and implemented in consultation with New Mexico State University research faculty, USDA Natural Resources Conservation Service research personnel and/or other consultants.

4.3.4.2 Storage Cover Test Plot Study

A storage cover test plot study will be conducted upon approval of the revised closure plan in order to evaluate the net infiltration, or cover flux, through the proposed storage cover. It is intended that this test plot program will be installed in the field in the summer of 1999. This allows for detailed design of the test plot program and review by NMED during the winter of 98/99. The cover test plot study was designed to meet the following objectives:

- measure climatic conditions at the site;
- measure in-situ material properties (characteristic curves); and
- calibrate a soil-atmosphere model in order to predict net infiltration.

It is important to recognize that the primary objective of the test plot study is <u>not</u> to measure cover fluxes per se but instead, to calibrate the soil-atmosphere model for known (measured) boundary conditions. The ultimate goal is to use the calibrated soil-atmosphere model to predict with a high degree of confidence the performance of the storage cover for conditions relevant to final closure (i.e. deep, unsaturated tailings profile; mature vegetation; range of climatic conditions). These final closure conditions cannot, of themselves, be duplicated in a field trial of only a few years, but instead have to be simulated.

A total of three cover test plots will be instrumented to measure the performance of three different combinations of cover thickness and vegetation development (see Figure 4-4):

Cover Test Plot #1: old 9” thick alluvial cover with mature shrub vegetation overlying in-situ sandy tailings (very deep tailings profile);

Cover Test Plot #2: 9” thick alluvial cover with no vegetation overlying back-filled sandy tailings (~2.5 m deep tailings profile); and

Cover Test Plot #3: 36” thick alluvial cover with no vegetation overlying back-filled sandy tailings (~2.5 m deep tailings profile).

Cover test plot #1 is most representative of post-closure steady-state conditions, i.e. with a mature vegetation established on the alluvial cover which overlies undisturbed hydraulically placed tailings, i.e. the ‘natural’ condition. This cover test plot is designed as an open system, i.e. the monitoring instrumentation will be installed into the existing cover and tailings profile (without prior excavation). Any excavation of the cover and tailings profile would destroy the root system of the vegetation, which is considered a vital component of this cover system, as well as the ‘natural’ soil structure and density of the hydraulically placed tailings. Cover test plot #1 will be used to calibrate the soil-atmosphere model against measured changes in soil moisture and soil suction over time. The calibrated soil-atmosphere model of cover test plot #1 will be used to predict the net flux through a mature cover system for post-closure steady-state conditions.

Cover test plots #2 and #3 represent closed systems or “lysimeter plots”, in which the test plot is lined to capture all moisture entering the cover-tailings system (Figure 4-4). This approach has the advantage that the critical performance parameter, i.e. net flux at the base of the cover system, can be measured directly. However, the lysimeter design will differ from in-situ conditions in two ways. First, the properties of the mechanically placed, back-filled tailings may differ from those of the in-situ tailings. Second, a water table is introduced at the base of the lysimeter plot, which will influence the soil moisture profile in the overlying cover system. The lysimeter approach is conservative in a sense that both of these factors tend to result in greater net fluxes through the cover.

Cover test plots #2 and #3 will be used to calibrate the soil-atmosphere model against measured net fluxes. Note that the (known) effects of the lysimeter design (e.g. shallow depth of tailings) can be taken into account during model calibration. These cover test plots will be kept free of vegetation for two years in order to allow the calibration of the soil-atmosphere model without the complexity of root transpiration (i.e. evaporation is the only mechanism of soil water removal from the lysimeter plot). In year three, cover test plots #2 and #3 will be vegetated according to the methods outlined in the re-vegetation plan (Section 4.3). The observed net fluxes in cover test plots #2 and #3, in conjunction with model predictions for a deeper tailings profile, will allow an evaluation of the effect of cover thickness on cover performance immediately after closure. A comparison of the model predictions for test plots #1 and #2 will demonstrate the relative importance of evaporation versus evapotranspiration in cover performance.

The three cover test plots will be set up in the Section 35 Tailings Area located between Dam 1 and Dam 1C (Figure 4-5). This location has been selected for three reasons. Firstly, this tailings area has been covered for almost 25 years, which allowed the establishment of a mature shrub vegetation on the cover material (Photo 16). In other words, the conditions encountered here represent very closely those anticipated for post-closure steady-state conditions. (net infiltration minimized by evapotranspiration of a mature shrub vegetation). Secondly, the tailings in this area consist of coarse tailings, which are expected to allow greater net infiltration than fine tailings (see Section 4.3.3). The coarse tailings also represent the predominant size fraction in any of the tailings impoundments (see Section 3.1.2). Hence, the study of cover performance on sandy tailings will yield conservative and most representative estimates of net infiltration. Thirdly, no future tailings discharge is planned in this tailings area providing stable test and hence model boundary conditions into the future, a deep unsaturated tailings profile, and continued access to the site.

Field performance of each test plot will be monitored by a system designed to measure climate conditions, changes in moisture conditions within the storage cover and in the underlying tailings, and net infiltration to the underlying tailings. All monitoring instrumentation will be controlled by data acquisition systems (DAS) powered by a battery/solar panel system. Monthly data collection (laptop computer) and maintenance by mine site personnel will be required. In the following discussion we briefly summarize the components of the preliminary field performance monitoring system. The preliminary field performance monitoring system, designed by O'Kane Consultants Inc., is described in detail in Appendix B.

The field performance monitoring system was designed to measure the components of the equations:

$FT = \Delta S + NSF$, and

$NSF = PPT - AET - RO$

where:

- FT is the net flux (percolation) into the deep tailings from the base of the storage cover system,
- ΔS is the change in soil moisture storage within the cover layer and tailings,
- NSF is the net surface flux,
- PPT is precipitation,
- AET is the actual evaporative flux, and
- RO is runoff.

The preliminary field performance monitoring system does not include provisions for measuring surface runoff. Surface runoff is considered to be minimal because the test plot area is essentially flat.

A fully automated meteorological station will be used to measure precipitation, wind direction, wind speed, net radiation, air temperature, and relative humidity (see Appendix B). The latter four parameters are used to calculate potential evaporation. The proposed components measured by the meteorological station are highly site specific and will be measured at the test plot area (Figure 4-5) to properly evaluate atmospheric boundary conditions for future numerical model calibration. The sensors will be mounted on a 30 foot tower anchored to the surface using a small concrete pad and guy wires. The meteorological station will have a stand alone data acquisition system.

A fully automated Bowen Ratio System (BRS) will be used for measuring actual evapotranspiration (see Appendix B). The Bowen Ratio is the ratio of sensible heat loss from the surface to the atmosphere and the energy utilized for evaporation. The latter term is calculated based on measurements of net radiation, total soil heat flux, and the gradient of temperature and vapour pressure above the surface. The actual evapotranspiration rates are highly site specific. Hence the Bowen Ratio System will be moved in regular intervals among the three test plots to obtain representative data for all three sites.

Changes in soil moisture storage will be measured using soil matrix suction sensors and water content sensors installed into the cover layer and underlying tailings profiles of each test plot (Appendix B). Soil matrix suction is measured using a thermal conductivity sensor that indirectly measures matrix suction while also providing an in-situ temperature measurement. Field matrix suction values provide a means of verifying field water content measurements. In addition, the hydraulic conductivity of the unsaturated soil material can be determined based on the response time of a matrix suction sensor. Finally, the hydraulic gradient, or direction of moisture flow can be evaluated based on matrix suction measurements.

Field soil water characteristic curves (SWCC) for future numerical modeling can be developed using regular soil suction and soil water content measurements at the same time and depth within the cover system profile. A total of 10 pairs of soil suction and water content sensors will be installed in each test plot (see Figure 4-4 for a preliminary design of the vertical spacing of the sensors).

The net flux, or percolation, from the base of the cover system into the underlying tailings will be monitored in the lysimeter plots #2 and #3 (Figure 4-4). Two piezometers will be installed in each lysimeter to measure the volume of water reporting to the base of the lysimeter. The first containing a sensitive pressure transducer connected to the DAS and the second serving as a back-up which could also be used for manual measurements of the lysimeter water level (Figure 4-4).

The net flux is back-calculated from the observed rise in the water table in the lysimeter plots using the soil water characteristic curve and the void ratio of the material being wetted. The more accurate these soil parameters are known the more accurate will be the estimate of net flux. It is proposed to place a basal layer of uniform sand with a hydraulic conductivity greater than that of the overlying tailings in the bottom ~0.5m of the lysimeter plots (Figure 4-4). The uniformity of the material would ensure a more accurate calculation of net flux through the cover based on readings of the rise in the water table.

The piezometers also serve as sampling points for tailings pore water for water quality analyses. Water quality sampling will be conducted annually to provide insight into the water quality of tailings pore water accumulating at the base of the lysimeter plots, i.e. just below the storage cover.

Two conceptual designs are being considered for construction of the lysimeter plots (Figure 4-6). In option 1, the lysimeters would be installed by excavating into the existing tailings with a backhoe to create an inverted truncated pyramid excavation with 1.5:1 side slopes (Figure 4-6). The sloping sidewalls are dictated by the need for safety during construction and cost. The walls would be lined with a textured HDPE product to the elevation of the cover surface creating a closed system for each lysimeter. In this option, the lysimeter would be approximately 2.5m deep and have a foot print area of approximately 7.5m x 7.5m at the bottom and approximately 15m x 15m at the surface. In this design option, a significant portion of the lysimeter plot has a tailings thickness less than the design depth of 2.5m thus introducing 2D flow effects. The HDPE liner could be folded back near the tailings surface (within the cover layer) to prevent any atmospheric fluxes in those areas of the lysimeter plot, which lie outside of the basal foot print (see Figure 4-6).

In option 2, a circular, pre-cast manhole unit or a circular tank would be lowered into the excavation to provide shoring and, at the same time, provide an impermeable wall for the lysimeter plot (see Option 2 in Figure 4-6). The manhole unit or tank could be made of concrete, steel or reinforced fiberglass. The inside walls of the manhole unit or tank would have to be lined if the material is chemically active and could possible influence tailings pore water quality (i.e. concrete or steel). Option 2 has the advantage that there are no two-dimensional flow effects due to the vertical walls of the lysimeter plots. This way, the dimensions of the lysimeter plot can be kept considerably smaller. The diameter of such a circular lysimeter plot is more controlled by logistics during construction than by boundary effects. A diameter of about 3m would probably be sufficient to allow easy handling of tailings material during back-filling as well as instrument installation within the lysimeter.

Two-dimensional (2-D) saturated-unsaturated modeling will be done before finalizing the design of the field lysimeters. The parameters to be finalized as part of this modeling program are:

- geometry and dimensions of lysimeter plots #2 and #3;
- required thickness of tailings below cover layer;
- thickness and type of bottom drain layer; and
- vertical spacing of soil suction and moisture content sensors.

The design of the lysimeter plots should be finalized once preliminary modeling of various test plot configurations has been completed and other issues such as material availability, costs and local safety regulations have been reviewed. This initial design phase is included in the costing of the cover test plot study (see Appendix B for details).

As outlined earlier the primary objective of the cover test plot study is the calibration of a soil-atmosphere model. It is proposed to use the finite element code SOILCOVER, developed by the University of Saskatchewan, for interpretation of the cover test plot results. SOILCOVER is a one-dimensional finite element model, which simulates the exchange of water and energy between the atmosphere and the soil profile. The theory is based on the well known principles of Darcy's

Law and Fick's Law, which describe the flow of liquid water and water vapour, and Fourier's Law to describe conductive heat flow in the soil profile (University of Saskatchewan, 1997). SOILCOVER predicts the evaporative flux from an (un)saturated soil surface on the basis of atmospheric conditions, vegetation cover, and soil properties and conditions. The model is also capable of modeling the effects of freezing conditions within the soil profile.

After the completion of one year of monitoring an initial model calibration will be performed for each test plot in order to determine, whether the cover test plots have stabilized (i.e. recovered from initial disturbance during construction). At this time any potential problems with the instrumentation and/or the cover test plot design may also be rectified. Final model calibration will be performed once two years of monitoring data are available past the initial stabilization period. The calibrated model will then be used to predict the net fluxes through the various cover alternatives for long-term closure conditions.

The monitoring of cover test plots #2 and #3 may optionally be continued until closure to observe the change in net infiltration with a maturing cover vegetation.

4.4 Drainage Plan

The regional hydrology and drainage pattern, as well as the diversions of flows around the tailings impoundment are described in Sections 2.2, 2.3, 3.1.1 and 3.2.1. The objective of the Drainage Plan is to provide for long-term stable diversion of flows around the tailings impoundments and for the drainage of water from the surface of the tailings impoundments.

4.4.1 Diversions

The final tailings surface will be above the general terrain such that the tailings will represent a 'mound' with low drainage 'valleys' represented by the west and east diversion ditches on either side of this mound. These diversions therefore become permanent drainage channels. These channels were originally designed for peak flood discharges calculated using the US Soil Conservation Service design standards and criteria for low hazard and flood control facilities. Typical sections for these channels are shown in Figure 3-7 and the plan locations on Figures 2-3 and 4-1. During the more than 25 years of operation there have been no observed flows in the west diversion channel indicating that the run-off from the permeable volcanic bedrock which underlies much of its catchment is very low. The east diversion channel receives a small flow from spilled irrigation ditch water but again there have been no recorded high flows during storm events, due probably to the relatively high permeability of the alluvium and the nearly flat upper catchment topography. Inspection of the ditches indicated no signs of erosion (Photo 2). This suggests that the current design is very conservative.

A summary memorandum on the selection of an appropriate design event, and the ability of the diversion ditches to pass this flow, prepared by Vail Engineering, is provided as Appendix F. Post-closure, there will be no water storage behind any dams and thus no potential for the dams and diversion structures to increase flood flows. Also there is no significant development along the downstream flow channel. Therefore the appropriate flood control Hazard Rating would be

'Low'. The diversion ditches, as constructed, are able to pass double the SCC design flood flow without overtopping. Review of the design of the diversion ditches by Vail Engineering indicates that the existing diversion channels can pass this flood event within the existing channels with an increased flow depth that falls within the design freeboard. This is considered an appropriate criterion for long term event design, particularly given the likely conservatism of the run-off estimates. No increase in diversion ditch size or change in design is proposed.

Some minor earthworks are required to extend the western diversion ditch another 50 yards to ensure that it will discharge to the natural side hill drainage and not flow downslope to erode Dam No. 4. The end of the western diversion ditch is in rock so that there is no risk of down-cutting erosion during a large precipitation and run-off event. The requirement for the breaching of the Pope Lake embankment has been discussed in the Surface Shaping Plan (Section 4.1).

4.4.2 Surface Drainage, Channels and Spillways

Surface drainage from the tops of the tailings impoundments will be collected in shallow riprap lined swales constructed on the tailings surface as shown in Figures 4-1 (plan) and 4-7 (section). The purpose of these swales is to collect surface run-off in erosion resistant riprap lined channels. The channels break up the drainage path lengths reducing the potential for concentrated flows on the cover surface. The swales drain to the drainage channels discussed in Section 4.1. These channels are also riprap lined as shown in Figures 4-8a, 4-8b, and 4-8c. Outlet structures are required to spill flow from each of the five impoundment areas into the downstream receiving channel without causing erosion. Different designs will be applicable depending on the height of the discharge drop (hence energy to be dissipated) and the foundation conditions. Three conceptual designs are illustrated in Figures 4-8a to 4-8c. Typical details for both concrete drop structures and riprap lined spillway channels may be appropriate. Detailed designs will be prepared once the final impoundment geometry at each outlet structure becomes known as the impoundment approaches closure, i.e. when the first impoundment area is being prepared for final closure (about 5 years before final closure).

The final shaping plan and the outlet structures anticipate that minimum pond elevation would be about 5 ft above the invert level of the west diversion channel. This is sufficiently great that it exceeds the theoretical maximum flow height in the diversion ditch in all but extreme events. During such extreme events, when flow heights rise to above the base of tailings elevation, water may back into the tailings impoundment causing temporary flooding of the lower portions of the covered tailings surface. This would result in temporary submergence (hours) of some of the vegetation. No adverse impacts are foreseen from such very rare events.

4.4.3 Erosion Control

The gravel alluvium has a high percentage of gravel and is resistant to sheet erosion, even for steep slopes. This conclusion is well demonstrated by the negligible erosion that is observed on the interim cover (Photo 14) as well as the dam faces (Photos 4 to 6) and the sidewalls of the diversion ditch excavations (particularly in the deep cut near the discharge end of the east diversion ditch) (Photo 2). This erosion resistance will be further increased as the re-vegetation develops to maturity. No additional erosion stabilization measures are proposed.

4.5 Revegetation Plan

4.5.1 Introduction

The revegetation plan that follows is slightly modified from previous submissions to the New Mexico Environment Department as part of DP-933. However, the long term end result will be the same as previously indicated, the only differences exist in the short term projections for the tailings facilities. The revegetation of the tailings facilities will result in an area vegetated with woody shrubs and trees, as well as some grasses and forbs. The projected use (or Post-Mining Land Use) is for open space with wildlife use being the predominant use. This is discussed later in Section 4.8. It should be noted here that this plan will also be submitted as a revision to the Closeout Plan previously submitted to the New Mexico Mining and Minerals Division.

Previous revegetation plans focused on the vegetation serving three functions: 1) to stabilize the cover (dust control); 2) to meet an appropriate land use; and 3) for erosion control (water). This version of the plan adds a fourth function, which takes into account the amount of water used by the plant community. In other words, the vegetation is now recognized as an integral part of the cover design. In designing and modeling the cover, woody shrubs and trees were anticipated to be the climax community. This assumption was based on evidence of the encroachment by woody species in areas previously seeded with grasses and forbs. This seeding occurred from the 1970s through 1994. In particular, the species invading the site are big *sagebrush (Artemesia tridentata*) and rubber rabbitbrush (*Chrysothamnus nauseosus*) (Photos 16 to 18). The natural encroachment of woody species and knowledge of the pre-existing vegetation at the site indicate that the area will become primarily a woody shrub and tree ecosystem. In light of this evidence, the modified revegetation plan for the site will focus on the establishment of woody shrubs and trees.

In order to achieve the goal of a self-sustaining woody shrub and tree ecosystem in the shortest amount of time possible, the revegetation plan will be modified. In the past, woody shrubs and trees were a minor component (if a part at all) of the seed mix. The previous seeding mixes were used to establish grasses and forbs, while woody shrubs and trees were allowed to encroach naturally. In this plan, the primary component of the initial seeding and planting program will be woody shrubs and trees. By seeding and planting woody shrubs and trees, the desirable species will be established in a much shorter time frame.

The revegetation plan is designed with the end goal of ensuring a self-sustaining ecosystem comparable to the surrounding area. In order to achieve that goal, it is important to consider the dominant plant type desired, the species necessary to ensure a successful reclamation project and the requirements of not only establishing plants but of long term growth and survival. All of these factors have been carefully evaluated in designing the revegetation plan for the site. In addition, research conducted by the USDA SCS (1980-1986) provides important information and data for the planning. Appendix E contains background information on research, soil analysis, etc.

Lastly, because of the past operational practices, many areas of the tailings ponds have been covered with topsoil and seeded successfully over the years. The vegetation is well established at the site and the site can be considered a large test plot that continues to provide evidence of a successful revegetation program (see Photos 16 to 20 and Appendix E for more detail).

The revegetation plan has three main components: the conceptual design, the planting methods and techniques, and establishment period maintenance requirements. Post-establishment monitoring and associated issues are discussed in Section 4.7. The conceptual design is intended to give an overview and general picture of the final configuration of the revegetation plan. Details are of course subject to the actual elevations and contours at closure. The planting methods and techniques describe the process of implementing the revegetation plan and following these will ensure a successful program. The methods and techniques are based on accepted practices, knowledge and experience in establishing plants in the region. The establishment period maintenance requirements are often underestimated in their importance. The period for establishment and supplemental maintenance is three years post planting and will allow for the successful establishment of a plant community that will develop into a self-sustaining ecosystem.

4.5.2 Conceptual Design

The conceptual design encompasses the plant community types to be established, the species that may be planted in each type and the locations of each plant community type. For this plan, four different community types are planned, see Figure 4-9 for locations. Planting the distinct community associations adds an additional layer of diversity to the site, while allowing for the successful establishment of various plant types. Plant types have been categorized into three broad types: trees, shrubs and grasses/forbs. The communities are described below in general terms, the actual planting composition and seed mixes can be found in Table 4.2. Species to be selected from can be found in Table 4.3 and sample seed mix can be found in Table 4.4.

Table 4.2

Composition of plant types for plant community to be planted.

Plant Zone	*% Trees* / No. of species*	*% Shrubs / No. of species*	*Grasses/Forbs Seeding Rate*
Piñon-Juniper Woodland	75% / 2 species minimum	25% / 2 species minimum	15 PLS / ft^2 (drilled rate) 10 PLS / ft^2 (hydroseeding)
Mixed Woodland & Shrubland	50% / 2 species minimum	50% / 3 species minimum	15 PLS / ft^2 (drilled rate) 10 PLS / ft^2 (hydroseeding)
Shrub Community	<10% / 1 species minimum	90% / 3 species minimum	15 PLS / ft^2 (drilled rate) 10 PLS / ft^2 (hydroseeding)
Grasses and Forbs	None	None	35 PLS / ft^2 (drilled rate) 20 PLS / ft^2 (hydroseeding)

- *Percentage of trees and shrubs refers to transplanting numbers only.*

Table 4.3

Species that may be used for planting and seeding at the tailings ponds; species noted by * are the primary species that will be used.

Species – Common Name	***Species – Scientific Name***	***Plant Type***
Piñon Pine*	*Pinus edulis*	Tree – Conifer
Juniper (Rocky Mountain)*	*J. scopulorum*	Tree – Conifer
Juniper (Alligator)	*J. deppeana*	Tree – Conifer
Juniper (Eastern Red Cedar)	*J. virginiana*	Tree – Conifer
Juniper (Utah)	*J. osteosperma*	Tree – Conifer
Juniper (One Seed)	*J. monosperma*	Tree – Conifer
Russian Olive	*Elaeagnus angustifolia*	Tree – Deciduous
Narrowleaf Cottonwood	*Populus angustifolia*	Tree – Deciduous
New Mexico Locust	*Robinia neomexicana*	Tree – Deciduous
Oak	*Quercus undulata, Q. turbinella, Q. gambelli*	Tree – Deciduous
Chokecherry	*Prunus virginiana*	Tree – Deciduous
Threeleaf Sumac	*Rhus trilobata*	Shrub
Buffaloberry	*Shepherdia argentea*	Shrub
Shadscale	*Atriplex confertifolia*	Shrub
Four-wing Saltbush*	*A. canescens*	Shrub
Winter-fat	*Eurotia lanata*	Shrub
New Mexico Foresteria	*Foresteria neomexicana*	Shrub

Table 4.3 cont'd		
Yellow Menodora	*Menodora scabra*	Shrub
False Indigo	*Amorpha fruticosa*	Shrub
Fernbush	*Chamaebatiaria millefolium*	Shrub
Cliffrose	*Cowania stansburiana*	Shrub
Apache-plume	*Fallugia paradoxa*	Shrub
Big Sagebrush*	*Artemesia tridentata*	Shrub
Fringed Sage	*A. frigida*	Shrub
Black Sagebrush	*A. arbuscula*	Shrub
Mountain Serviceberry	*Amelanchier oreophila*	Shrub
Utah Serviceberry	*A. utahensis*	Shrub
Rubber Rabbitbrush*	*Chrysothamnus nauseosus*	Shrub
Fremont Barberry	*Berberis fremontii*	Shrub
Mountain Mahogany	*Cercocarpus montanus*	Shrub
Mormon Tea	*Ephedra torreyana (viridis)*	Shrub
Cliff Fendlerbush	*Fendlera rupicola*	Shrub
Mockorange	*Philadelphus microphyllus*	Shrub
Hoptree	*Ptelea trifoliata (angustifolia)*	Shrub
Wax Currant	*Ribes cereum*	Shrub
Greasewood	*Sarcobatus vermiculatus*	Shrub
Summer Cypress	*Kochia prostrata*	Shrub

Table 4.3 cont'd		
Indian Ricegrass	*Oryzopsis hymenoides*	Grass – Cool Season
Blue Grama*	*Bouteloua gracilis*	Grass – Warm Season
Sideoats Grama	*B. curtipendula*	Grass – Warm Season
Hairy Grama	*B. hirsuta*	Grass – Warm Season
Little Bluestem*	*Schizachyrium scoparium*	Grass – Warm Season
Western Wheatgrass*	*Pascopyrum smithii*	Grass – Cool Season
Galleta*	*Hilaria jamesii*	Grass – Warm Season
Cane Beardgrass	*Bothrochloa barbinoides*	Grass – Warm Season
Bottlebursh Squirreltail	*Sitanion hystrix*	Grass – Cool Season
Alkali Sacaton*	*Sporobulus airoides*	Grass – Warm Season
Mammoth Wildrye	*Leymus racemosus*	Grass – Cool Season
Penstemon*	*Penstemon palmeri*	Forb – Perennial
Canyon Penstemon	*Penstemon pseudospectabilis*	Forb -
Fendler Beardtongue	*Penstemon fendleri*	Forb -
Lewis Flax (Blue Flax)	*Linum lewisii*	Forb – Perennial
Small Burnet	*Sanguisorba minor*	Forb – Perennial
Louisiana Wormwood	*Artemesia ludoviciana*	Forb – Perennial
Buckwheat*	*Eriogonum sp.*	Forb -
Fleabane	*Erigeron sp.*	Forb -
Aster*	*Aster tanacetifolius*	Forb – Perennial

Table 4.4

Sample seeding mix and rates for grass/forb areas only.

Plant Species	***Scientific Name***	***Seed / Pound***	***Pounds PLS/Acre Drilled***	***Pounds PLS / Acre Hydroseed***
Western Wheatgrass	*Pascopyrum smithii*	110,000	3.2	2.9
Indian Ricegrass	*Oryzopsis hymenoides*	141,000	2.5	2.3
Galleta	*Hilaria jamesii*	159,000 (floret)	0.8	0.7
Blue Grama	*Bouteloua gracilis*	825,000	0.6	0.5
Penstemon	*Penstemon palmeri*	610,000	0.3	0.3
Aster	*Aster tanacetifolius*	496,000	0.1	0.1

The first community type is the piñon – juniper woodland (Photo 21). This type will consist of planting all plant types. The major component will be trees such as piñon and juniper. Planted to a lesser extent, and making up a minor component of the type will be shrubs. Grasses and forbs will be seeded at a lower than standard rate (see Table 4.2 for seeding rates) to minimize competition with woody species while allowing for the establishment of the understory grasses and forbs. The second community type is the mixed woodland and shrub community, which is a transition between the woodland and shrub type communities. Nearly equal percentages of trees and shrubs will be planted in this type. Again, grasses and forbs will be seeded at the reduced rates. The third community type is the shrub community comprised of mainly shrub species (see e.g. Photo 22). It is possible that up to 10% of the total planting will be trees. Grasses and forbs will be seeded at similar rates to the first two community types. The last type is the grass and forb community, which will be seeded with grasses and forbs only, at standard seeding rates and no woody plants will be planted. These areas will be buffer strips between various community types and also occur in small areas at the west edge of individual ponds. These areas will add diversity and also provide somewhat quicker cover and eliminate the slight possibility of surface erosion during the establishment phase of the project.

4.5.3 Planting Methods and Techniques

The planting methods and techniques to be used follow standard reclamation seeding and transplanting practices. Seeding rates will be dictated by the plant community type and can be found in Table 4.2. Seed generally will be sown by drilling following standard agronomic practices and done either in the spring or fall. If drilling is not feasible, seed will be sown by hydroseeding using manufacturers recommended rates for mulch and tackifier. In areas where access is a problem, seed will be sown by hand broadcasting. Seed will be purchased from reputable seed dealers and will be certified seed when available. In some cases seed may be custom collected from on or near the site. In general, the species to be sown will be grasses and forbs, although some shrubs may be seeded as well (e.g., rubber rabbitbrush).

Most woody species will be transplanted in the spring, late summer or early fall. Plants will be placed on an average spacing of 10 ft. by 10 ft. The seedlings will be container grown, although bareroot stock may be used when appropriate. Containerized seedlings will be grown in a four cubic inch container or larger in order to be suitable for transplanting at the site. When possible, the seedlings will be transplanted using a mechanical transplanter developed for forest plantings. Hand transplanting will be used in all other cases following established guidelines and techniques. If necessary, grasses and forbs may be cleared from near planting sites prior to transplanting to allow the transplants to become established. No fertilizer will be applied with transplanting or in the year of seeding.

4.5.4 Establishment Period Maintenance

The establishment period maintenance will occur during the first three growing seasons following planting and seeding. During this time the plants will be monitored closely and appropriate management practices will be based on the monitoring. Fertilizer may be applied during this period if deemed necessary to ensure good plant establishment. Other practices that might be necessary include weed control, pest control and augmented seeding or transplanting if excessive mortality occurs. Based on the previous success of vegetation at the site it is anticipated that little management and input will be needed during this period. However, the monitoring will ensure that successful plant establishment occurs.

Since the five impoundment zones will become available for progressive reclamation over at least five years prior to closure, the successful completion of revegetation (including the establishment maintenance period) for the first zone should be complete before the last zone becomes available for reclamation. Thus the effectiveness of the revegetation should be well established prior to initiating the planting and maintenance periods for the last zone.

4.6 Seepage Interception Plan

A seepage interception system is currently in place down-gradient of the Questa tailings facility to ensure that no groundwater or surface water state standards are being violated during current and future tailings operation (see Sections 3.1.5 and 3.2.5). This interception system is operating successfully and provides a logical basis for developing a seepage interception plan for closure of the facility. Nevertheless, alternative methods of seepage interception are available and have been considered for the post-closure interception system (Section 4.6.1). The post-closure interception system should be designed to handle any future changes in the seepage pattern from the tailings impoundments which may result from closure of the facility. Predictive modeling of post-closure seepage flows and water quality was conducted to evaluate the requirements for the seepage interception system after closure (Section 4.6.2). Based on these seepage flow and water quality predictions a post-closure seepage interception plan has been developed (Section 4.6.3).

4.6.1 Alternatives Evaluation

The following options were evaluated for use in the post-closure seepage interception system:

- cut-off walls to prevent downstream migration;
- interceptor drains to passively intercept seepage;
- extraction wells to actively intercept seepage; and
- “biobarriers” to treat seepage in-situ.

Cut-off walls typically consist of slurry walls or sheet piling which is placed in the pathway of contaminated seepage to prevent downstream migration. However, cut-off walls by themselves represent only a short-term solution. The storage capacity upgradient of these flow barriers is finite and seepage will eventually flow above, below, or around the cut-off walls. Hence, extraction wells would still be required to extract the seepage which will accumulate upgradient of the cut-off wall. Considering the very high cost of such cut-off walls and their limited benefit, cut-off walls were not selected for the post-closure interception plan.

Interceptor drains consist of trenches (typically less than 30 feet deep) into which drain pipes are placed. These interceptor trenches are typically back-filled with very permeable material such as coarse gravel to facilitate flow of seepage water into the drain pipe. The collected seepage is either drained by gravity or pumped from a collection sump. Interceptor drains are very efficient in intercepting shallow seepage (if designed properly, virtually all seepage along the depth of the drain will be intercepted). Several interceptor drains are successfully intercepting shallow seepage downstream of Dam 1 at present (see Section 3.1.5).

Extraction wells are used to pump seepage from a desired depth interval of the aquifer system. During pumping the piezometric head at the well is lowered creating a capture zone within which all seepage is flowing towards the well. Extraction wells are often used in combination with either cut-off walls or interceptor drains. They require more maintenance than interceptor drains but can be used to intercept seepage at greater depths than typically achieved with interceptor drains. Pumping of the extraction wells has to be monitored and controlled to avoid pumping of surrounding groundwater not impacted by contaminated seepage. A system of extraction wells is easily adapted to varying seepage conditions by either adding more wells or shutting down wells depending on observed trends in seepage water quality. Extraction wells are currently used to assist in intercepting shallow seepage down-gradient of Dam 1.

Biobarriers do not represent a physical barrier to flow but act as a chemical barrier in which contaminated seepage is treated in-situ. In most applications a trench would be excavated and back-filled with chemically active material designed to treat the contaminants of the seepage water. For seepage with elevated sulfate and metals concentrations typical for tailings seepage, a reducing material such as organic waste would be used. However, the concept of bio-barriers is still considered experimental technology. In particular the question of longevity of the reactive material and maintenance of the biobarrier has to be further researched and developed.

The combined use of interceptor drains and extraction wells was selected for the post-closure interception system for the following reasons:

i. interceptor drains and extraction wells are already installed on site and readily available;

ii. interceptor drains and extraction wells represent a flexible technology which has been demonstrated here and at other sites; and

iii. a combination of interceptor drains and extraction wells are the most cost-effective alternative.

At present, there appears to be no technical, environmental or cost advantage to placing biobarriers in lieu of the existing interception system. However, we recommend that the option of placing biobarriers be revisited, once the design and performance of biobarriers has been researched. Biobarriers may offer a lower cost alternative to seepage interception, in particular at that time after closure when there will be no active maintenance required at the site, except perhaps for maintenance of the interception system.

4.6.2 Post-Closure Seepage Quantity and Quality

4.6.2.1 Section 35 Tailings Area

The transient seepage flows from the Section 35 Tailings Area (behind Dams 4 and 5) were evaluated using a saturated/unsaturated flow model (RGC 1997a). The tailings in Section 35 are located on top of very permeable volcanics covered only by a thin layer of alluvial sediments. The water table in the underlying volcanic aquifer is several hundred feet below the base of the tailings (see Section 2.5). Under these conditions it can be assumed that the tailings at the base of the tailings are free-draining, i.e. there is no resistance to flow out of the tailings impoundment.

It was further assumed that tailings seepage in Section 35 is essentially vertical with negligible horizontal flow components. This is a conservative assumption in so far that the resulting time to steady-state is greater than if horizontal flow (through permeable berms or dams) would take place. Note, that the upstream face of Dam No. 4 has been lined with asphalt and geomembrane liners resulting in very low seepage rates through this dam (no seepage has been observed in recent years below the toe of this dam) which is consistent with the assumption of vertical seepage flow.

Transient flow within the tailings of Section 35 was modeled in a vertical column of unit cross-sectional area and a representative height of 150 feet. Initially, the tailings were assumed to be completely saturated with the water table at the tailings surface. The tailings were then allowed to drain freely at the base resulting in a gradual dewatering of the tailings column.

The placement of a soil cover onto the tailings reduces the net infiltration (recharge) into the tailings profile. A detailed modeling of the seasonal processes of infiltration into and evapotranspiration out of the cover indicated that the annual net infiltration through a 9 inch thick alluvial soil cover would be about 1.1 and 0.4 inches per year for coarse tailings and fine tailings, respectively (see Section 4.3.3). These representative infiltration rates were applied to the top of the tailings as a steady-state surface flux. For more details on the numerical methods and model assumptions the reader is referred to RGC (1997a).

Figures 4-10a and 4-10b show the simulated decline in tailings seepage for the coarse and fine tailings, respectively. The modeling results suggest the following with respect to dewatering of the tailings in time:

- the tailings begin to dewater whenever the surface flux into the tailings is reduced to less than the vertical (saturated) hydraulic conductivity of the tailings; the coarse tailings of the tailings impoundments at Questa are sufficiently permeable to allow natural dewatering, even without cover placement; the fine tailings probably require a cover to achieve dewatering;

- seepage fluxes at the base of the tailings ("seepage losses") decrease exponentially with time (assuming the tailings are allowed to drain by discontinuing discharge of tailings slurry and/or by placing a soil cover) (Figure 4-10a/b); and

- the time to reach steady-state conditions after closure, i.e. when seepage losses equal net infiltration through a soil cover, are estimated to be in the order of 27 – 37 years for the coarse tailings (Figure 10a) and 50 to 70 years for the fine tailings (assuming free drainage at the base of the tailings) (Figure 4-10b).

At present the water quality in the underlying volcanic aquifer meets New Mexico Ground Water Standards. For example, sulfate concentrations in MW 11, located just down-gradient of Dam 4, are currently about 120 mg/l SO4, i.e. five times lower than the New Mexico Ground Water Standard of 600 mg/l SO4 (see Section 3.1.6). The very low impact of tailings seepage on the deep, volcanic aquifer is a result of the much larger flows of deep groundwater relative to tailings seepage. Using the local groundwater flow model developed for the site, the underflow of deep groundwater beneath the Section 35 Tailings Area was estimated to be about 5.4 cfs (RGC 1997a). Seepage losses from the Section 35 Tailings Area were estimated to be in the order of 0.5 cfs assuming similar dewatering rates as observed in Section 36 Tailings Area during the temporary shut-down in the early 80's (Geocon 1983). These estimates are consistent with observed rates of dilution of sulfate in seepage originating from the tailings impoundments. The relative proportion of tailings seepage is estimated to be about 5-8 % of total flow in the deep groundwater system assuming a range in source concentration of 800-1130 mg/l sulfate.

The transient seepage modeling results suggests that, once the final cover has been placed, the seepage losses from the Section 35 Tailings Area will decline exponentially resulting in even greater dilution of tailings seepage in the deep volcanic aquifer. Under these anticipated conditions a seepage interception system will never be required down-gradient of the Section 35 Tailings Area.

4.6.2.2 Section 36 Tailings Area

A detailed two-dimensional saturated/unsaturated flow model was developed to simulate seepage from the Section 36 Tailings Area (behind Dam 1 and Dam 1C) and to predict seepage water quality trends after closure (see Appendix A). Figure 4-11 shows the conceptual model of the tailings impoundment and the underlying aquifer/aquitard system. Note the vertical exaggeration (1 x 7) in this and subsequent cross-sectional drawings.

The spatial distribution of the tailings represents the tailings deposition history; i.e. tailings were initially discharged from the northern dam sections with process water ponding against Dam 1. Subsequently, the pond area was pushed towards the north by spigotting predominantly from the southern dam sections.

Using information on soil stratigraphy obtained from borehole logging and field reconnaissance, the complex system of alluvial sediments below the tailings impoundment was conceptualized as follows. A permeable “basal aquifer” unit was assumed to be present at the base of the tailings impoundment, underlain by a “basal aquitard” unit, i.e. a semi-confining bed of clayey silt, running approximately parallel to the original ground surface (Figure 4-11). This semi-confining layer represents a leaky barrier to vertical seepage from the tailings impoundment allowing some vertical seepage into deeper aquifer units while forcing some of the tailings seepage to flow horizontally (under perched conditions) beneath the toe of Dam 1. This conceptual model is consistent with water quality surveys, which show that shallow seepage consists predominantly of tailings pore water whereas deeper seepage consists predominantly of natural groundwater (see below).

A detailed description of the numerical methods is provided in Appendix A.

The cross-sectional model was initially run at steady-state to calibrate the seepage model against current conditions to the extent possible. The steady-state seepage model was calibrated against the following field observations (see Appendix A for more details):

- observed elevation of phreatic surface in Section 36 impoundment;
- observed areas of ponding on tailings surface;
- estimates of total seepage flows based on drawdown of phreatic surface (Geocon, 1983);

- observed flow rates of shallow tailings seepage intercepted at toe of Dam 1 (in EW 5 series); and
- observed flow rates of deep tailings seepage intercepted downgradient of Dam 1.

The calibration targets and simulation results are summarized in Table 4.5. Figure 4-12 shows the total hydraulic head distribution for the calibrated steady-state flow model. The flow vectors indicate the direction of flow and are scaled in proportion to the magnitude of the specific discharge for a given element.

It is seen that the basal aquitard represents a partial barrier to vertical movement of tailings seepage into the deeper aquifer layers. Hence a significant portion of tailings seepage accumulates in the overlying basal aquifer (forming a perched aquifer) and flows in a near-horizontal direction towards the base of Dam 1 (Figure 4-12). The basal aquitard is sufficiently leaky, however, to allow some of the tailings seepage to gradually leak through the aquitard and into the deeper aquifer units. About 2/3 of the total seepage from the tailings impoundment flows in the shallow basal aquifer ("shallow tailings seepage") at the toe of Dam 1 (Table 4.5). The remaining 1/3 of total seepage flow leaks vertically through the clayey silt layer and mixes with groundwater in the deeper aquifer units ("deep tailings seepage") (Table 4.5).

Table 4.5

Comparison of Calibration Targets and Simulation Results.

Parameter	***Calibration Target***	***Simulated***
Phreatic Surface below Dam 1C (in feet a.s.l.)	7463 – 7503	7465
Phreatic Surface north of Dam 1 (in feet a.s.l.)	7430 – 7470	7430
Total Tailings Seepage (in cfs)	0.45 – 0.65	0.58
Shallow Tailings Seepage (in cfs)	0.32 – 0.42	0.37
Deep Tailings Seepage (in cfs)	0.13 – 0.23	0.21

The total head distribution of the calibrated steady-state solution was used as the initial condition for the transient run which simulates dewatering of the tailings. For the transient simulation, a cover was assumed to be present at the tailings surface, thus reducing surface fluxes into the tailings. Previous cover modeling suggested that the long-term flux through a vegetated alluvial cover (9 inches thick) would be 0.4 inches/year ($9.1 \cdot 10^{-5}$ ft/day) over the fine tailings and 1.1 inches per year ($2.5 \cdot 10^{-4}$ ft/day) over the coarse tailings (see RGC 1997a). For the purposes of this analysis it was assumed that the placement of the cover reduces surface fluxes initially to half of the (calibrated) steady-state flux of a given tailings unit. After that surface fluxes were assumed to decline exponentially reaching the long-term fluxes for a mature cover after about 10 years (see Appendix A for more details).

The simulated trends of total seepage (at base of tailings impoundments), shallow seepage and deep seepage are shown in Figure 4-13. The assumed surface flux through the cover is shown for comparison. The transient model indicates that total tailings seepage flux at the base of the tailings impoundment would decline exponentially in time (Figure 4-13). After about six to seven years the simulated total flux has declined to approximately 1/2 of the initial flux. The decline in the total flux gradually diminishes with time (Figure 4-13). Approximately 30 to 35 years after cover placement the total seepage flux leaving at the base of the tailings impoundment approaches the surface flux entering the tailings.

The shallow seepage flow also decreases very rapidly declining to 10% of its initial flux within ~12 years after cover placement (Figure 4-13). The transient model further suggests that shallow seepage in the basal aquifer would dry up completely after about 20 years (Figure 4-13).

The simulated deep seepage flow (i.e. tailings seepage flowing at the toe of Dam 1 below the basal aquitard) declines over a greater time period and more gradually than the shallow tailings seepage (Figure 4-13). The apparent delay in the decline of the deep seepage is caused by the fact that the deep seepage has to move through the (low permeable) basal aquitard and some unsaturated alluvial material before it mixes with the groundwater in the more permeable aquifer units below. The transient model suggests that the system reaches “post-closure steady-state”, i.e. when the deep tailings flux approaches the surface flux entering the tailings, approximately 35 to 40 years after cover placement (Figure 4-13).

The transient modeling results indicate that the flux of tailings pore water from the impoundment and into the underlying aquifer system will decrease significantly after final covering of the tailings. This reduction in tailings seepage volume will tend to reduce the total load of sulfate and molybdenum in the shallow and deep seepage currently being intercepted and/or monitored. However, as the tailings dewater, more and more tailings seepage will be derived from percolation of precipitation through the cover, which seeps through unsaturated portions of the tailings profile. This fresh infiltration water may pick up sulfate and molybdenum from the oxidizing tailings near the surface, possibly resulting in higher concentrations of these oxidation products than the present tailings pore water which consists to a large extent of process water deposited with the tailings. The net effect of decreased seepage volumes with increased sulfate, molybdenum and TDS concentrations was evaluated as follows.

The model predictions of transient seepage flows were used to estimate the effects of reduction in seepage flows on the water quality in the shallow and deep seepage down-gradient of Section 36 Tailings Area over time. The potential change in tailings pore water quality was accounted for by assuming a range of conditions for tailings pore water quality. The resulting estimates of transient water quality provide a first indication of how long the seepage interception system in Dam 1 arroyo will have to be operated after final cover placement. It is recognized, however, that our predictions of long-term water quality bear a significant degree of uncertainty and should not be used for scheduling of the shutdown of the interception system. Instead, the groundwater quality down-gradient of Dam 1 will have to be monitored, and the interception system will be shut down, if and when the monitoring demonstrates that the intercepted seepage meets all New Mexico Ground Water Standard concentrations.

Water quality predictions were made for three constituents, i.e. sulfate, molybdenum and total dissolved solids (TDS). The following approach was taken to estimate concentrations of sulfate, molybdenum and TDS in shallow and deep seepage over time. First, the current contributions of tailings pore water to shallow and deep seepage were estimated using recent sulfate concentrations observed in pore water and seepage water. Based on these mixing ratios the flows of shallow and deep groundwater, which receive tailings seepage (or pore water), were estimated. Next, the future concentrations in seepage water were calculated assuming conservative mixing of tailings pore water and receiving groundwater and assuming that the receiving groundwater flows remain constant whereas tailings seepage flows decline (as predicted by the 2D transient seepage model).

The following key assumptions are made in our approach to predict long-term trends in seepage water quality:

- for the purpose of seepage water quality predictions seepage flow at the toe of Dam 1 can be divided into two components: shallow seepage comprising shallow tailings seepage and shallow (perched) groundwater perched on top of a basal aquitard and deep seepage comprising deep tailings seepage and deeper groundwater below a basal aquitard;

- the rate of (shallow and deep) groundwater flow receiving tailings pore water seepage can be estimated using sulfate as a conservative tracer and assuming complete mixing of tailings pore water and groundwater;

- the flow rate of tailings pore water seepage declines over time as predicted by the 2D transient seepage model while groundwater flow rates remain constant with time;

- average (constant) concentrations of sulfate, molybdenum and TDS can be assigned to the mixing components (i.e. tailings pore water and unimpacted groundwater); and

- sulfate, molybdenum and TDS behave conservatively in the groundwater system, i.e. their concentrations are not influenced by sorption and/or precipitation/dissolution reactions within the alluvial aquifer(s).

Recall that tailings pore water contributes to shallow seepage (currently intercepted by the seepage barriers and shallow extraction wells) as well as deep seepage (currently monitored by deep monitoring wells). The relative contribution of tailings pore water to each of those seepage flows was estimated using the following equation:

$X_{PW} = (C_{SEEP} – C_{GW}) / (C_{PW} – C_{GW})$

where X_{PW} is the fraction of tailings pore water in total seepage and C_{PW} ,C_{GW} ,and C_{SEEP} are the present sulfate concentrations in tailings pore water, groundwater (not impacted by tailings seepage), and total seepage flow, respectively.

The sulfate concentration of tailings pore water (C_{PW}) was taken from measurements of inflow of tailings water into the deep boreholes BH 1, BH 3 and BH 4 near the base of the impoundment (Table 4.6). The average sulfate concentration of all three samples (1130 mg/l) is very similar to those values observed in the shallow extraction wells (EW5 series) prior to pumping (980-1364 mg/l, Souder, Miller & Associates, 1997). A sulfate concentration of 20 mg/l was assumed as background concentration for groundwater not impacted by tailings seepage (Vail, 1993). Using the average sulfate concentration of all collected seepage flows (outfall 002) as a surrogate for sulfate concentration in the shallow seepage (C_{SS} = 800 mg/l) the relative (present day) contribution of tailings pore water is estimated to be about 70%.

A representative sulfate concentration for deep seepage is more difficult to obtain. There are only a limited number of deeper monitoring wells (say greater than 50 ft below ground surface) and the observed sulfate concentrations vary significantly, indicating that the mixing of tailings pore water and groundwater is not very uniform. There is a general trend of decreasing concentrations with depth ranging from about 475 mg/l (average of MW2, EW4, and EW3) in the upper layers (<70 ft below ground surface) to about 40 mg/l (e.g. MW12, EW2) at greater depth (>150 ft below ground surface). For the purpose of this analysis, it was assumed that the sulfate concentration in deep seepage show a parabolic decline from 500 mg/l to 40 mg/l over a distance of 100 feet (see Appendix A for more detail). Using the resulting average concentration of sulfate for deep seepage (C_{DS} = 140 mg/l), the relative (present day) contribution of tailings pore water to deep seepage is estimated to be about 9%. This estimate is consistent with modeling results reported in RGC (1997a). The local groundwater flow model suggests that groundwater flow in the alluvial aquifer(s) below the tailings impoundment is in the order of 2.5 cfs (Section 3; RGC 1997a). Using the estimate of deep tailings seepage obtained from the 2D seepage model (0.21 cfs; Table 4.5), the relative contribution of tailings pore water to deep, alluvial groundwater flow would be about 8%.

Table 4.6 lists the various sulfate, molybdenum and TDS concentrations used to predict long-term water quality in shallow and deep seepage. The most critical parameter in this analysis is the assumed constituent concentration in tailings pore water (C_{PW}). The water quality of the tailings pore water was estimated based on leach extraction tests of tailings samples from the near-surface (<20 ft below tailings surface) and the deeper tailings profile (>20 ft depth). The leach extraction results were scaled to field conditions (higher solid-liquid ratio) while accounting for solubility constraints. The water quality predictions for tailings pore water are discussed in detail in Appendix D. This approach tends to give very conservative (high) estimates of future constituent concentrations.

Table 4.6. Input Parameters used for Water Quality Predictions.

As expected the back-calculated constituent concentrations for the shallow tailings samples were higher than those calculated for the deeper tailings samples, in particular for molybdenum, presumably due to a greater degree of oxidation of the tailings near the tailings surface (Table 4.6). The sulfate concentrations (and consequently TDS) are largely solubility controlled and therefore do not show as large a range between the near-surface and the deeper tailings samples. Note that the back-calculated constituent concentrations in tailings pore water are significantly higher than those currently observed near the base of the tailings impoundment (Table 4.6). It is believed that current tailings seepage is dominated by process water which has significantly lower sulfate, molybdenum and TDS concentrations (~800 mg/l SO4; ~2 mg/l Mo, and ~1100 mg/l TDS) than those back-calculated concentrations from leach extraction tests. The seepage modeling suggests that process water will remain the dominant component of tailings seepage for at least 15 to 25 years after cover placement. Only at that time will unsaturated flow through the oxidized tailings (with potentially higher sulfate, molybdenum and TDS concentrations) become a major component of tailings seepage entering the groundwater system.

Water quality predictions were made for all three estimates of tailings pore water concentrations of the three constituents (sulfate, molybdenum and TDS) in order to illustrate the effects of a possible increase in source concentration of the tailings seepage over time. For these predictions it was conservatively assumed that all the seepage from the tailings suddenly had the new high concentrations. In reality, there will be a gradual change in this quality as the percentage of of process water in the tailings seepage decreases and the percentage of leachate from the oxidized tailings increases. The first scenario (i.e. using observed C_{PW} near the base of the tailings) likely provides a lower bound for seepage water quality predictions (applicable during the early years after cover placement), whereas the third scenario (i.e. using back-calculated C_{PW} for near-surface tailings) provides an upper (conservative) bound (applicable only many years after cover placement).

The predicted trends of water quality in shallow and deep seepage over time are shown in Figures 4-14a/b/c and 4-15a/b/c, respectively. The estimated times to reach acceptable groundwater quality standards in shallow and deep seepage are summarized in Table 4.7. The model calculations suggest that sulfate concentrations in shallow seepage will improve significantly within 5-10 years after pond drainage and cover placement (Figure 4-14a). Clearly, the sulfate predictions for scenario 2 (C_{PW} = 2278 mg/l) and scenario 3 (C_{PW} = 2654 mg/l) are unrealistically high for early times for the reasons mentioned above (note that observed sulfate concentration in shallow seepage are presently only at ~800 mg/l). In our opinion the slow dewatering of the tailings (with predominantly process water) will result in only a very small rise in sulfate concentrations for the first 15 years or so after cover placement as indicated by the dashed line in Figure 4-14a. This conclusion is also consistent with the actual observations of seepage water quality during the extended “shut-down” period that occurred in the mid-1990’s.

According to model calculations molybdenum concentrations in shallow seepage will also meet New Mexico Groundwater Standards within 10-20 years after pond drainage and cover placement (Figure 4-14; Table 4.7). Again, the calculated molybdenum concentration values for the first fifteen years are considered very conservative. In light of the slow dewatering of the tailings the molybdenum concentrations are not likely to increase above current values over this (short) time period (see dashed line; Figure 4-14b).

The sulfate concentrations in deep seepage are not expected to rise above New Mexico Groundwater Standards (Table 4.7). Even in the conservative scenario with very high sulfate concentrations for tailings pore water (controlled only by solubility constraints) the predicted sulfate concentrations in deep seepage never rise above 300 mg/l (Figure 4-15a).

Table 4.7

Estimated Time to meet New Mexico Ground Water Standards in Shallow and Deep Seepage for different Source Concentrations in Tailings Pore Water

Constituent	Estimated time to meet New Mexico Ground Water Standards (in years after cover placement)	
	in shallow seepage	in deep seepage
Sulfate (NWGS = 600 mg/l)		
C_{PW} = 1130 mg/l	~5	0
C_{PW} = 2278	~10	0
C_{PW} = 2654	~11	0
Molybdenum (NWGS = 1.0 mg/l)		
C_{PW} = 5.2 mg/l	~11	0
C_{PW} = 24.6	~17[1]	~27[1]
C_{PW} = 48.1	~18[1]	~32[1]
TDS (NWGS = 1000 mg/l)		
C_{PW} = 2000 mg/l	~6	0
C_{PW} = 3285	~10	0
C_{PW} = 3890	~11	0

Notes:

1. molybdenum concentrations assumed for pore water likely too high (see text)
2. "0" indicates that constituent concentration is estimated to never rise above New Mexico Ground Water Standard

Again, simulated trends for TDS in deep seepage closely follow those predicted for sulfate (Figure 4-15c). TDS in the deep seepage is not expected to ever rise above the New Mexico Groundwater Standards (Table 4.7).

For the case of molybdenum in deep seepage, the model predictions differ significantly for the three alternative source concentrations assumed for tailings pore water (Figure 4-15b). Assuming present tailings pore water concentrations the molybdenum concentrations in deep seepage would always meet New Mexico Groundwater Standards (Figure 4-15b). This prediction is consistent with current observations (molybdenum concentrations in deeper monitoring wells are typically less than 0.06 mg/l). Again the early trends of molybdenum predicted for scenarios 2 and 3 are considered unrealistically high due to the large proportion of process water draining during the first twenty years. Only after that time are the molybdenum values likely to rise somewhat (possibly above 1 mg/l Mo) before they fall again due to the decline in tailings seepage mixing with the groundwater (see dashed line in Figure 4-15b). In other words, the deep seepage is expected to meet New Mexico Ground Water Standards for molybdenum at all times except, possibly, for a short period 25-30 years after pond drainage and cover placement (Figure 4-15b).

All water quality predictions discussed so far assumed a surface flux ranging from 1.1 inches per year in the coarse tailings to 0.4 inches per year in the fine tailings, as predicted in the cover performance analysis (Section 5, RGC, 1997a). In order to illustrate the impact of alternative cover types on post-closure seepage water quality, the transient seepage analysis and water quality predictions were repeated for the following additional closure scenarios:

- "**no cover**"; the tailings will be reshaped to allow gravity drainage (no ponding); however, the tailings will not be covered; evaporation from the tailings surface is the only mechanism to remove infiltrating precipitation from the tailings profile; the net infiltration into barren tailings was predicted to range from 3.1 to 1.3 inches per year for the coarse and fine tailings, respectively (using the same cover modeling approach as outlined in Section 5 of RGC, 1997a); and

- "**high quality cover**"; the tailings will be reshaped to prevent ponding and a complex multi-layer cover will be placed onto the tailings; it is assumed that this high quality will be designed in such a way that it reduces the net infiltration into the tailings profile to 0.11 and 0.04 inches per year in the coarse and fine tailings, respectively (i.e. one tenth of the predicted cover fluxes for a vegetated 9 inch thick alluvial cover)

These alternative "cover scenarios" were chosen intentionally to represent extreme (high and low) infiltration rates. On one hand, the net infiltration into uncovered tailings will likely be less than 3 inches per year due to the establishment of at least some vegetation. On the other hand, the net infiltration into even the most complex cover systems are likely greater than 0.04-0.11 inches per year considering construction and maintenance issues. Note that the range of infiltration rates assumed here also covers the range of infiltration rates ('cover fluxes') to be expected for a storage cover for a depth of root zone likely to establish in the alluvial cover and underlying tailings. Cover modeling indicated that cover flux through a storage cover on sandy tailings for an exceptionally wet year may range from 13% to 20% of total annual precipitation for a root zone depth ranging from 2 to 3 feet (see Section 4.3.3 of main report). Applying these results to an average year of precipitation (used for calculating long-term performance) the cover flux would be 1.7 inches per year for 2 feet of root zone depth versus 1.1 inches per year with 3 feet of root zone. The cover fluxes through a storage cover on fine tailings would be accordingly lower. These fluxes through a storage cover fall within the range assumed here for water quality predictions (0.04 to 3.1 inches per year). Over the long-term, the climax vegetation is expected to produce root development, which reaches deeper than 3 feet; hence, use of the currently observed root penetration depth (2 to 3 feet) is conservative. The use of extreme (high and low) infiltration rates for water quality predictions serves to further illustrate the effect of variable cover performance on long-term water quality.

Figures 4-16a and 4-16b show the simulated trends for sulfate in the shallow and deep seepage, respectively. The predicted sulfate concentrations in the shallow seepage do not differ significantly for the three different cover types (Figure 4-16a). do not show any detectable difference in the predicted sulfate concentrations. As discussed earlier, tailings seepage is dominated by tailings pore water presently stored in the impoundment for at least 20 – 30 years after cover placement, i.e. until the majority of the tailings impoundment is dewatered (c. Figure A9). It follows that a change in the cover flux (caused by using different cover designs or different root zone depth in the storage cover) will not cause any significant changes in the flow rates of (deep or shallow) tailings seepage during this time period. The transient seepage model suggests, however, that shallow seepage will have declined to negligible flow rates within 20 years after cover placement, at which time unimpacted groundwater will control seepage water quality (Figure 4-16a).

The water quality predictions for deep seepage are consistent with the above line of argument. Again there is no significant difference in predicted sulfate concentrations in deep seepage for the first 25 to 30 years after cover placement (Figure 4-16b). The predicted sulfate concentrations in deep seepage differ only after about 30 years, i.e. when the unsaturated cover flux becomes the dominant component of tailings seepage. As expected, the post-closure steady-state sulfate concentrations for the “high quality” cover option (60 mg/l) are lower than for the “no cover” option (112 mg/l) (Figure 4-16b). Nevertheless, these concentrations still meet New Mexico Groundwater Standards. Note again that a storage cover with a variable root zone depth of 2-3 feet would result in a seepage water quality intermediate of those resulting from the two “extreme” cover options simulated here.

Simulated trends for molybdenum and TDS in shallow and deep seepage are identical to those discussed above for sulfate (not shown).

In summary, the water quality predictions for shallow and deep seepage are not influenced significantly by cover type. The “no cover” option and the “high quality” cover options result in nearly identical constituent concentrations in shallow seepage and only marginal differences in deep seepage in the long-term (i.e. approximately 30 years after cover placement). The water quality predictions suggest that seepage water quality will meet New Mexico Ground Water Standards for all cover types studied, including the proposed storage cover with 2-3 feet of root zone depth. The main factors controlling seepage water quality are (i) slow drainage of currently stored tailings pore water (w/ process water quality) in the short term (<25-30 years) and (ii) dilution of tailings seepage in the deeper groundwater system in the long-term (>30 years).

The water quality predictions suggest that the current interception system (which collects shallow seepage) may have to be operated for about 10-15 years after cover placement. Groundwater in the deeper aquifer layers ("deep seepage") is expected to never require interception. It is emphasized again that the water quality predictions provided here are for illustrative and general evaluation purposes only. It is essential that seepage water quality downstream of the Section 36 Tailings Area (Dam 1) be monitored to determine if and when the seepage interception system can be shut down.

4.6.3 Seepage Interception Plan

4.6.3.1 Section 35 Tailings Area

At present the deep groundwater flowing beneath the Section 35 Tailings Area shows sulfate, molybdenum and TDS concentrations well below New Mexico Ground Water Standards owing to the large dilution of tailings seepage in the large flows of deep groundwater in the volcanic aquifer (see Section 3.1.6). The seepage flow and water quality modeling further suggests that water quality of the deep groundwater flowing in the volcanic aquifer beneath the Section 35 Tailings Area will continue to meet New Mexico Ground Water Standards (see Section 4.6.2.1). Subject to current trends continuing there will thus be no need to intercept seepage down-gradient of this tailings area.

Monitoring of the water quality of the deep groundwater in the volcanic aquifer will be continued after closure using existing monitoring wells (see Section 4.7.2 for more details).

4.6.3.2 Section 36 Tailings Area

At present, some shallow, perched groundwater flowing in the alluvial sediments beneath the Section 36 Tailings Area is impacted by tailings seepage resulting in concentrations of sulfate, molybdenum and TDS above New Mexico Ground Water Standards (see Section 3.1.6). In compliance with the final order of the Discharge Permit #933 this shallow seepage is currently being intercepted in the Dam 1 arroyo just down-gradient of Dam 1. The water quality predictions suggest that this shallow seepage will continue to show elevated concentrations of sulfate, molybdenum and TDS for approximately 10-15 years after closure of the facility, i.e. after the drainage of all surface ponds and the final cover is placed (see Section 4.6.2.2). The seepage modeling further indicates that the current interception system is adequate to intercept future flows of shallow seepage (seepage flows are anticipated to decline exponentially after closure).

Hence it is planned to continue the existing seepage interception system until such time as the water quality in the shallow seepage meets all New Mexico Ground Water Standards (likely 10-15 years after closure). The existing interception system represents a flexible system that can easily be adapted to handle the anticipated changes in seepage quantity and quality after closure. As outlined in Section 3.1.5, the existing seepage interception system consists of seven extraction wells and four seepage barriers (see Figure 3-13). At closure, all components of the seepage interception system will likely be operating, albeit with possibly higher extraction rates to account for higher seepage rates, should additional tailings be placed behind Dam 1 C (see Section

3.2.5). After placement of the final soil cover, seepage rates will decline rapidly. The pump rates of the various extraction wells will be gradually adjusted downward to accommodate for this decrease in tailings seepage after closure. The water quality of the seepage flows intercepted in the various components of the seepage interception system (seepage barriers, extraction wells) will also be monitored. Individual components of the seepage interception system may then be shut down one by one if and when the intercepted seepage meets New Mexico Ground Water Standards (see Section 4.7.2 for more details).

Monitoring of the water quality in the shallow, perched seepage flows of the alluvial sediments downgradient of the Section 35 Tailings Area will be continued after closure using existing monitoring wells (see Section 4.7.2 for more details).

Deep groundwater flowing beneath the Section 36 Tailings Area in the deeper alluvial layers currently meets state standards (see Section 3.1.6). Water quality modeling suggests that this “deep seepage” will never exceed New Mexico Ground Water Standards (see Section 4.6.2.2). Hence, a post-closure interception of deep groundwater downgradient of the Section 36 Tailings Area is not anticipated.

Monitoring of the water quality of the deep groundwater in the deep alluvial sediments will be continued after closure using existing monitoring wells (see Section 4.7.2 for more details).

4.7 Monitoring and Maintenance Plan

Monitoring and maintenance will be performed, after implementation of the final closure measures and until the success of the closure measures have been demonstrated. The monitoring and maintenance plan has been divided into three sections for:

i. Performance of structures (primarily stability and erosion),

ii. Ground and surface water, and

iii. Successful re-vegetation.

4.7.1 Performance of structures

4.7.1.1 Monitoring

At the time of closure all of the dams and the diversion ditches will have been operational for many years (many tens of years for the main dams and diversion ditches) and their long term stability and performance will have been demonstrated. With the decline in the phreatic surface within the tailings impoundments the stability of the dams will increase. The rate of decline of this surface is of primary interest to assess the seepage conditions. Thus continued monitoring of the piezometers, installed and functional at the time of closure, will be reviewed and a select number would continue to be monitored annually as part of the groundwater monitoring program.

The State Engineer has extensive requirements for the on-going monitoring and maintenance of dams under the National Dam Safety Act. It is anticipated that monitoring by the State Engineer will require at least an annual inspection of all dam embankments and diversion structures (by a Professional Engineer: for erosion, seepage, deterioration and vegetation development) together with annual monitoring of the piezometers and surveying of the deformation pins on the dam walls. Reports are required to be filed to the State Engineer following each of the se inspections. It is anticipated that such monitoring will be required for at least fifteen years after dam closure.

No further inspections or monitoring of the dams and diversions is considered necessary for the purposes of the Closure Plan.

The performance of the cover and the shallow drainage swales on the covered surface of the tailings impoundments may require inspection over and above that provided for the dams, embankments and diversion ditches. The monitoring program therefore provides for the dam inspections to include a walk along each of the drainage swales to check for any signs of cover or riprap erosion.

These inspections and reports are expected to involve two days of a two man surveying crew for piezometer readings and deformation surveying and results preparation, and three days of professional engineers time for the site inspection and annual inspection report preparation.

4.7.1.2 Maintainance

As for monitoring, maintenance of the dams and diversions are a specific requirement of the State Engineer under the National Dam Safety Act. Based on past experience with the performance of the dams and diversions, no specific maintenance requirements are anticipated. Should any maintenance be required this is likely be to remove slumps into, or debris accumulation in, diversion ditches or repairs of minor gulleying in dam embankments. Conservatively, allowance is made in the post closure maintenance cost estimate for two periods of one week of a backhoe, a truck and a crew of two for such maintenance during the 15 years of monitoring and inspection (at the end of 5 and ten years).

4.7.2 Groundwater and Surface Water

4.7.2.1 Monitoring

The existing groundwater and surface water monitoring programs will be continued after closure, albeit with reduced scope, to ensure that the seepage interception system protects the receiving groundwater and surface water.

The following post-closure groundwater monitoring plan is proposed. All existing monitoring wells, which are still functional at the time of closure, will be sampled twice a year for an initial observation period of five years after closure. A list of all existing, monitoring wells is provided in Table 3.8. The location of these monitoring wells is shown in Figure 3-.

The initial observation period serves to identify any early time trends of groundwater quality caused by the cover placement. After this initial five-year period the number of monitoring points will be gradually reduced. Any monitoring well which shows a stable and/or improving trend in water quality and which meets all New Mexico Ground Water Standards for two consecutive sampling campaigns (i.e. a full year of monitoring) will be removed from the groundwater monitoring program. The groundwater monitoring program will be terminated once all monitoring wells show acceptable groundwater quality or once the seepage interception system is finally shut down (see below).

The water quality of the seepage intercepted by the various components of the seepage interception system (extraction wells, seepage barriers, outfall 002) will also be monitored biannually. The various components of the existing seepage interception system are shown in Figure 3-13. Those extraction wells and/or seepage barriers, which collect seepage of stable, acceptable groundwater quality, as evidenced by two consecutive sampling campaigns in which the intercepted seepage meets all New Mexico Ground Water Standards, may be disconnected from the interception system. Any such changes to the seepage interception system will be submitted to the NMED for approval prior to implementation.

The samples obtained from the various monitoring wells, extraction wells and seepage barriers will be analyzed for field parameters, general chemistry and metals, as outlined in the Discharge Plan 933. At the time of water quality sampling, static (or dynamic) water levels will also be recorded in all monitoring and extraction wells. In addition, the total cumulative flow rate of intercepted seepage will be monitored for seepage flow assessment purposes.

The monitoring of piezometers, which have been installed in the tailings impoundments upstream of the dams to suite the requirements of the dam designers and the State Dam Safety Engineer, and functional at the time of closure, will be also be continued on a once annual basis until such time as these data are no longer required for groundwater quality assessment purposes.

In addition to the groundwater monitoring plan, several springs located downstream of the Questa Tailings Facility near the Red River will be sampled once a year during base flow conditions. The springs to be sampled as part of the post-closure surface water monitoring plan are those listed in the Discharge Plan 933, i.e. Hatchery Cold Water Supply, Questa Springs Surface Discharge, Questa Springs Old Discharge Pipe, First Creek below Pope Creek, South Side Spring, Spring near Concrete Collection Box, and Hatchery Warm Water Supply. All samples will be analyzed for field parameters, general chemistry, and metals as outlined in the Discharge Plan 933. The monitoring of the spring water quality will be continued as long as the seepage interception system is operating.

4.7.2.2 Maintenance

The seepage interception system will require some maintenance after closure. Extraction wells may have to be purged occasionally to remove any fines drawn into the intake sections of the extraction wells. Seepage barriers will have to be upgraded or replaced if the collection of shallow seepage becomes ineffective due to clogging of the seepage barriers with fines. Any electrical components of the extraction system (pumps, coyote switches, flow meters etc.) will have to be serviced and/or replaced occasionally to minimize any downtime of the extraction system.

4.7.3 Revegetation

The revegetation monitoring program begins four years post-planting. As described in Section 4.5 the first three years post-planting will involve both monitoring and maintenance required to establish the vegetation. During the monitoring period, years four to sixteen, maintenance will only occur if a major problem is perceived to threaten the vegetation. Because of bond release requirements by the Mining and Minerals Division, the bonding period is for a minimum of twelve years after the last augmented seeding, fertilization and/or irrigation. The only management allowed is interseeding to establish diversity and is allowed only in years one to nine.

The objective of the monitoring is to evaluate plant establishment and growth to ensure and document that the plant community is developing into a self-sustaining ecosystem. Monitoring will be both informal and formal. On an annual basis formal monitoring includes plant counts (density), shrub and tree survival and growth, and species present. Formal monitoring will occur during the growing season, at a time determined to give an accurate representation of the status of the plant communities. Informal monitoring will occur once or more a year and will include cover estimates, and production of grasses and forbs. On a biennial basis the formal monitoring will also include cover determinations and production of grasses and forbs. During the last two years all monitoring data will be collected formally.

The monitoring data will be evaluated to determine the status of the revegetation project. As mentioned above, if problems and trends are detected, appropriate action will be taken to ensure the successful establishment of a self-sustaining ecosystem. Data collected during the last two years will be used to document the achievement of reclamation standards.

The reclamation standards for the site follow and are based on technical standards and best professional judgement (see Buckner, 1990; Burns and Honkala, 1990; Eyre, 1980; Garrison et al., 1977; Wagner and Harrington, 1995). As described in Section 4.3.4, verification of these standards will be demonstrated in the revegetation test plot program before final closure. Achievement of reclamation standards will be determined by representative sampling of the revegetation areas, followed by appropriate statistical analysis of the data.

The following reclamation standards apply:

***Woodland Community**:*

200 stems / acre trees – minimum of 2 species
100 stems / acre shrubs – minimum of 1 species
30 % ground cover
grass / forb production = 150 lbs / acre
- minimum 2 grass species (at least 3 %)
- minimum 1 forb species (at least 3%)

Mixed Community:
300 stems / acre of both trees and shrubs
- at least 20% of each type
- minimum of 3 species

35 % ground cover
grass / forb production = 300 lbs / acre
- minimum 2 grass species (at least 3%)
- minimum 1 forb species (at least 3%)

Shrub Community:
340 stems / acre shrubs – at least 2 species
40 % ground cover
grass/forb production = 400 lbs / acre
- minimum 2 grass species (at least 3%)
- minimum 1 forb species (at least 3%)

Grass/Forb Community:
50 % ground cover
grass/forb production = 600 lbs / acre
- minimum 3 grass species (at least 3%)
- minimum 2 forb species (at least 3%)

4.8 Post Closure Land-Use Plan

As part of the closure plan a post closure land-use plan has been developed. The revegetation has been designed to meet this land-use. Other elements that are involved in post closure include the removal, maintenance or placement of fences and roads.

4.8.1 Land-use

The post closure land use will be open space with utilization of the area by wildlife. The establishment of the proposed vegetation types will create plant communities, which will be suitable for a range of wildlife use. The area will be established as a piñon-juniper woodland, mixed tree and shrub community, sagebrush ecosystem and a grass/forb dominated ecosystem. These ecosystems are suitable for use by a variety of wildlife which was described in Sections 2.6.2 and 2.6.3. It is anticipated that the wildlife known to be in the area and wildlife that typically uses these ecosystems will in fact utilize the reclaimed area. The location of the tailings ponds between the Guadalupe Mountains and Questa, will allow the area to be a buffer zone between wildlife areas and human activity. The reclamation of the ponds will allow for the expansion of habitat for use by animals already present in the area.

4.8.2 Fences and Roads

As part of the closure and reclamation process the presence and necessity of fences and roads will be evaluated. Fences will continue to be 3-strand barbed wire in accordance with local customs. Where necessary, fences will be maintained to limit access to the site. Some roads will need to be retained in order to allow access to monitor wells, dams, piezometers, etc. Those roads not needed for maintenance and monitoring purposes will be reclaimed. The reclamation will included ripping of the compacted surface, and seeding or planting to meet the appropriate plant community requirement. Seeding and planting of these areas will follow the guidelines described in Section 4.5.

5.0 CLOSURE COST ESTIMATE

5.1 Cost Estimate for Revised Closure Plan

This section presents the basis for the cost estimate for the implementation of the Revised Closure Plan as defined in the eight separate closure plans described in section 4, and the associated figures. The cost estimate has been developed on a basis similar to that which was adopted for the previous closure plan cost estimate as contained in the appendix for the 'Questa Mine Tailings Impoundment Contingency Closure Plan for 2001' (Robertson GeoConsultants 1996) entitled 'Closure Cost Estimate Details'.

The unit rates and cost estimates are based on having contractors perform the work; and the costs are in 1998 dollars.

The cost estimate provides for 15% of the direct costs to cover unexpected or incidental expenses as required by in the Financial Assurance Regulations (NMED, 1996).

A summary of the costs for the implementation of the Revised Closure Plan is provided on Table 5.1. Table 5.2 provides greater detail of the items, units, quantities and amounts for the various tasks. Further details of the basis for the cost estimate are provided below.

The following notes relate to the corresponding items on these tables:

1. Buildings removal:

The steel frame metal clad IX building and contained equipment will be disassembled and transported to Questa mine for consolidation with the salable scrap and equipment. No allowance is made for salvage value. Allowance is made for 1300 yd^3 of rubble, scrap and debris to be transported to the mine for disposal in the permitted landfills.

2. Cover Placement

i) Progressive Reclamation

The cost estimate assumes that Molycorp will practice progressive reclamation with regard to cover placement and re-vegetation. Molycorp has committed to such progressive reclamation and it is a requirement for control of wind erosion and dust from the tailings impoundments.

The tailings impoundments have been divided into 6 zones of about 200 acres each. A maximum of two zones will be in use or under development at any one time. Those not in use will be covered with an interim cover of 9 inches of alluvium, similar to the final cover. Those reaching their final height will be covered and re-vegetated progressively. Zones will become available for final covering and reclamation progressively.

Table 5.1.
Adjusted Estimate for the Revised Closure Plan.

No.	Item	Total Cost
1	Buildings Removal	$89,000
2	Cover Placement Plan	$2,875,309
3	Verification Test Program	$149,200
4	Complete the Western Duversion Spillway	$53,000
5	Pope Lake/Western Diversion discharge preparation	$50,000
6	Permanent Decants	$59,144
7	Tailings Surface Drains	$394,509
8	Revegetation Plan	$750,252
9	Groundwater Interception Plan - Groundwater Pumping	$535,000
10	Maintenance and Monitoring of Site	$450,000
11	Miscellaneous Cleanup and Reclamation	$100,000
12	Perimeter Fences - East side only	$80,000
13	Roads (upgrading)	$45,000
	Total (Excluding cover and vegetation to Zones 5 and 6)	**$5,630,414**
14	Engineering & Supervision @ 10% of Total Direct Cost	**$563,041**
15	Provision for unexpected& incidental costs @ 15% of Total Direct Cost	**$844,562**
	Grand Total	**$7,038,018**

Insert table 5.2 (2 pgs)

Insert table 5.2 (2 pgs)

Molycorp will complete the development of the tailings impoundments and tailings deposition in Dam 4 complex (Section 35) prior to discharging into the impoundment of Dam 1 complex (Section 36). As operations progress to zones 3 and 4, zones 1 and 2 will have been completed and will be available for covering and reclamation. Zones 1 and 2 will be covered and reclaimed prior to initiating tailings placement in zones 5 or 6. By practicing progressive covering and reclamation there is a reduction in the maximum closure cost at any tim

ii) Maximum Area Requiring Covering

With the proposed development and reclamation sequence, the maximum area of uncovered tailings that can be envisaged occurs during the latter stages of the development of the Dam 4 complex. At most, all four zones in the Dam 4 complex may be fully developed but uncovered, or only partially covered and undergoing reclamation. The Revised Closure Plan therefore anticipates that the worst case scenario for cost of closure is that if all of zones 1 to 4 require covers to be placed and, in addition covers must be placed on the pond (fine tailings) areas presently uncovered in zones 5 and 6. All other operating scenarios result in lesser estimates of areas requiring covering and re-vegetation.

On Table 5.2 the costs for the placement of covers and re-vegetation on the coarse and intermediate beach areas of zones 5 and 6 are indicated. These costs are not included in the Grand Total of closure cost estimates.

iii) Cover Placement Cost Estimates

Placement will be principally achieved using scraper assisted push dozers to load the alluvium. The alluvium would then be hauled to the area to be covered, dumped and spread with motor graders. A percentage of the fill (over the pond areas) may have to transported by truck and placed using light dozers with low pressure tracks. For the purposes of this cost estimate it is assumed that the cost of such placement will not be substantially greater than that for placement by scraper.

Figure 4.1 outlines the six zones that will be covered with alluvium borrow material to a depth of 9" (0.75') on the intermediate and coarse beach zones. Currently fine tailings represent 11.9% of the tailings surface area. A similar percentage is assumed on final closure. Provision is made for an average of 18" of alluvial material over the fine tailings areas, both for vegetation growth purposes and to give enough surface strength for placing equipment to operate.

A swell factor of 20% is assumed from bank cubic yards to loose cubic yards; and that placed material will have the same density as bank material after the equipment operates on top of it.

<u>Zones 1 to 4 plus zone 5 & 6 pond areas - Calculation of volume of alluvial material required:</u>

Area of zone 1-4 = 31,723,619 sq. ft

Area centre strip (east of zones 1-4) = 1,587,209sq. ft

Measured area of fines on impoundments 1C and 2A = 1,541,739sq. ft

9" alluvial material Volume required = (31,723,619 sq. ft. X 0.75') divided by 27	= 881,211cy
Add 9" to 11.9% of this area	= 104,864cy
Strip East of Zones 1-4 = 1587209 x 0.75 /27	= 44,089cy
18" cover on fines areas measured on impoundment 1C and 2A (1541739X1.5)	= 85,652cy

Zones 5 and 6 - Calculation of volume of alluvial material required:

Area of zone 5 and 6 = 13,909,287 sq. ft

Note: already allowed for covering 18" to a fines area of 1,541,739 sq.ft in above estimate

volume required = (13,909,287x0.75x1.119 -1,541,739 x 1.5) divided by 27 = 346,695cy

The alluvial material hauling plan is based on the use of four (4) Cat 631E wheel tractor-scrapers. Heaped capacity is 31cy. Molycorp experience on the site has been that a scraper can be loaded with 28cy of broken material using a push dozer.

Almost all of the haul road going to any of the six zones is flat. One short grade has to be pulled in either direction (coming or going). Molycorp's experience from previous tails capping projects has shown that the haul roads pack very well, and with some blading are easy to keep graded and reasonably smooth.

Assume one 10 hour working shift per day and a 45 minute hour to cover start-up, shutdown, lunch and minor breakdowns, etc.

Five (5) scrapers are leased, with four (4) operating during any shift.

Average haul distance is measured to the centroid of each area. The borrow area is located in the Molycorp property North of the Tailings site. Haul distances are measured as follows:

Average haul distance to Zones 1 to 4 = 7,000' and average haul to Zones 5 and 6 = 3,500'

Time Calculation:

Scraper cycle times are calculated as shown on Table 5.3.

4 scrapers over a 7,000' haul one way with 10 minute cycle time

4.5 cycles per hour X 28cy per cycle X 10 hours/day X 4 scrapers = 5,040 cy/day

1,115,817cy total divided by 5,040cy/day = 221 days

Assuming a 20 day work month for a total of 11 months.

4 scrapers over a 3,500' haul one way with a 7 minute cycle time

6.4 cycles per hour X 28cy per cycle X 10 hours/day X 4 scrapers = 7,168 cy/day

346,695cy total divided by 7,168cy/day = 48 days or 2.4 months.

Calculation of cost of cover placement

11 and 2.4 months of cover placement are required for zones 1 to 4 and 5 & 6 respectively using the proposed equipment fleet. In practice, this cover placement would be implemented progressively as each tailings zone becomes available.

A summary of the costs for cover placement is provided in Table 5.4.

The costs for equipment are developed as shown on Table 5.5.

The costs for labour are developed as shown in Table 5.6.

The costs for fuel are developed as shown in Table 5.7.

The cost of lubricants, grease, filters, coolant, hydraulic, engine oil, transmission and torque converter oil, and tire wear is based on $1.00 per hour for all equipment, or 16 pieces of equipment operating 2380 and 520 hours, yielding cost estimates of $38,080 and $8,320, for zones 1 to 4 and 5 & 6 and respectively.

Move in and out' for all equipment has been calculated at **$25,000.**

Special tools, tankage, instrumentation, shackles, slings, misc., will cost an additional **$20,000**.

Repair parts for all equipment which includes wear metal, transmission/ engine/ converter/ hydraulics repair, brakes, etc. is based on past experience at a rate of $16,000 per month for the proposed fleet or $176,000 and $38,400 for zones 1 to 4 and 5 & 6 respectively.

Table 5.3.
631 Scraper Cycle Time.

Cycle Breakdown	7,000 Ft Distance	7,000 Ft Distance
Wait	0.25 minutes	0.25 minutes
Load	0.75 minutes	0.75 minutes
Haul	5.00 minutes	3.00 minutes
Dump	0.50 minutes	0.50 minutes
Return	3.00 minutes	1.75 minutes
Delays	0.50 minutes	0.75 minutes
Totals	**10.00 minutes**	**7.00 minutes**

Table 5.4.
Cost of Placing Alluvium Cover Over Tailings.

Task	Zones 1 to 4	Zones 5 & 6
Equipment	$1,578,500	$344,400
Labor	$734,250	$160,200
Fuel	$284,886	$62,244
Lubricants	$38,080	$8,320
Repair Parts	$76,000	$38,400
Tankage & Misc.	$20,000	$20,000
Move – in and out	$25,000	$25,000
Site & haul road preparation	$33,587	$7,328
Total	$2,926,023	$638,492
Cost per cy	$2.62	$1.84

Table 5.5

Cost of Equipment.

Equipment	Quant.	Unit $	$/mo	$/11 mo's	$/2.4 mo's
631 Scraper	5	14,000	70,000	770,000	168,000
D9 push cat	2	14,000	28,000	308,000	67,200
16G motor grader	2	11,000	22,000	242,000	52,800
950 front end loader	1	7,000	7,000	77,000	16,800
5,000 gal wtr. truck	1	6,000	6,000	66,000	14,400
Service truck	1	3,500	3,500	38,500	8,400
Maint. truck	1	3,000	3,000	33,000	7,200
Supv. pickup	2	2,000	4,000	44,000	9,600
			Total	1,578,500	344,400

Table 5.6

Labor Cost.

Occupation	Quant.	Single $ rate	Single $ rate w/OT, 10 hr day	Single $ rate/mo. +10% OT 20 days/mo. +1 Sat.	$/11mo's. x 1.25 for indirects x No. of employees	$/2.4mo's. x 1.25 for indirects x No. of employees
Scraper	4	$14/hr.	$154/day	$3,600	$198,000	$43,200
Dozer	2	$14/hr.	$154/day	$3,600	$99,000	$21,600
Motograder	2	$14/hr.	$154/day	$3,600	$99,000	$21,600
Front end loader & wtr. truck	1	$14/hr.	$154/day	$3,600	$49,500	$10,800
Mechanic	3	$14/hr.	$154/day	$3,600	$148,500	$32,400
Supv./Tech	2	$20/hr.	$220/day	$5,100	$140,250	$30,600
Totals	14				$734,250	$160,200

Table 5.7.
Diesel Fuel Consumption & Cost.

Equipment	Quant.	Unit fuel consumption	Subtotal fuel consumption x 2380 hours (11 mo.)	Subtotal fuel consumption x 520 hours (2.4 mo.)
Scraper	4	18 gph	171,360	37,440
Push dozer	2	12 gph	57,120	12,480
Motorgrader	2	8 gph	38,080	8,320
Front end loader	1	5 gph	11,900	2,600
Water truck	1	3 gph	7,140	1,560
Service truck	1	2 gph	4,760	1,040
Maint. Truck	2	1 gph	4,760	1,040
Supv. pickup	2	1 gph	4,760	1,040
Total			299,880	65,520
X $0.90/gallon			$269,892	$58,968

Table 5.8.
Cost Estimate for Revegetation Test Plots.

Installation Costs	Totals
Plot 1 – Depth of cover over fine tailings Maximum 1 acre at $4,000 per acre	$4,000
Plot 2 – Species trials Maximum 3 acres at $1,500 per acre	$4,500
Plot 3 – Fertilizer/Amendment tests Maximum 2 acres at $2,000 per acre	$4,000
Plot 4 – Demonstration test plots Maximum 4 acres at $1,500 per acre	$6,000
Maintenance and monitoring Maintenance estimated at: $300/acre x 10 acres x 3 years	$9,000
Monitoring estimated at: $2,500/year x 5 years	$12,500
Grand Total	$40,000

3. Verification Test Program

Cost estimates for the cover infiltration test plot program has been developed as indicated in Appendix B. Cost estimates for the vegetation test plot program are as shown on Table 5.8.

4. Completion of West Diversion Ditch Spillway

The cost for refurbishing the existing Western Division Ditch as follows:

Approximately 800 lineal feet of ditch will have to be cut to bedrock and re-sloped. 18" - 36" riprap will be quarried from the bedrock exposed in the ditch adjacent to and above the west abutment of Dam 4. It is assumed that a contractor will be commissioned to perform the work. Cost items are shown on Table 5.2.

5. Pope Lake/Western Diversion Discharge Preparation

After the IX plant is no longer needed, the channel between the Western Diversion Ditch Spillway and the creek channel below Pope Lake dam will be upgraded and Pope Lake Dam will be breached. Provision is made for the removal of the pipeline to the IX plant. Cost items are shown on Table 5.2.

6. Permanent Decants

Five permanent decants will be constructed to drain the six impoundment zones into the new decant spillway and channel. It is anticipated that two of these decants will be Type B requiring concrete drop structures. Cost items are shown on Table 5.2.

7. Tailings Surface Drains

Riprap will be produced by screening the local alluvial gravels to remove the minus 1 inch material, or by quarrying and screening rock from the bedrock exposed in the western diversion ditch. Cost items are shown on Table 5.2.

8. Re-vegetation Plan

Cost estimates are based on Molycorps extensive experience of re-vegetation costs at Questa mine. Cost items are shown on Table 5.2. As for the cover placement, the maximum area requiring re-vegetation is anticipated to be four zones, and separate estimates are made for zones 1 to 4 and 5 & 6.

9. Groundwater Interception Plan

Provision is made in the groundwater interception plan for the installation of one additional well and pump on closure. This would be followed by 15 to 20 years of pumping, maintenance and monitoring. Pumping rates will decline with time. Pumping costs are estimated assuming full pumping rates for 15 years. Cost items are shown on Table 5.2.

10. Maintenance and Monitoring

Higher intensity monitoring is anticipated for the first fifteen years after closure. A lower level of monitoring is anticipated for the next 15 years.

Higher intensity monitoring provides for the annual dam inspections ($5,000 pa), water quality sampling as described in the closure plans ($8,000 pa) and re-vegetation inspections $3,000, including reporting. Periodic maintenance, for minor erosion or slump clearance, is provided for at an average cost $4,000 pa ($20,000 every 5 years).

11. Miscellaneous Clean-up and Reclamation

Miscellaneous cleanup and reclamation would pickup small areas and items missed during the construction/reclamation program. A cost of **$100,000** is provided for and would occur in year 2 of the closure.

12. & 13. Perimeter Fences and Roads.

Provision is made for fencing the east and south sides of the impoundments and upgrading access roads to provide for access during the monitoring period.

14. Engineering, Supervision, Overhead and Profit

These items are estimated at 10% of the total closure cost or **$566,113.**

15. Unexpected or Incidental Provision.

Provision is made for unexpected or incidental expenses as required by the NMED Financial Regulations of 1996, as 15% of direct costs.

5.2 Recent Contractor Cost Reference

The largest single cost item of the Revised Closure Plan is for the placement of cover material. Cover placement cost estimates (excluding overhead and profit) are shown on Table 5.4 as $2.62 and $1.84 per cubic yard for cover placement on areas 1 to 4 and 5 & 6 respectively. The difference in cost results from the much larger hauling distance associated with areas 1 to 4 (7,000 ft average) compared with 5 & 6 (3,500 ft average). Molycorp recently contracted for the covering of 10 acres of south end tailings with Mascarenes Trucking and Construction as well as for placing earthfill on a road. A copy of the purchase order, dated February 25, 1998, is included as Table 5.9. This purchase order indicates that the cost of placing the cover, as well as placing general uncompacted earthfill is $2.00 per cubic yard. This price applies to a relatively small quantity of cover material. With the economies of scale even lower contract rates would be anticipated.

Insert table 5.9 (P.O. order)

6.0 References

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Photos

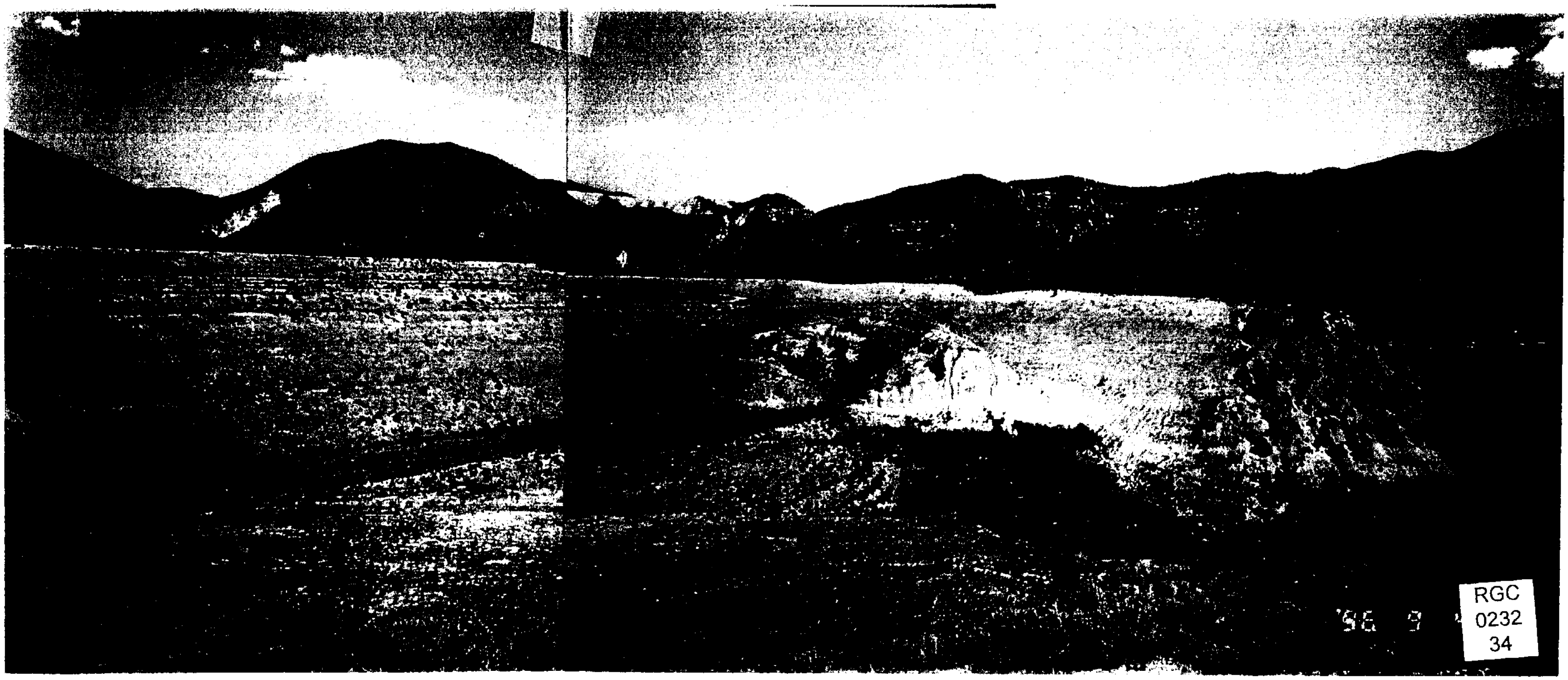


Photo 1: Looking northeast showing Tailings Dam 1. A smaller Dam 1C was placed immediately upstream of Dam 1 on tailings (left) and a dam buttress was placed at the toe of Dam 1 (center). V-shaped cut into eastern abutment shows final section of East Drainage Ditch (right). A seepage interception system is located in the arroyo to the south (right) of Dam 1. Mine waste rock from Questa Mine can be seen on skyline in center background of photo (photo taken September, 1996).

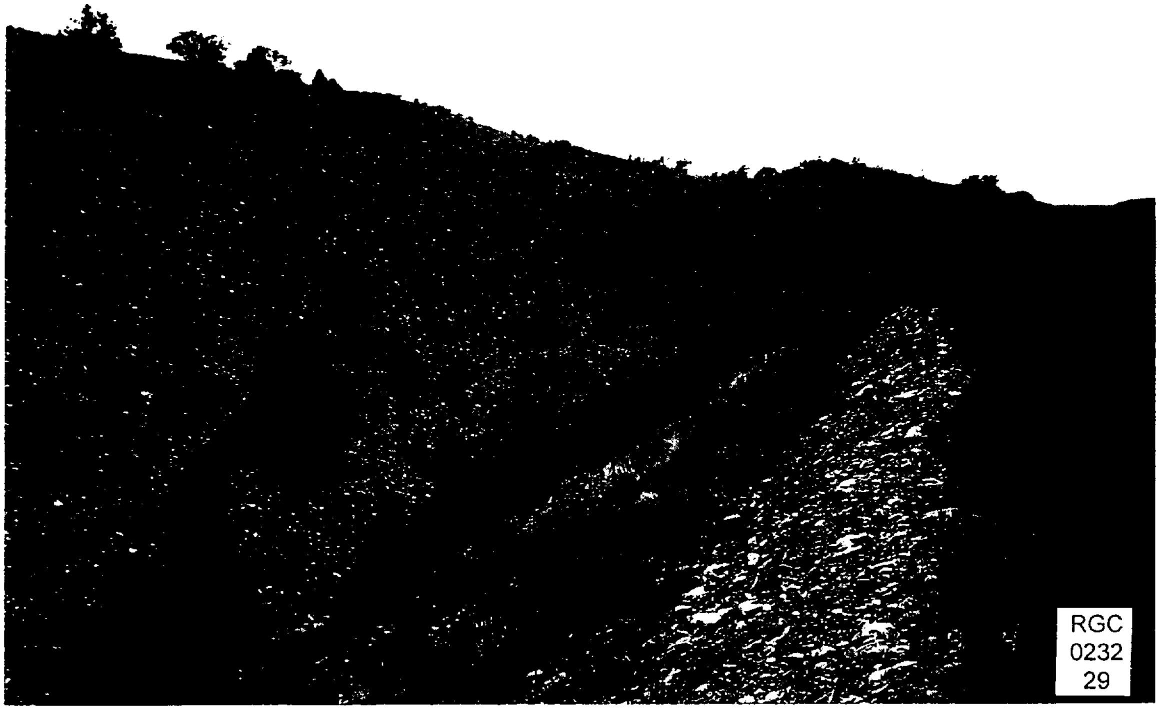


Photo 2: East Drainage Ditch looking south [redacted] approaching Dam 1C abutment showing little erosion and invasion of volunteer vegetation (photo taken September, 1996).

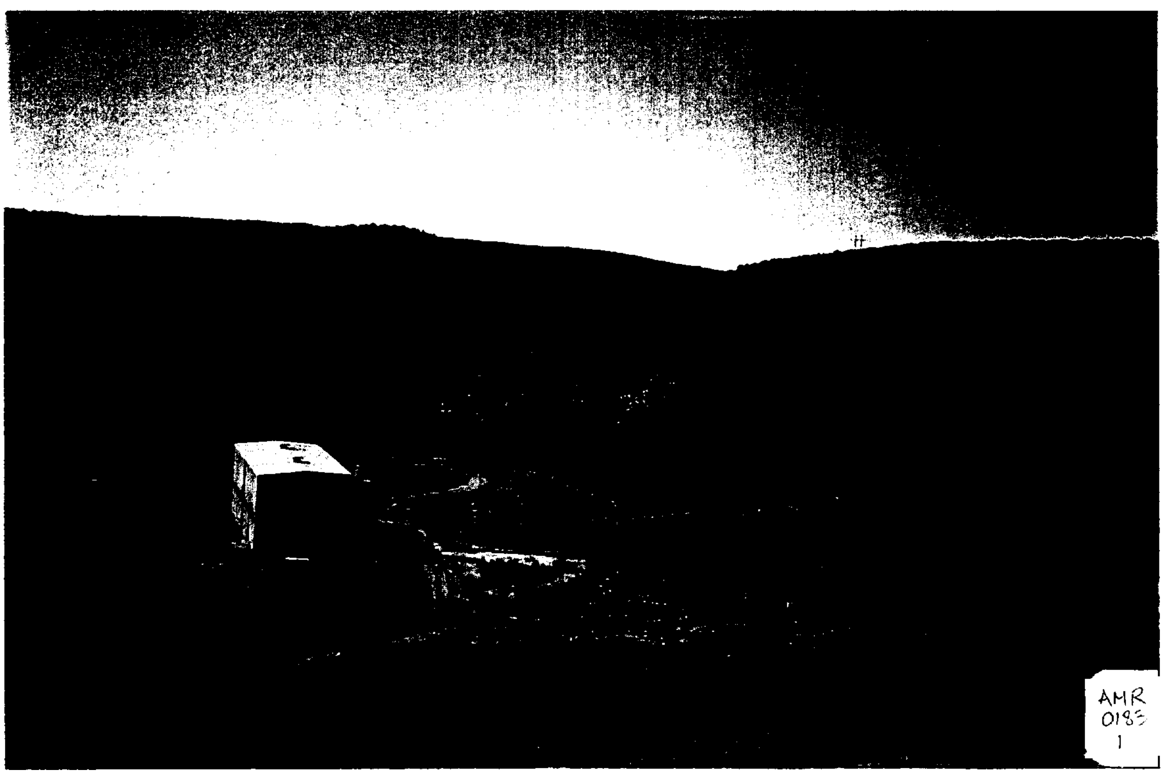


Photo 3: Looking south towards IX Plant and Pope Lake from Dam 4 crest (photo taken September, 1994).

Photo 4: Looking west along Dam 1 embankment showing vegetation development and minimal erosion (photo taken September, 1996).

Photo 5: Toe buttress near east abutment of Dam 1 showing well-developed brush vegetation (photo taken August, 1997).

Photo 6: Drilling of monitoring well MW-13 at toe of Dam 4 looking northeast (photo taken August, 1997).

Photo 7: Rock fill face of Dam 5A. looking northwest (photo taken May, 1997)

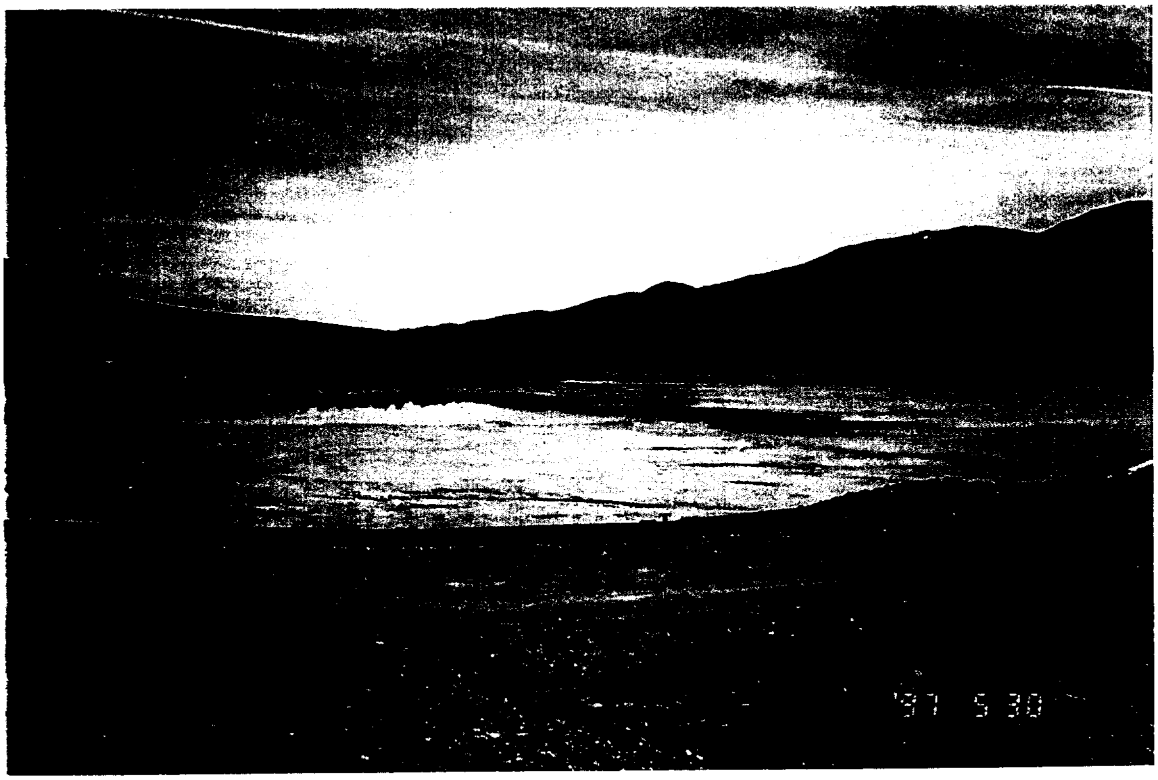


Photo 8: Tailings Discharge behind Dam 5A showing spigotted beaches and pond in background (photo taken May, 1997).

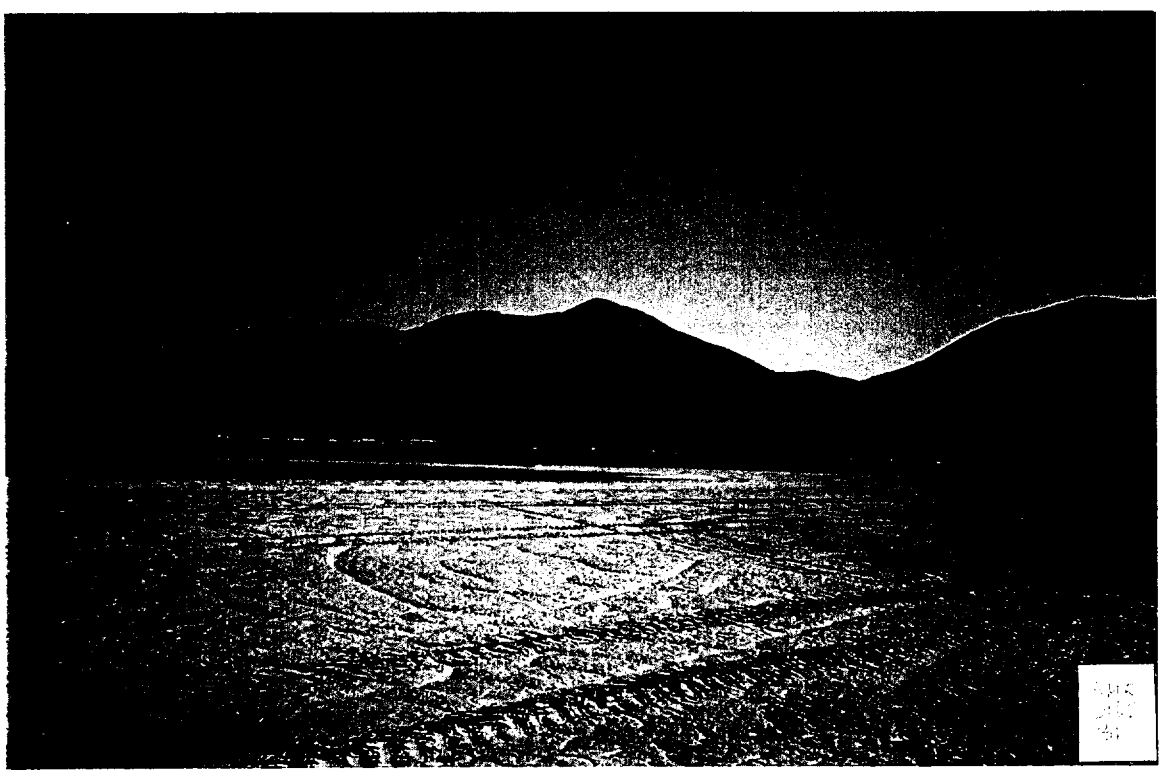


Photo 9: Desiccated beach approaching pond edge with vehicle tire tracks showing trafficability of tailings (photo taken in September 1994).

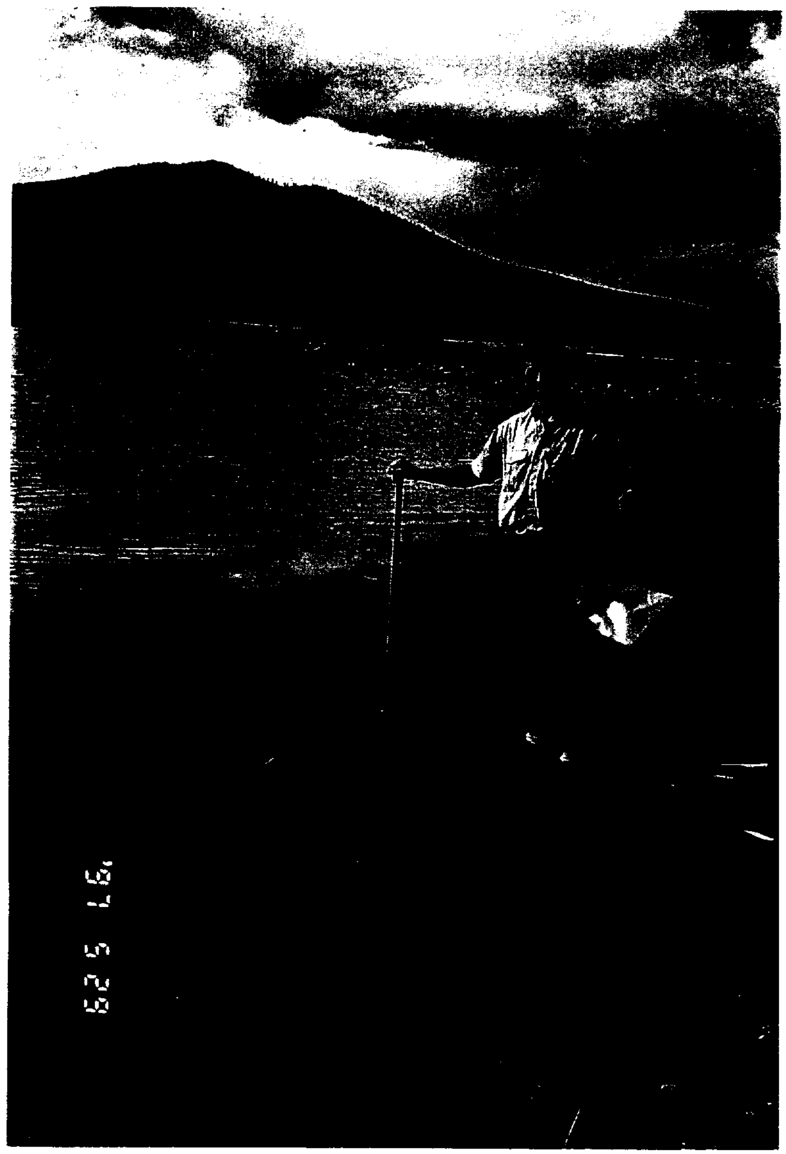


Photo 10: Intermediate tailings on beach adjacent to pond (sampling location 97-T-2 in section 35 impoundment) indicating shear strength and permitting access (photo taken May, 1997).

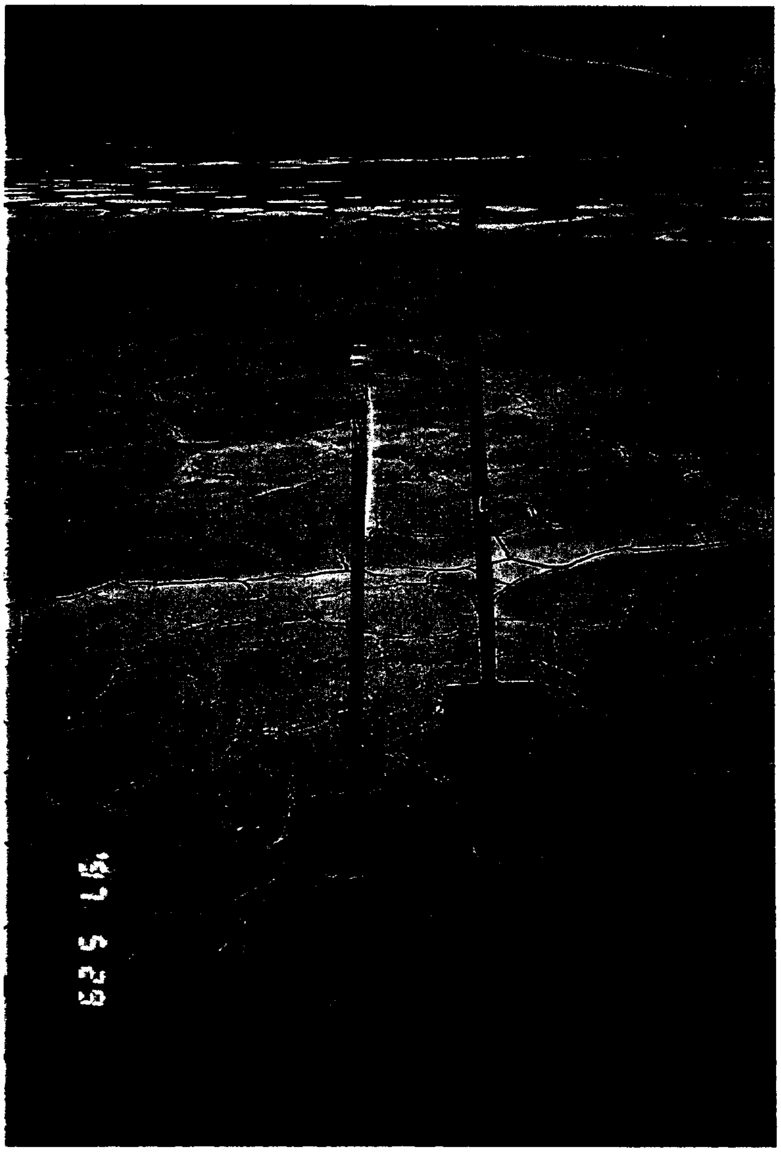


Photo 11: Desiccated fine tailings on beach adjacent to pond (sampling location 97-T-3 in section 35 impoundment) accessible and trafficable after desiccation (photo taken May, 1997).

Photo 12: Successful placement of alluvial cover material in uniform, controlled thin layers using scrapers (photo taken September 1994).

Photo 13: Looking north towards decant channel of Dam 5A exposing alluvial sediments used as cover material. At least three horizontally extensive (>200m) layers of fine sediment (clay/silt) can be seen in the alluvial sediment sequence (photo taken May, 1997).

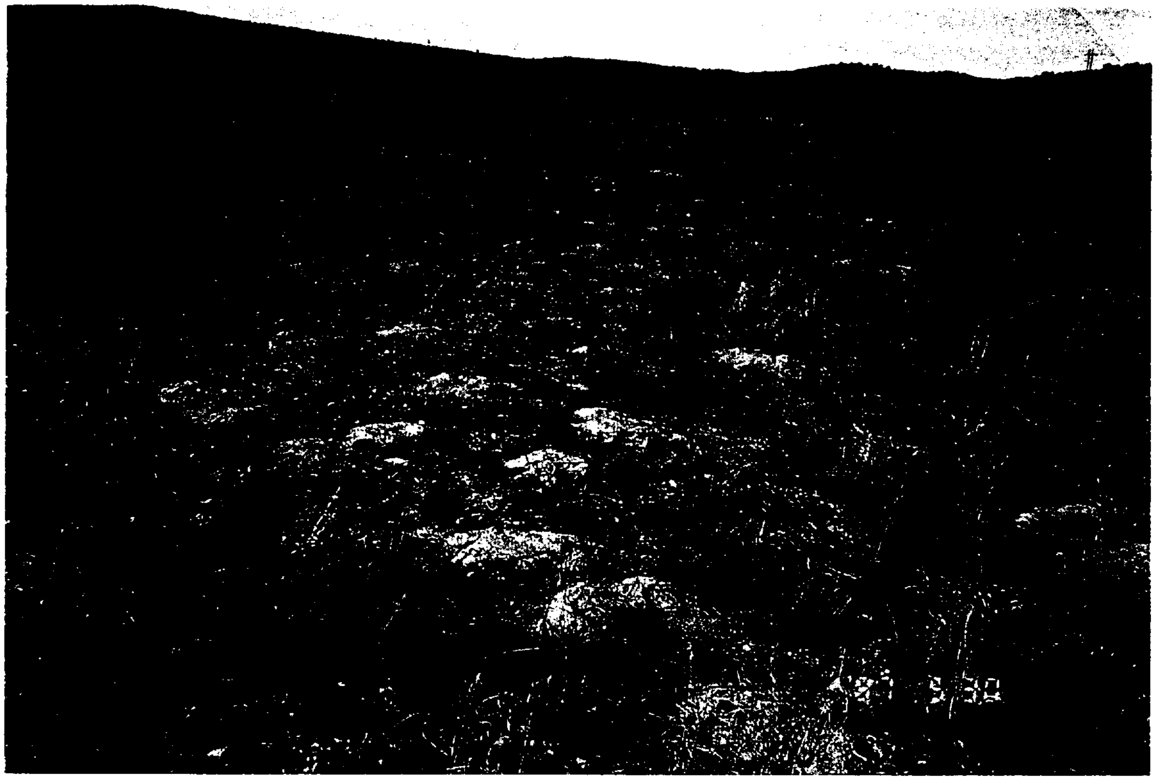


Photo 14: Tailings covered with alluvium showing early vegetation growth. Biotic activity of gopher colony has disturbed cover and brought tailings to surface (photo taken May, 1997).

Photo 15: Close-up of alluvial cover material showing gravelly nature of alluvium and penetration of ants down into the tailings (photo taken May, 1997).

Photo 16: Example of vegetation at the Dam 1 location. Tailings were covered and seeded in the 1970s (photo taken April, 1998).

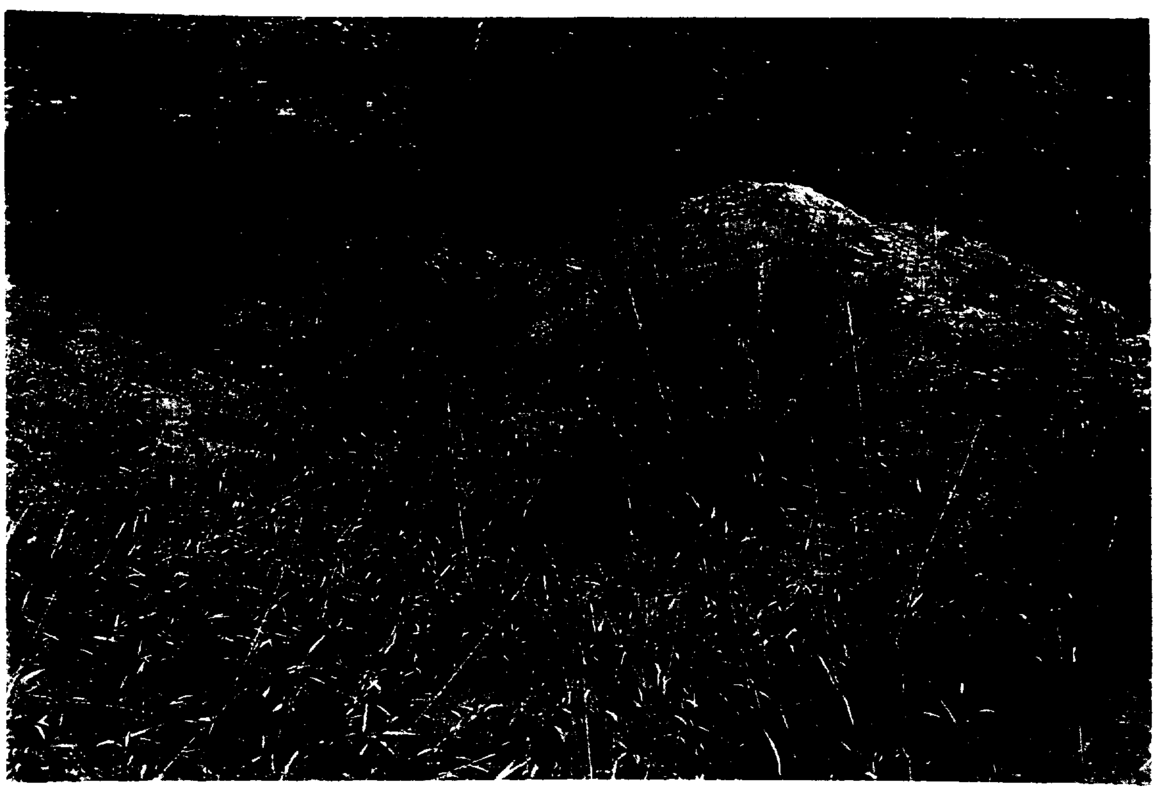


Photo 17: Grasses and shrubs growing directly in exposed tailings at Dam No. 1 (photo taken April, 1998).

Photo 18: Grasses and shrubs growing directly in exposed tailings at Dam No. 1 (photo taken April, 1998).

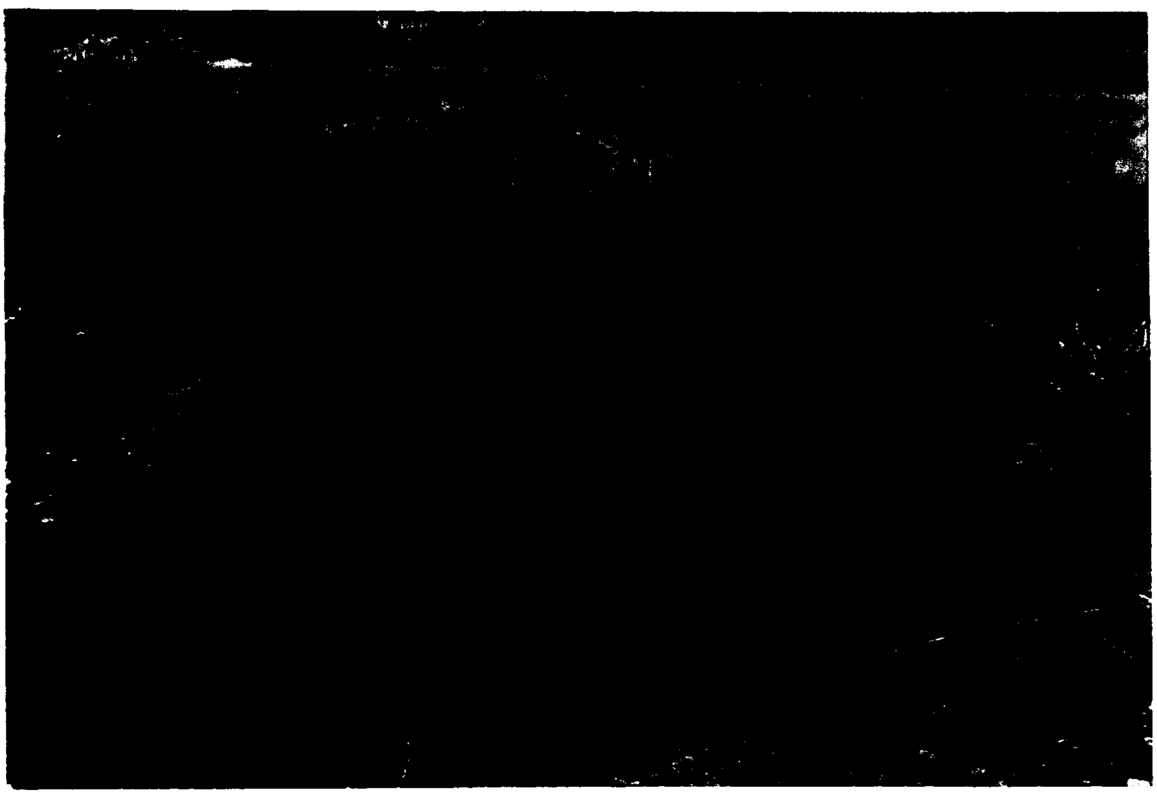


Photo 19: Roots found growing in the tailings near large shrubs on Dam No. 1. Small roots were found to 3 feet and deeper. (Photo taken October, 1997).

Photo 20: Roots found growing in the tailings near large shrubs on Dam No. 1. Small roots were found to 3 feet and deeper. (Photo taken October, 1997).

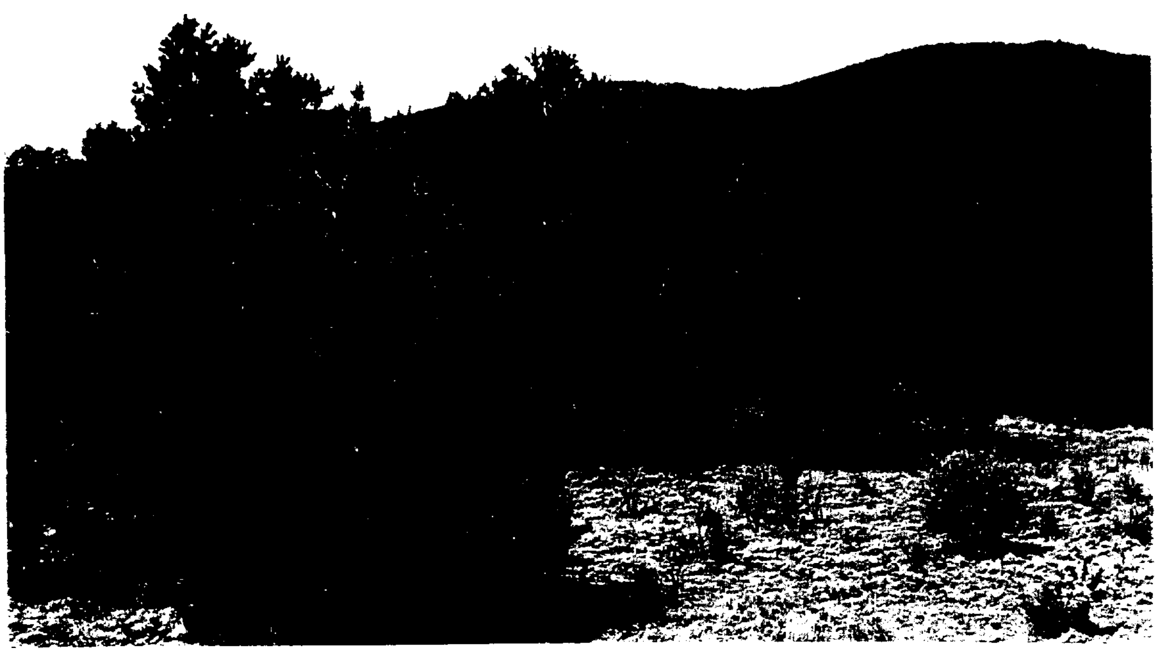


Photo 21: Example of a Piñon-Juniper woodland near the Questa Tailings Facility (Photo taken April, 1998).

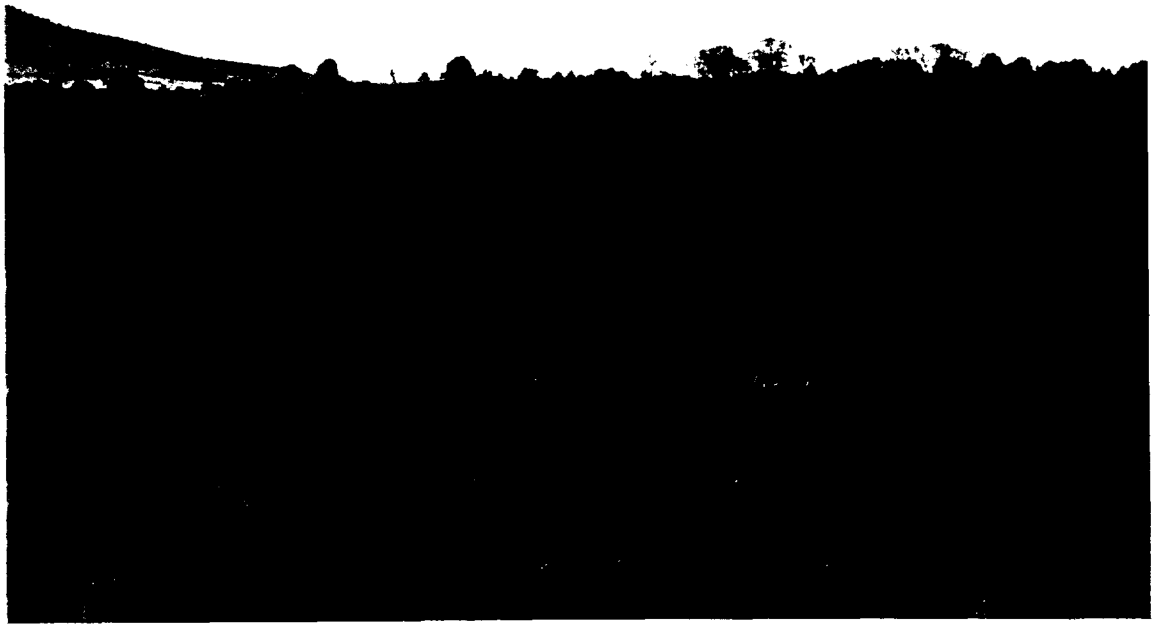
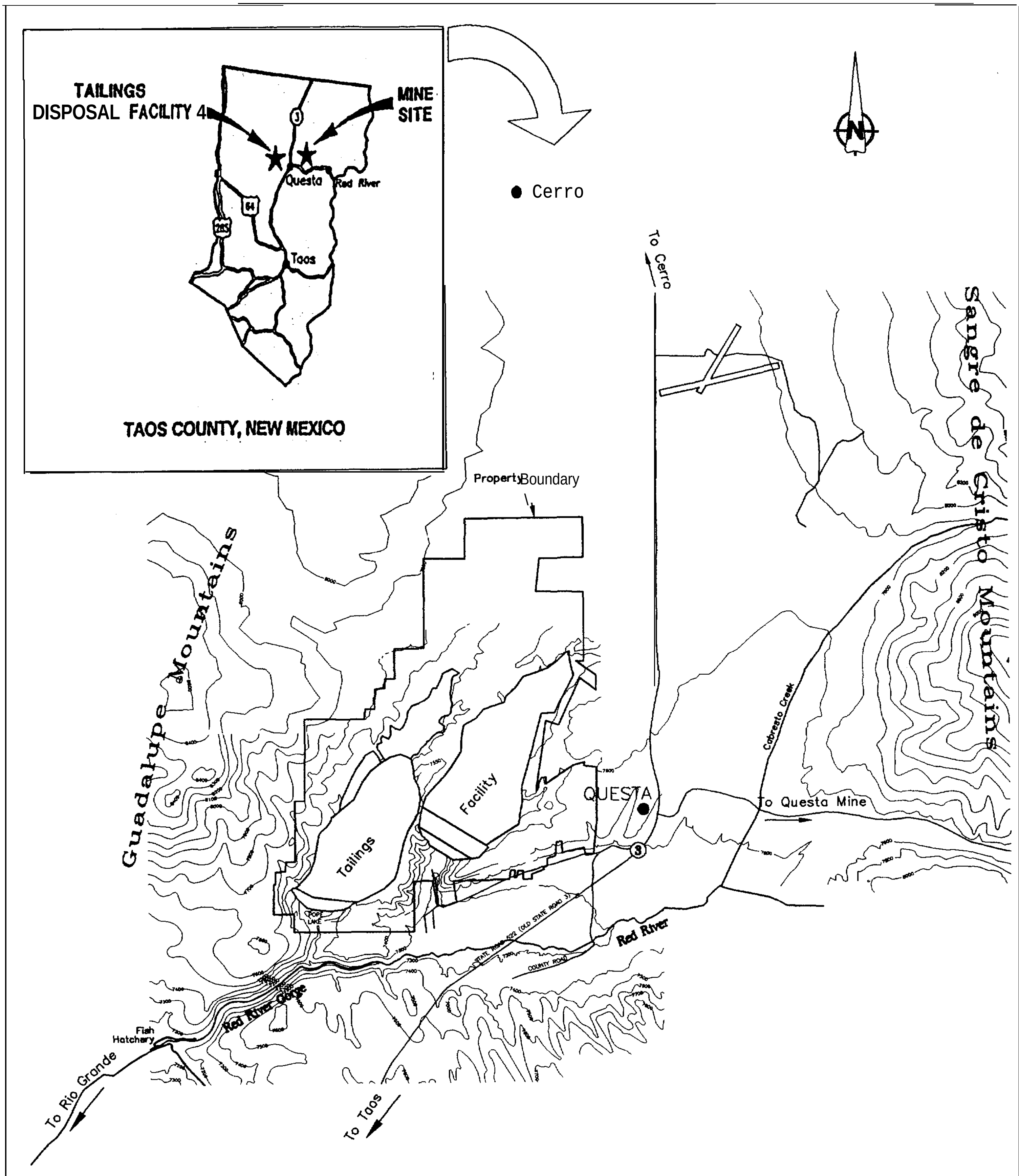


Photo 22: Example of a sagebrush ecosystem near the Questa Tailings Facility (Photo taken April, 1998).

figures -



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UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Location Map
Tailings Impoundments

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=4300'		2-1

\acad_questa\Questa-Final Report\2-1 location-map-new Tue Apr 28 08:34:52 1998 L. du Toit

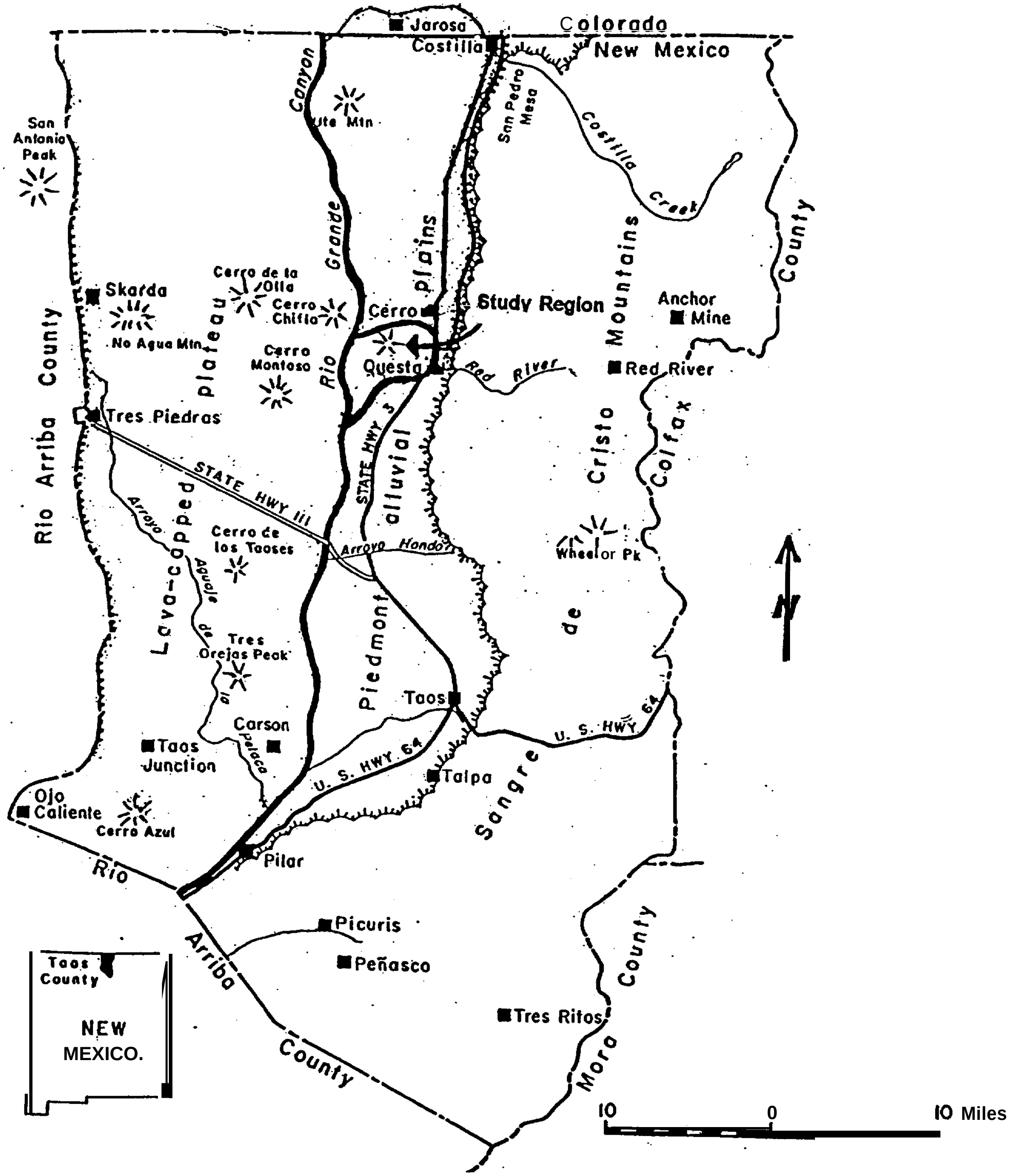
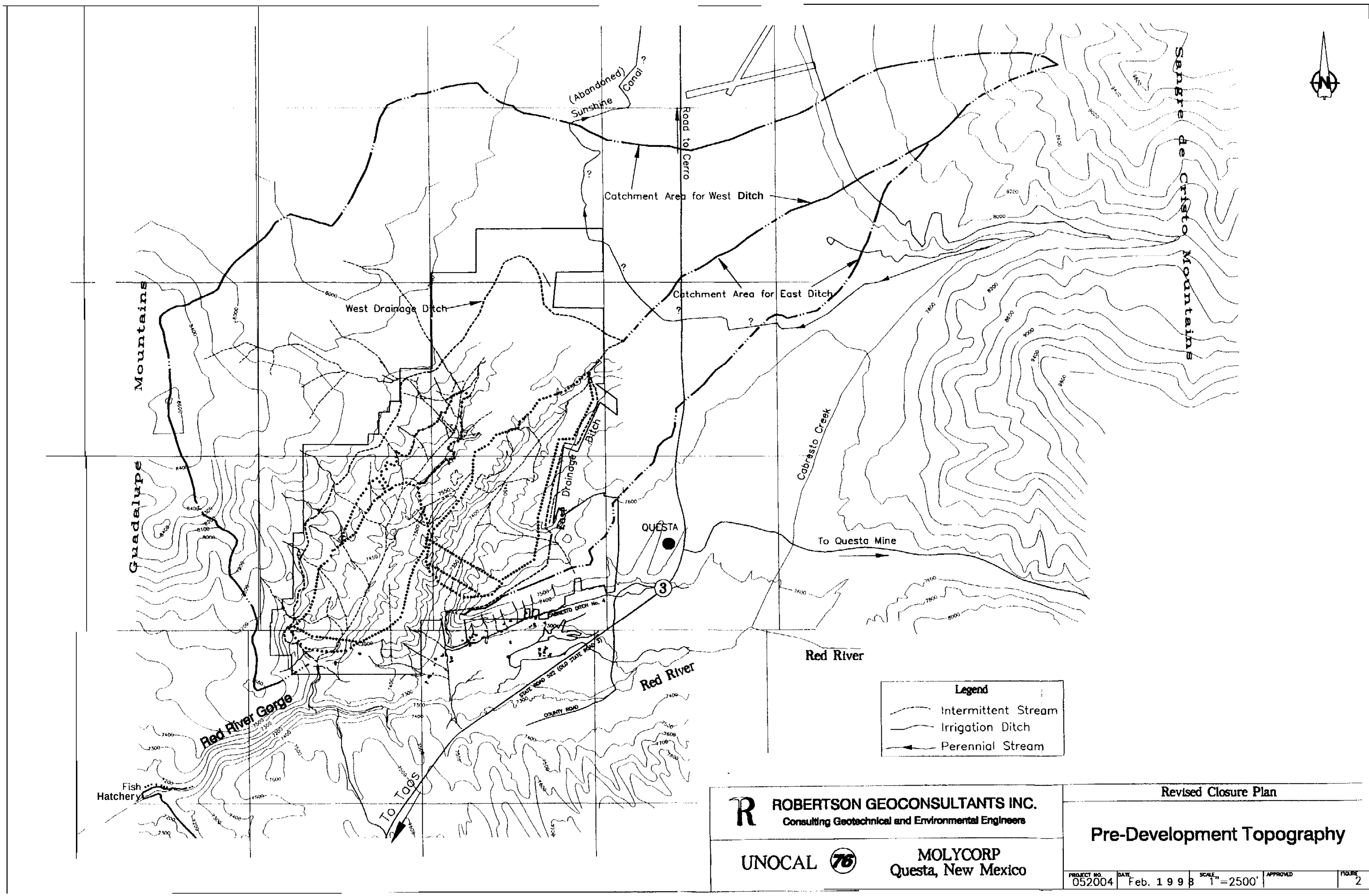


Figure 2.2

Location of Study Area (adapted from Winograd, 1959)



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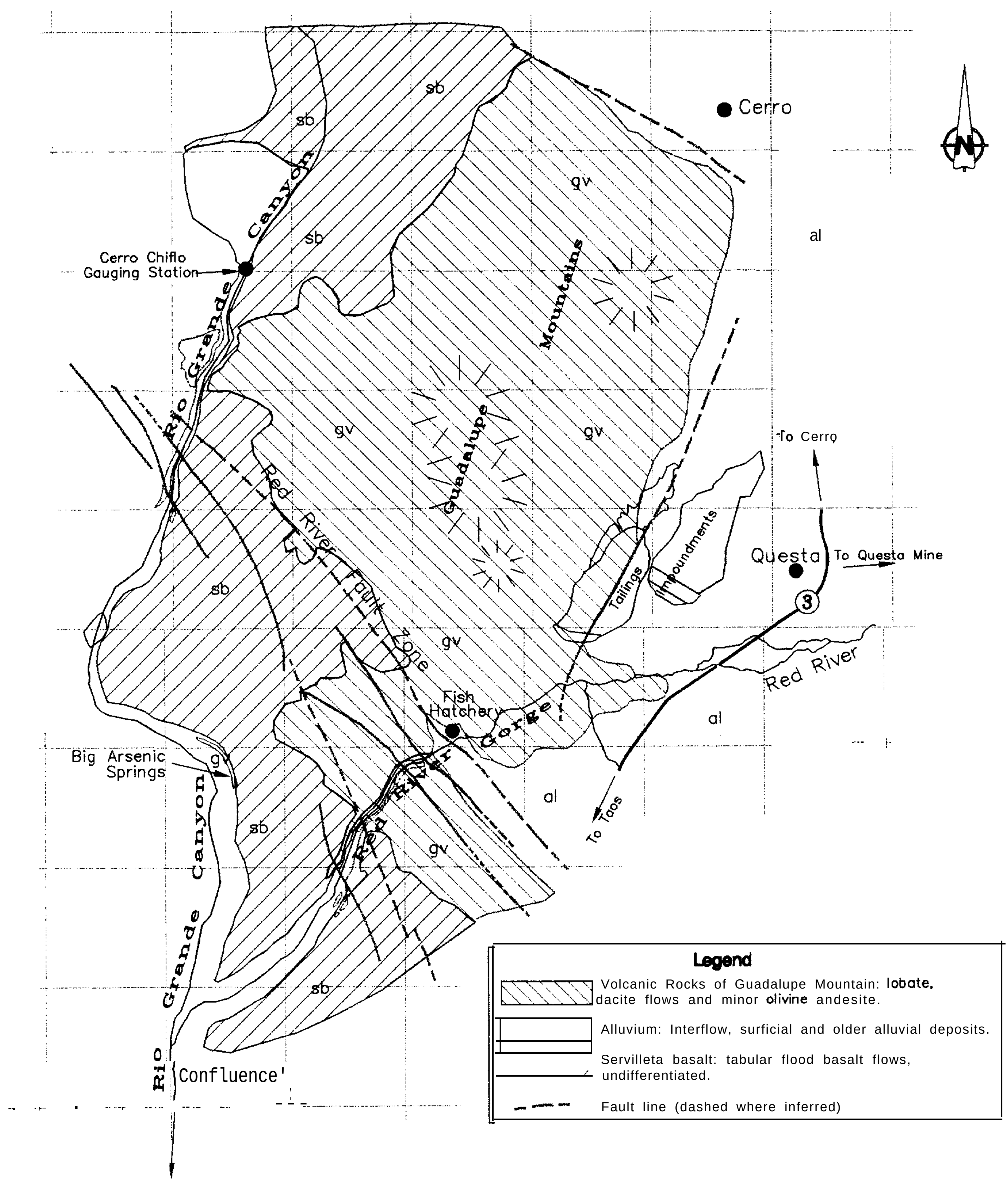
Revised Closure Plan

Pre-Development Topography

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=2500'		2



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MOLYCORP
Questa, New Mexico

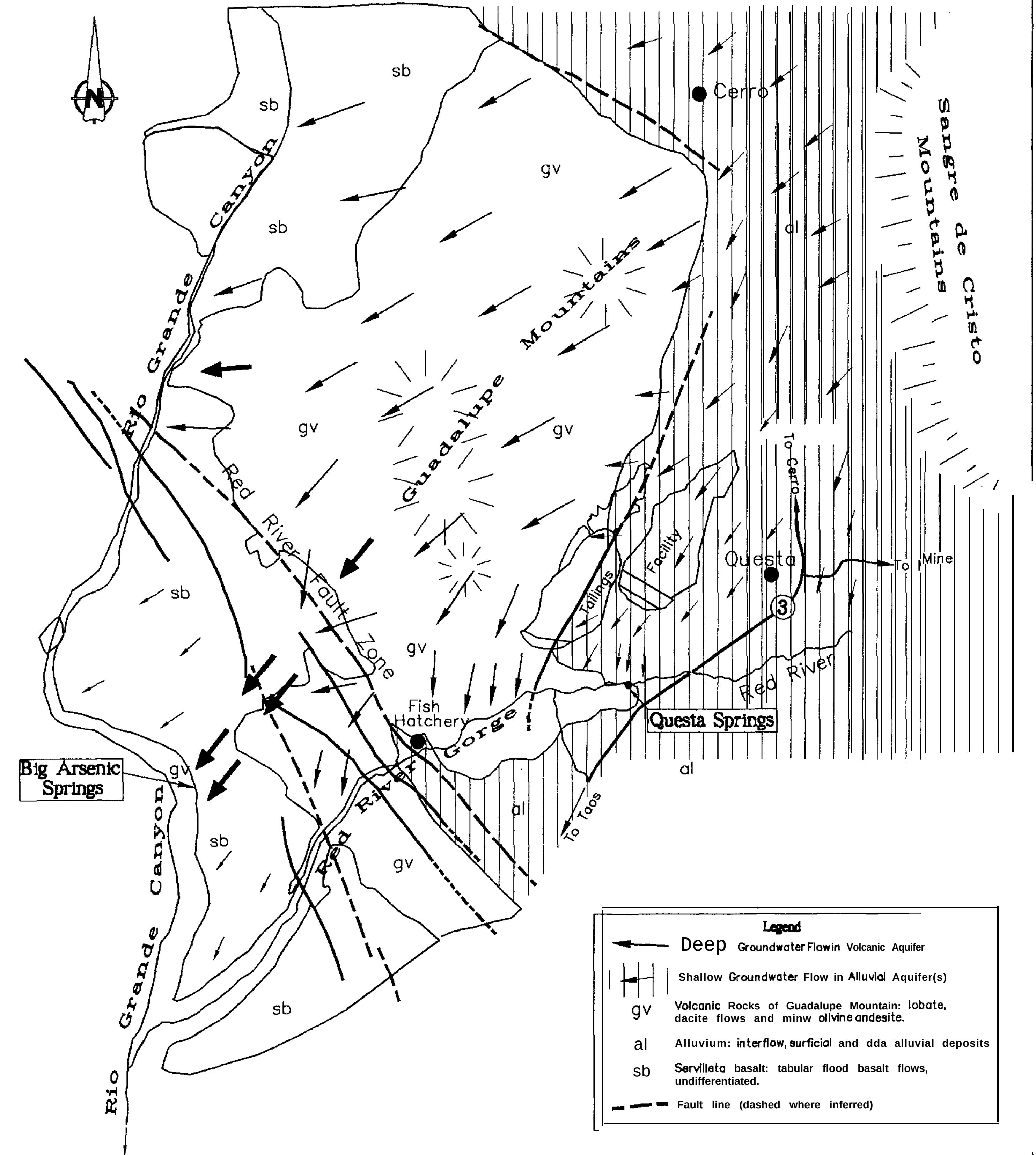
Revised Closure Plan

Surficial Geology

(after Vail, 1987)

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=6000'		2-

acad_questa\Questa-Final Report\2-4 Geology Tue Apr 28 07: 32:58 1998 L. du Toit



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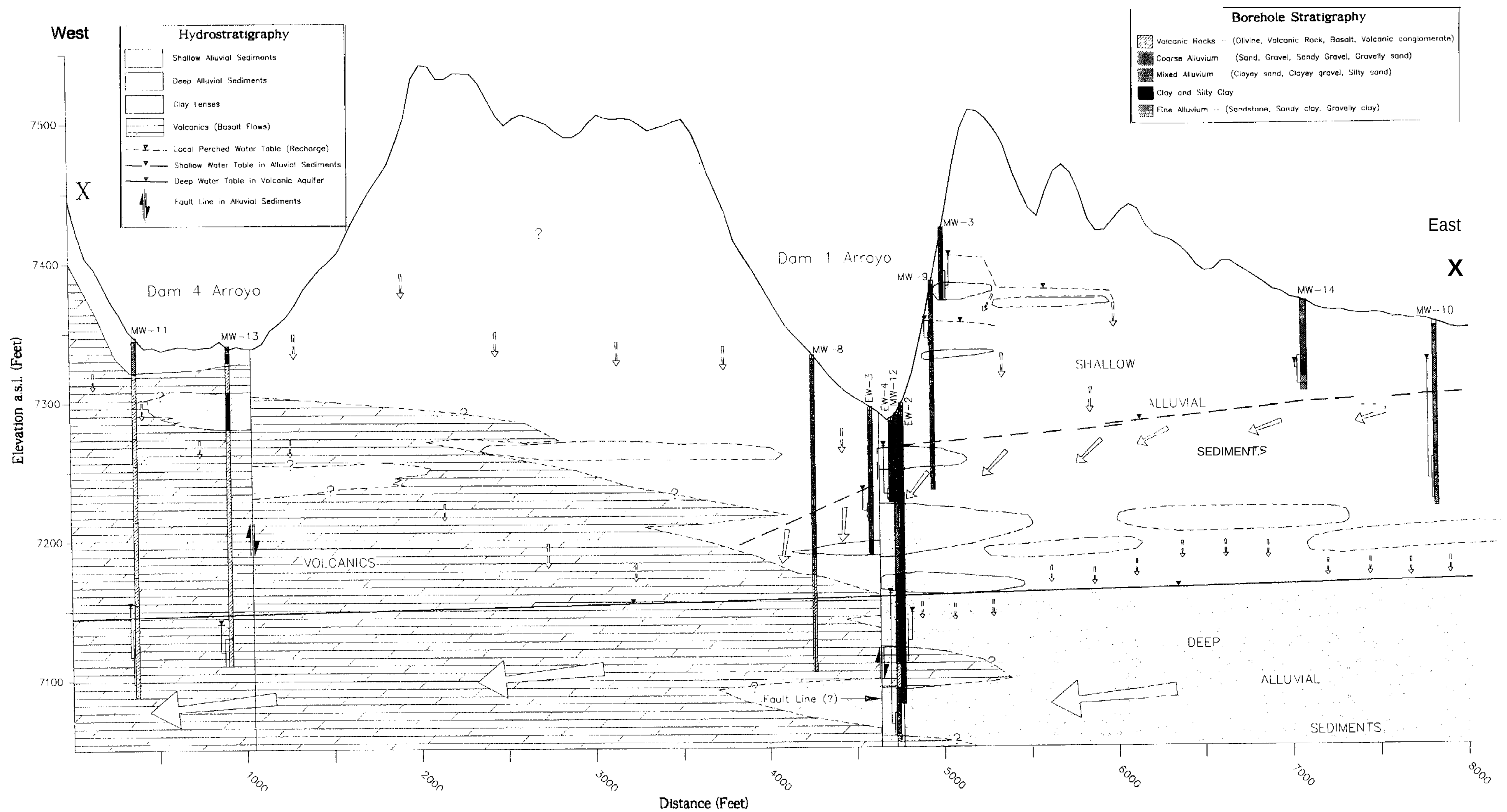
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Regional Groundwater Flow

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=5700'		2-5

\acad_questa\Questa-Final Report\2-5 Regina1 GroundwaterFlow Thu Apr 23 11:40:49 1998 L. du Toit



Note:
1. For location of cross section X-X' see figure no.
2. Stratigraphy inferred where borehole data missing (dashed lines).

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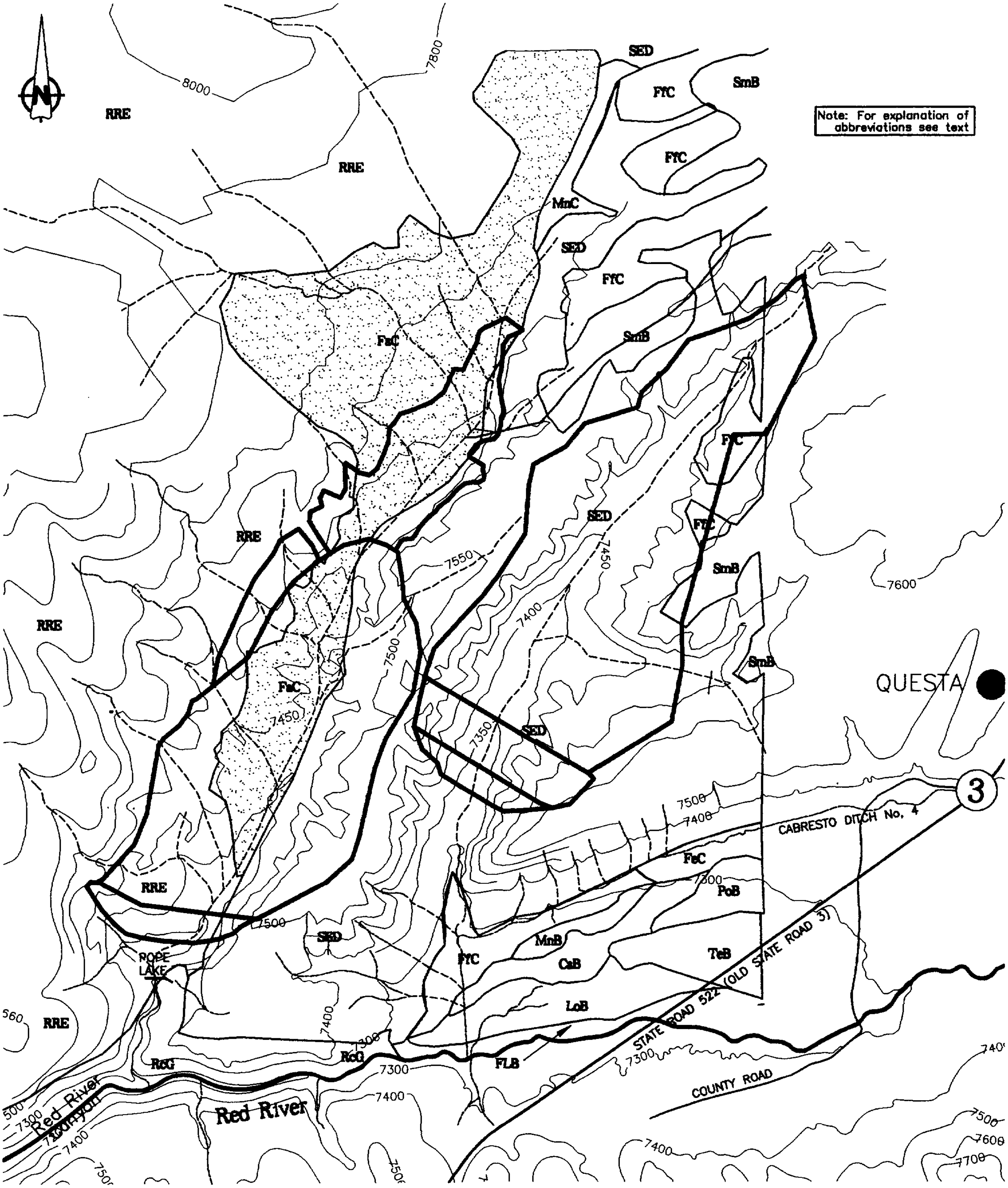
Revised Closure Plan

Hydrogeological Cross-Section

PROJECT NO	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=550'		2-6



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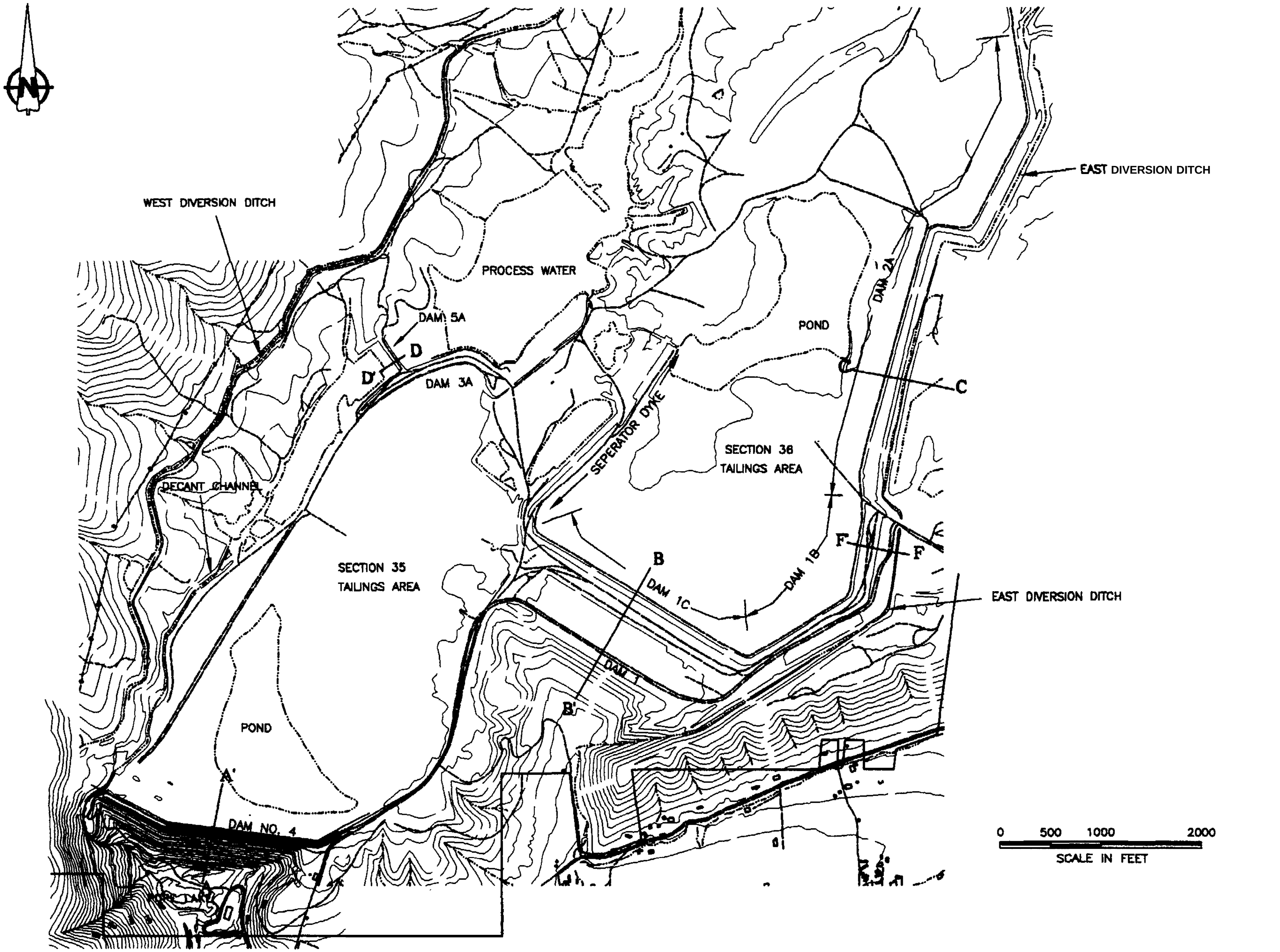
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Soils and Vegetation

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=1700'		2-7

\acad_questa\Questa-Final Report\2-7 Soils-Vegetation Tue Apr 28 09:52:47 1998 L. du Toit



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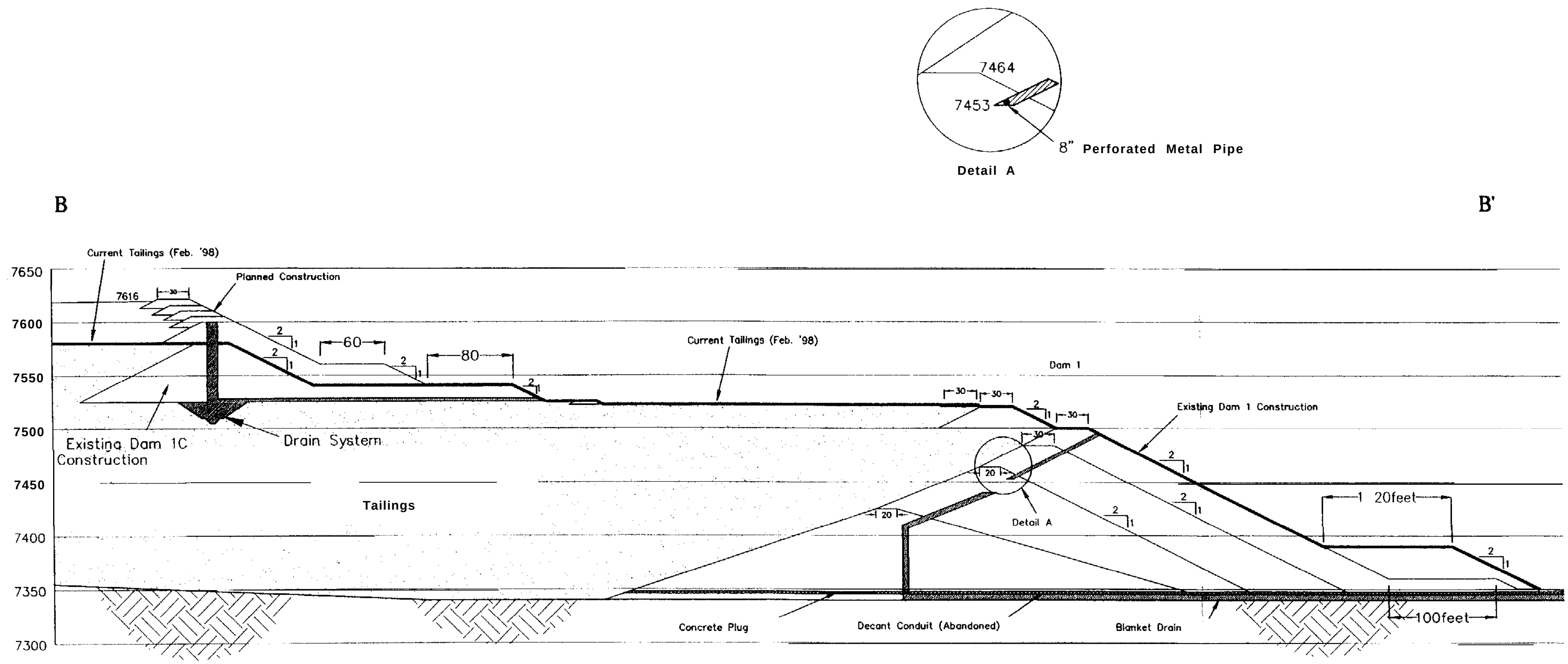
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Tailings Facility Overview

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=1400'		3-'



Note:
1. Drawing Modified from Molycorp Drawing by P. Lacombe.
2 For approximate location of cross-section. see Dwg. No. 3-l "Overview of Impoundment"

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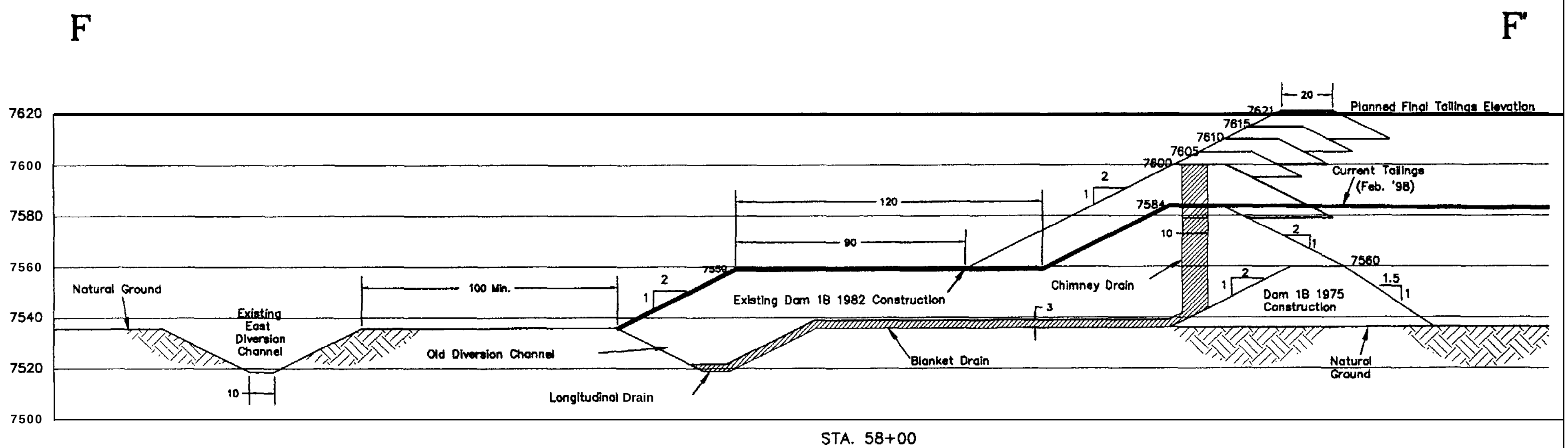
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Dam No. 1 and 1C
Typical Cross Section

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=95'		3-



Note: Refer to drawing 3-l for section location.

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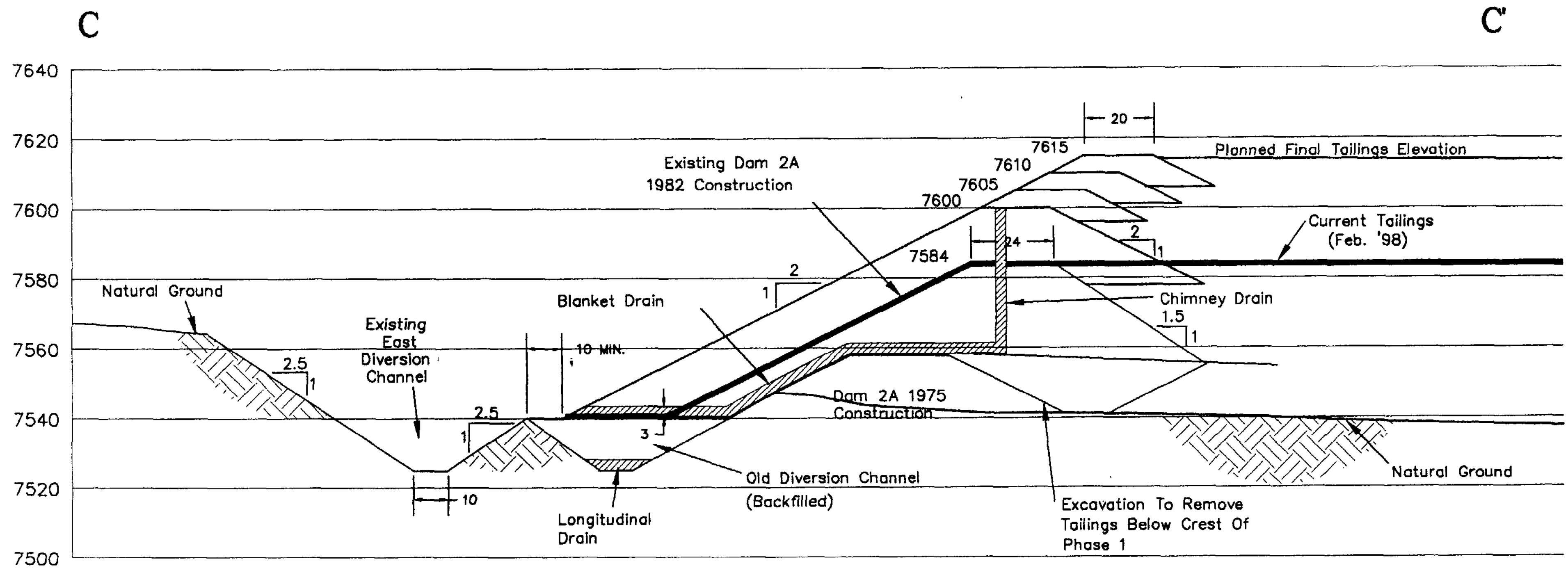
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Dam No. 1B - Sta. 58+00
Typical Cross Section

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=60'		3-3

\acad_questa\Questa-Final Report\3-3 Dam1B-Sta58 Mon Apr 27 18:56:59 1998

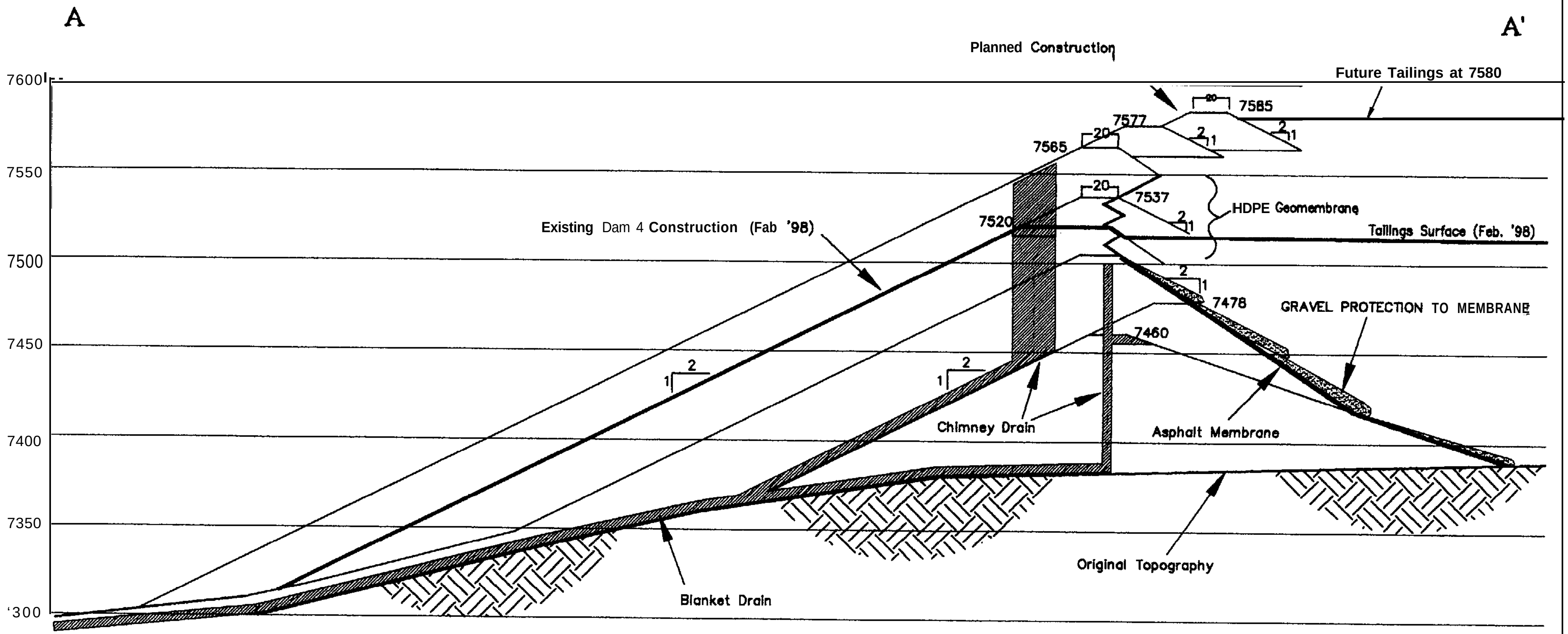


STA. 41+00

Note: Refer to drawing 3-1 for section location.

ROBERTSON GEOCONSULTANTS INC. Consulting Geotechnical and Environmental Engineers	Revised Closure Plan
UNOCAL 76 — MOLYCORP Questa, New Mexico	Dam No. 2a - Sta. 41+00 Typical Cross Section

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=45'		3-4



Note: Refer to drawing 3-l for section location.

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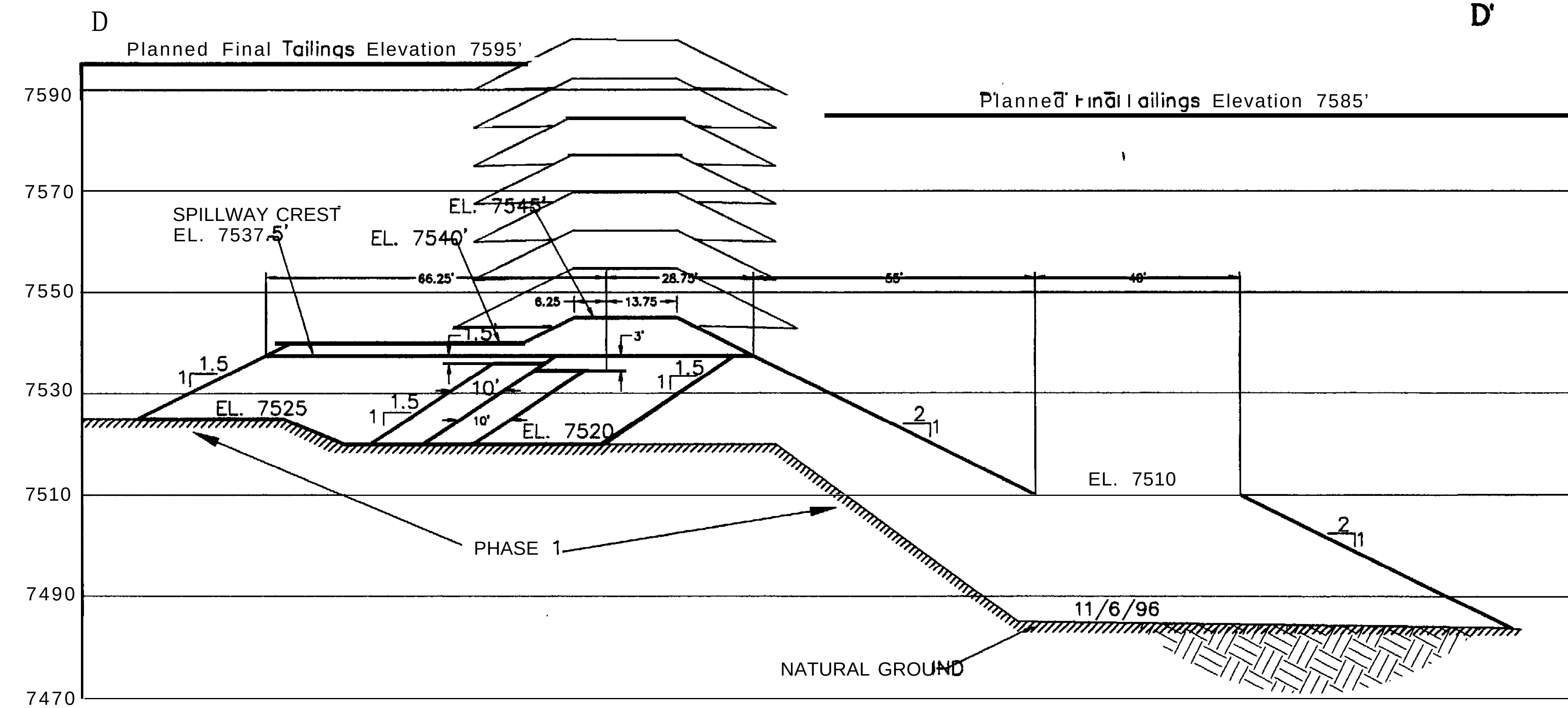
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Dam No. 4
Typical Cross Section

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=85'		3-5.



Note: Refer to Drowing 3-l for section location.

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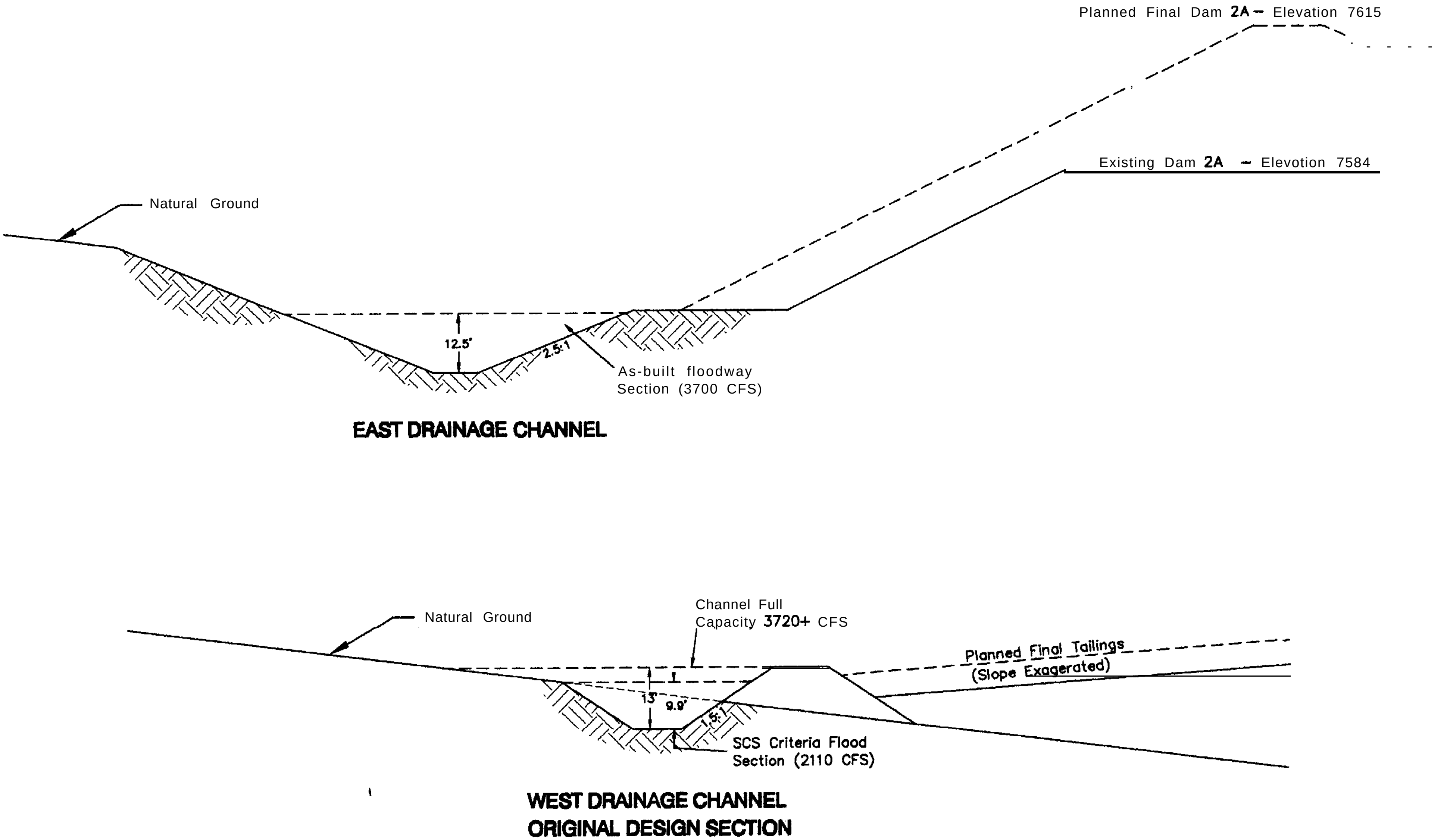
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Dam No. 5a
Typical Cross Section

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"=30'		3-6



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UNOCAL 76

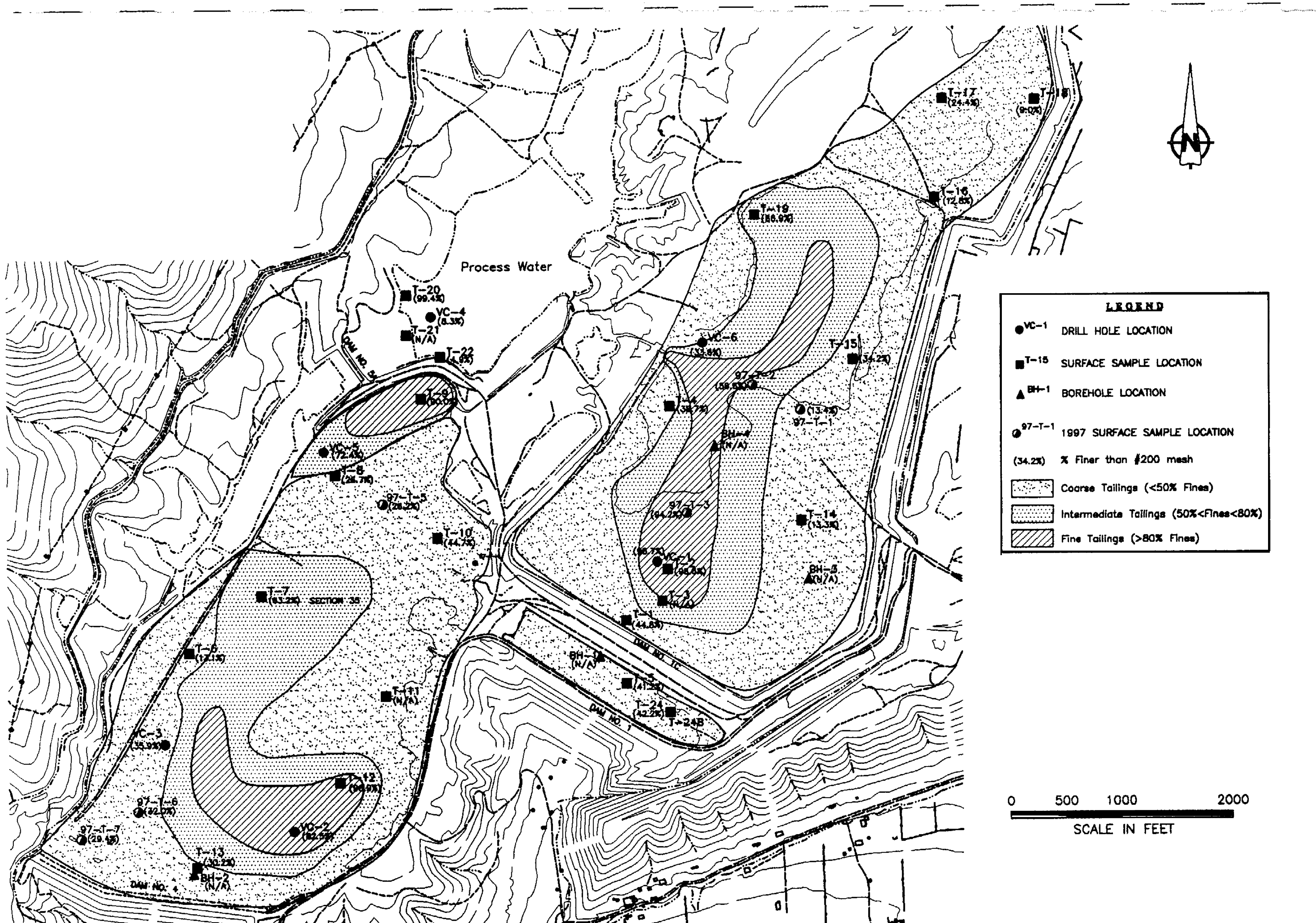
MOLYCORP
Questa, New Mexico

Revised Closure Plan

East and West Drainage Channels Typical Sections

(after Vail, 1998)

PROJECT NO.	DATE	SCALE	APPROVED
052004	Feb. 1998	1"=30'	



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UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Tailings Characterization Plan

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=1200'		3-8

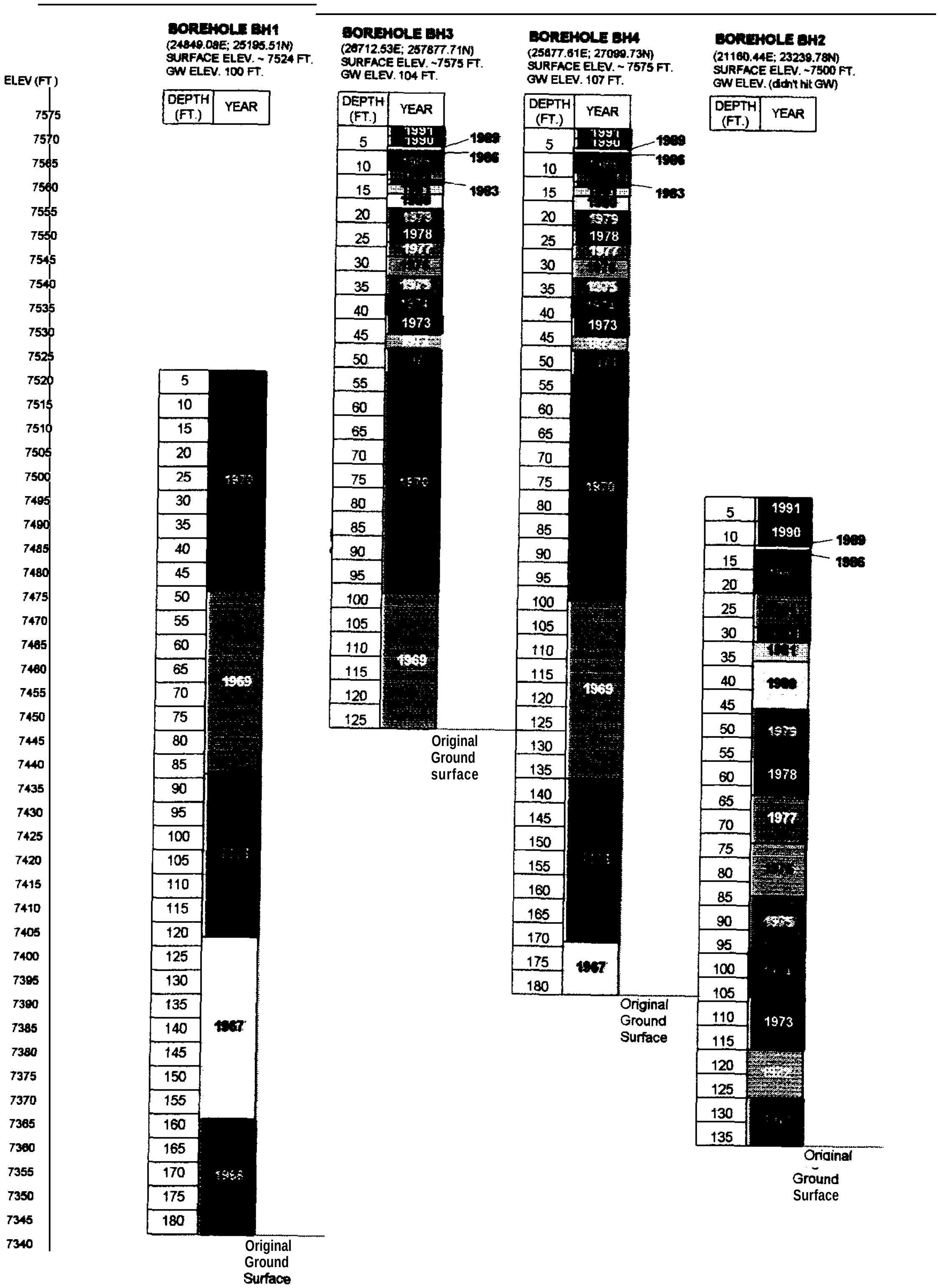
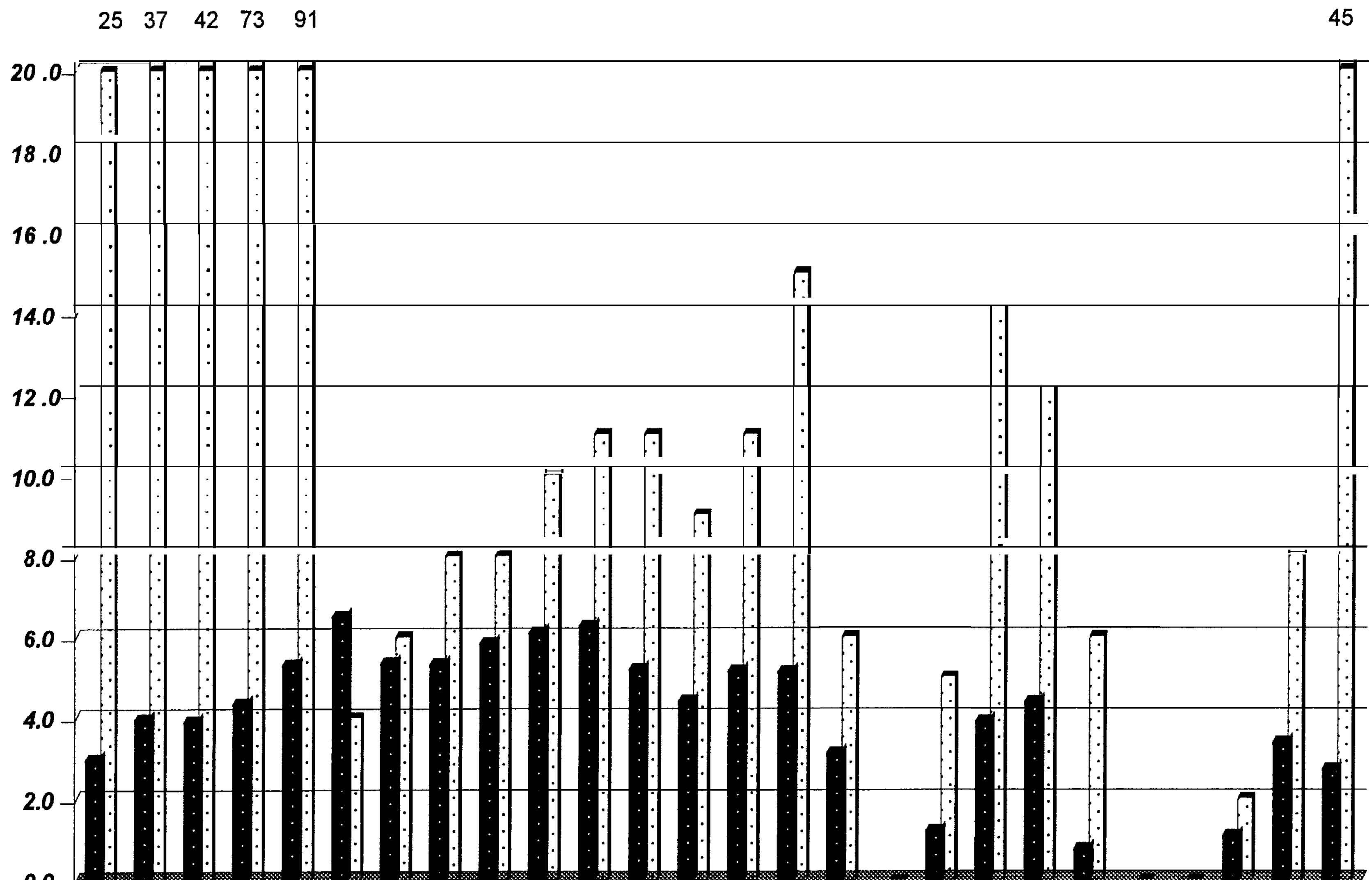
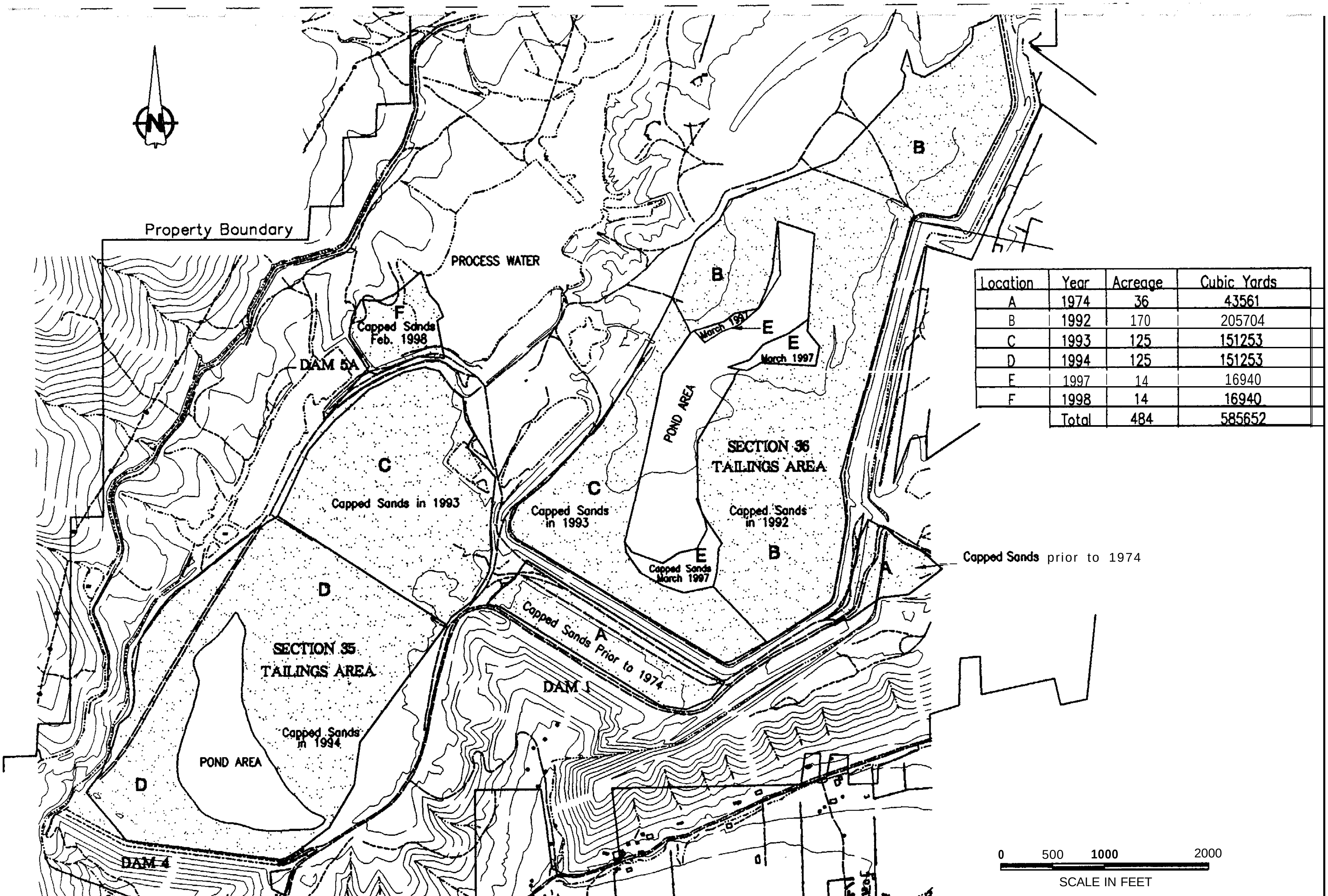


Figure 3-9.
Borehole Cross **Sections** with **Estimated** Year of Deposition **versus Depth.**



	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
■ tailings produced (million tons)	2.9	3.9	3.9	4.3	5.3	6.5	5.3	5.3	5.8	6.1	6.2	5.2	4.4	5.1	5.1	3.1		1.2	3.9	4.4	0.7			1.1	3.4	2.7
□ # of samples collected	25	37	42	73	95	4	6	8	8	10	11	11	9	11	15	6	0	5	14	12	6	0	0	2	8	45

Figure 3-10.
Volume of Tailings Produced Compared to the Number of Samples Collected For Each Year of Production.



Location	Year	Acreage	Cubic Yards
A	1974	36	43561
B	1992	170	205704
C	1993	125	151253
D	1994	125	151253
E	1997	14	16940
F	1998	14	16940
	Total	484	585652

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MOLYCORP
Questa, New Mexico

Revised Closure Plan

Interim Covers

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=1250'		3-1

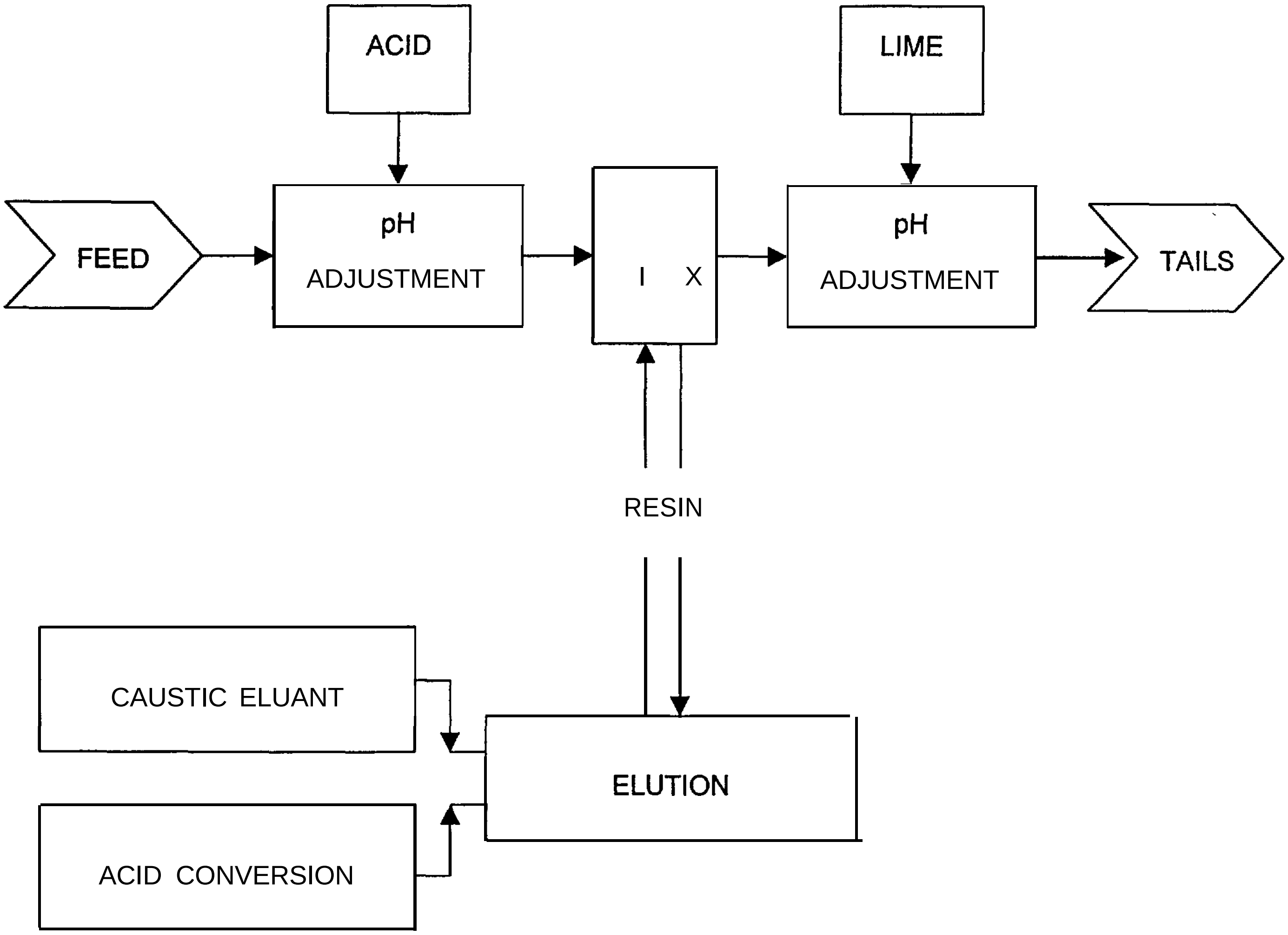
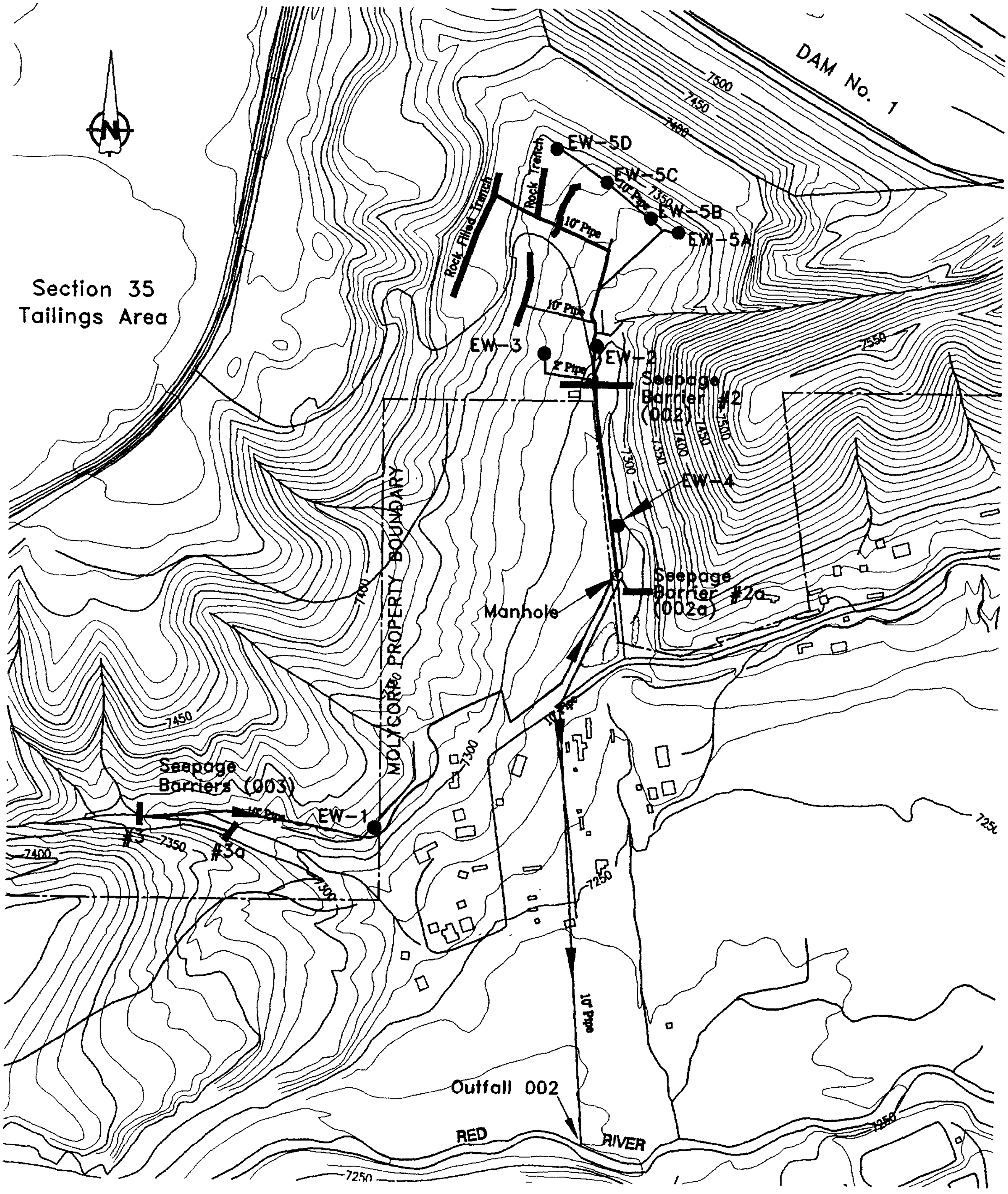


Figure 3-12.

Flowchart of Ion Exchange (IX) Plant.



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UNOCAL 76

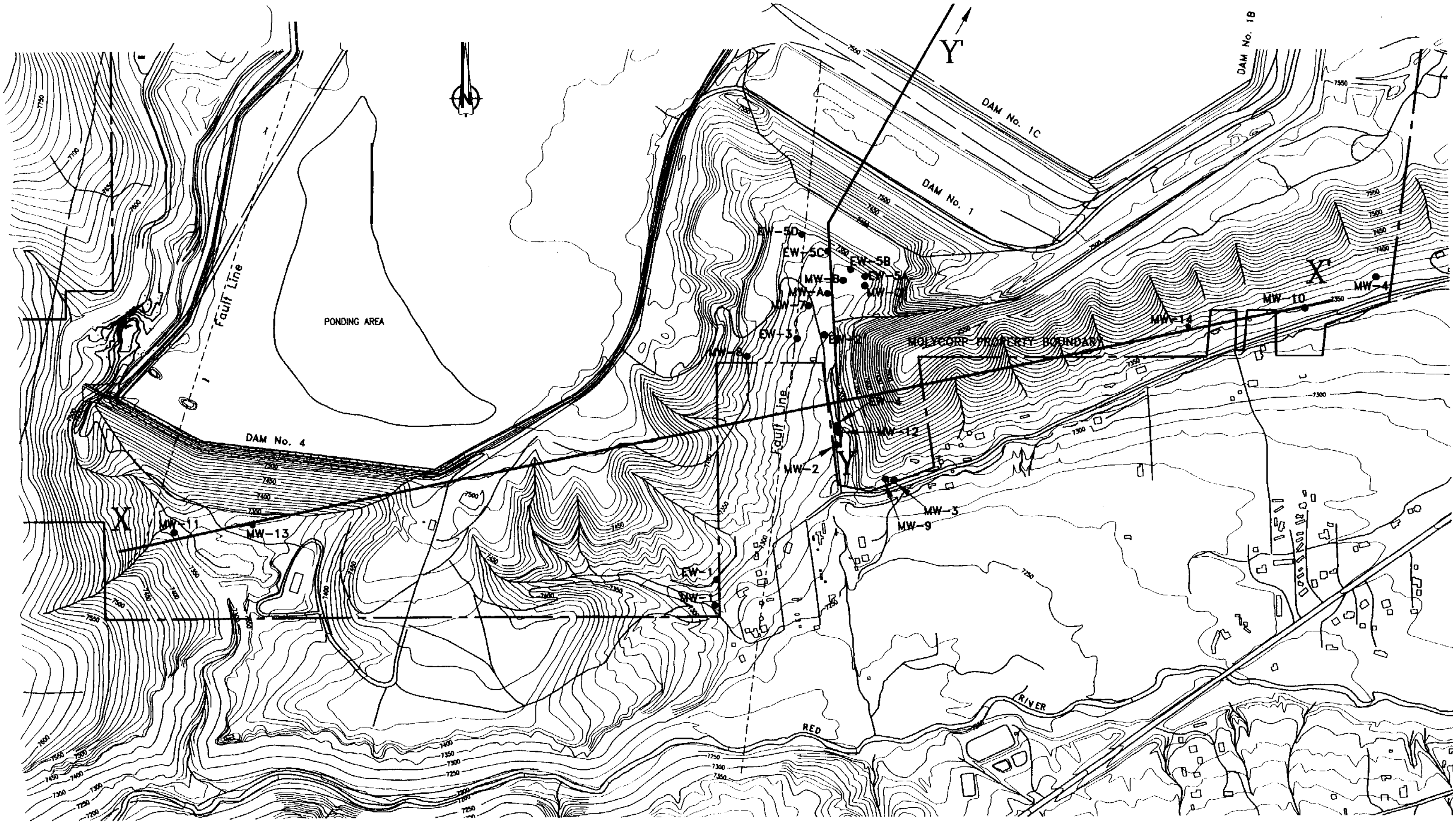
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Interception System at March 1998

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=440'		3-13

\acad_questa\Questa-Final Report\3-13 INTERCEPTION-system Tue Apr 28 10:30:19 1998 L.du Toit



ROBERTSON GEOCONSULTANTS INC. Consulting Geotechnical and Environmental Engineers	Revised Closure Plan
UNOCAL 76 — MOLYCORP Questa, New Mexico	Groundwater Monitoring Wells

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=600'		3

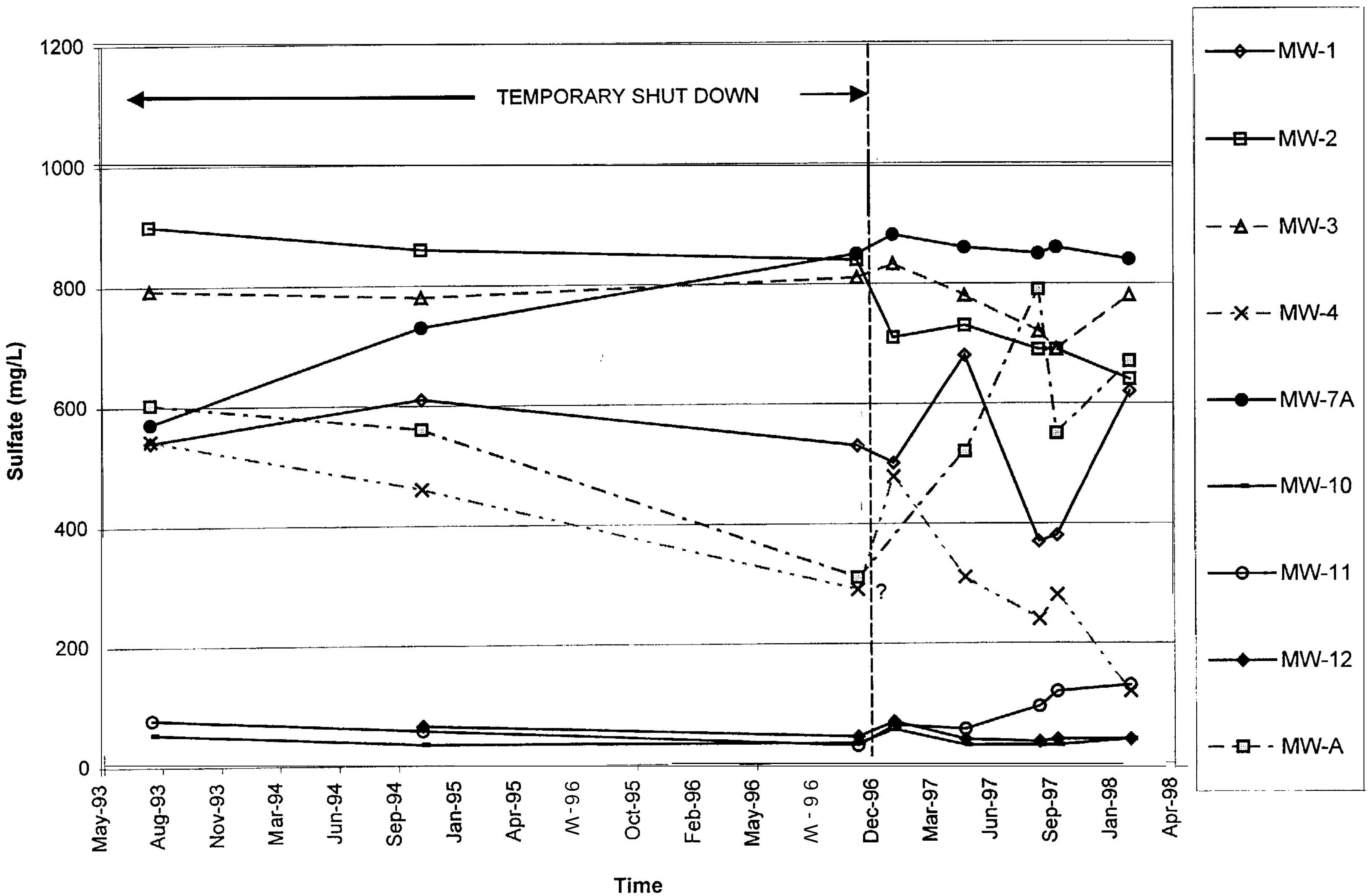


Figure 3-15a. Sulfate concentration versus time for selected monitoring wells.

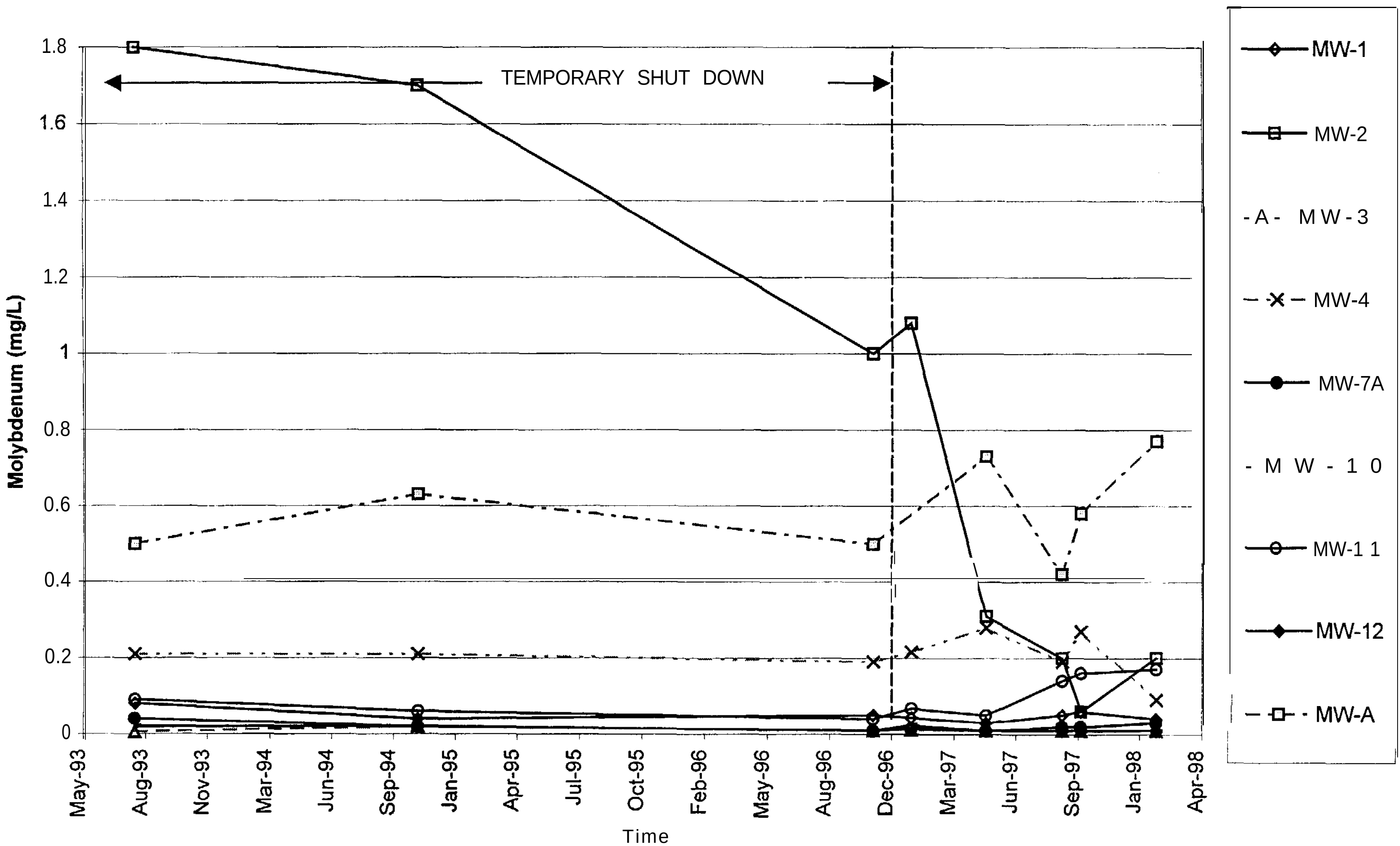


Figure 3-l 5b. Molybdenum concentration versus time for selected monitoring wells.

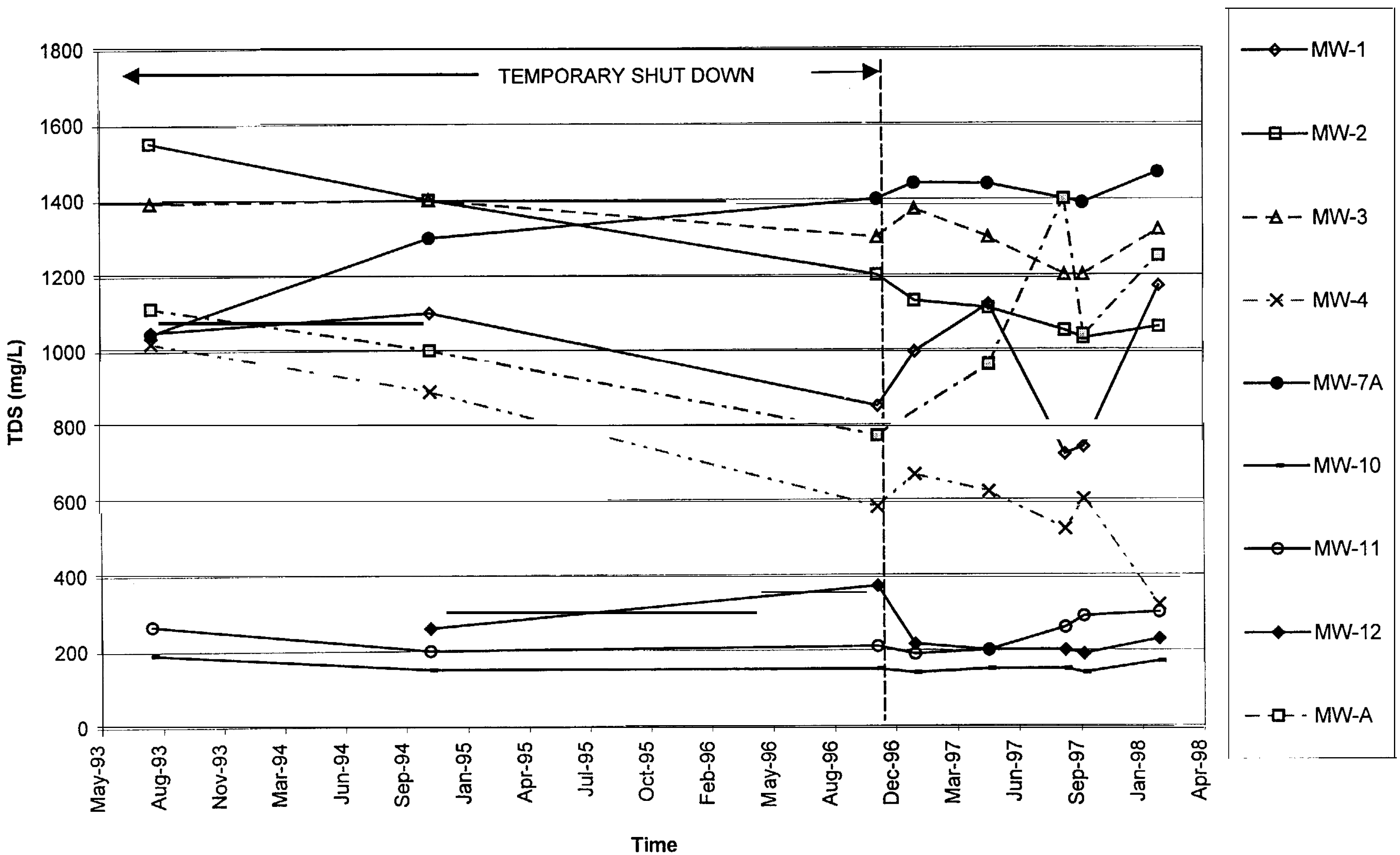
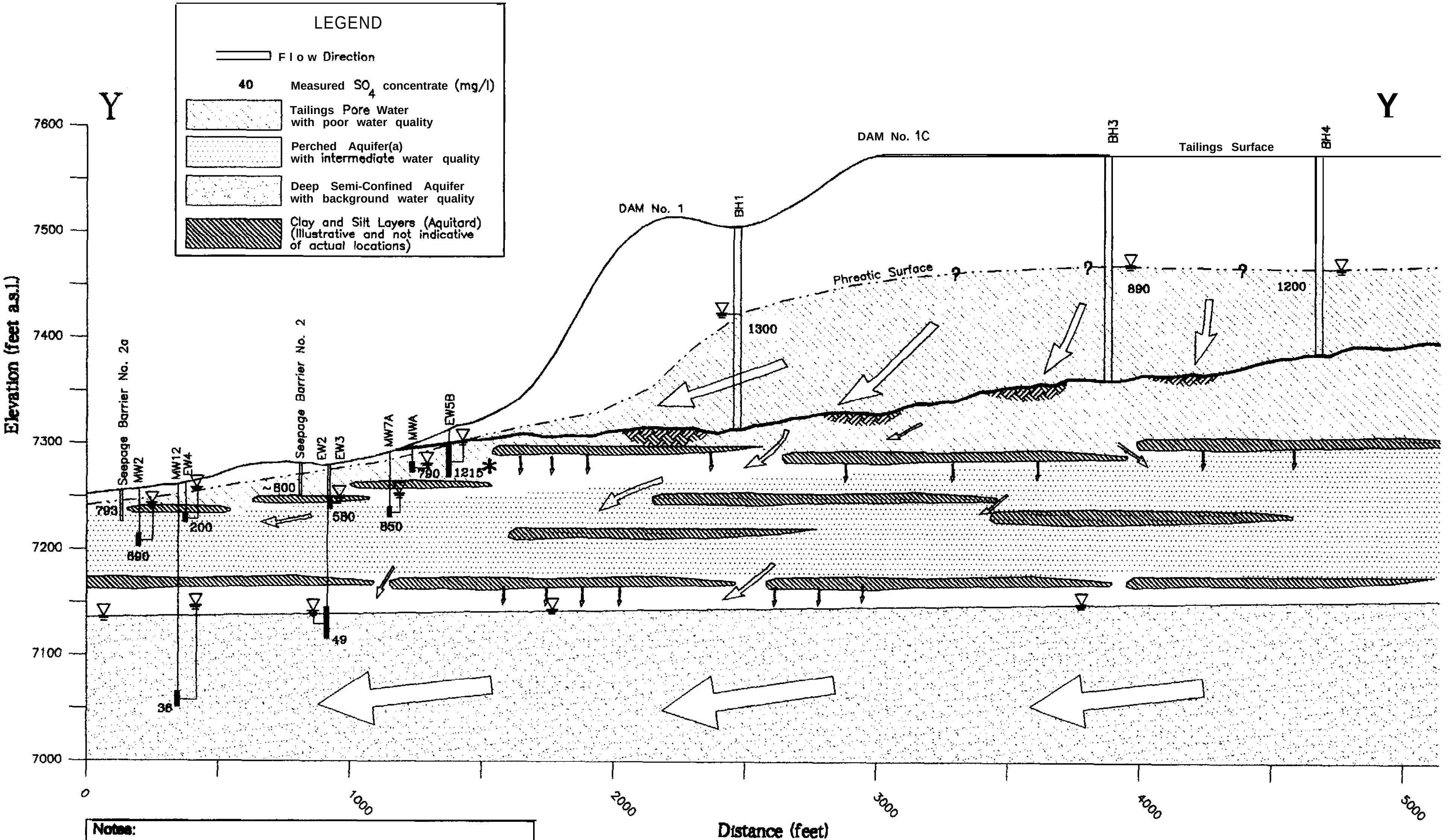


Figure 3-15c. TDS concentration versus time for selected monitoring wells.



Notes:

1. Sulphate in Monitoring Wells fmm September 1997
2. Sulphate in Boreholes from December 1996
3. Subsurface *hydrogeologic* interpretation is illustrative of interpreted conditions and not a reconstruction of known layering.

* ~880 mg/l after 4 months of pumping

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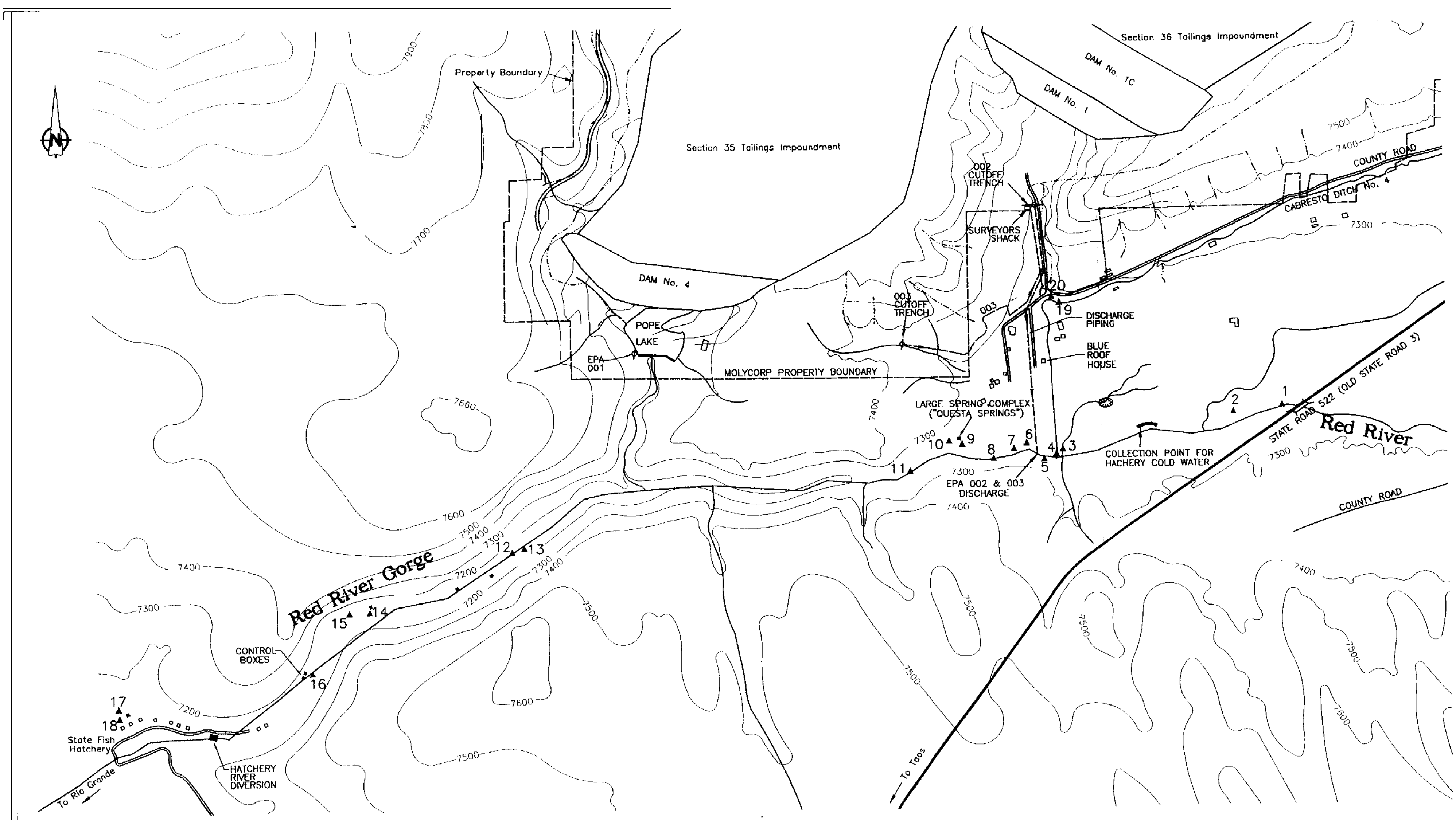
UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Conceptualization of Tailings Seepage

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=550'		3-16



LEGEND

▲ Sample Location (04-12-93)

■ Concrete Collection Box

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UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Surface Water Quality Sampling Stations
(after Vail 1993)

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=900'		3-17

Figure 3-18
Sulfate Concentration in Red River vs. Distance below Hwy Bridge

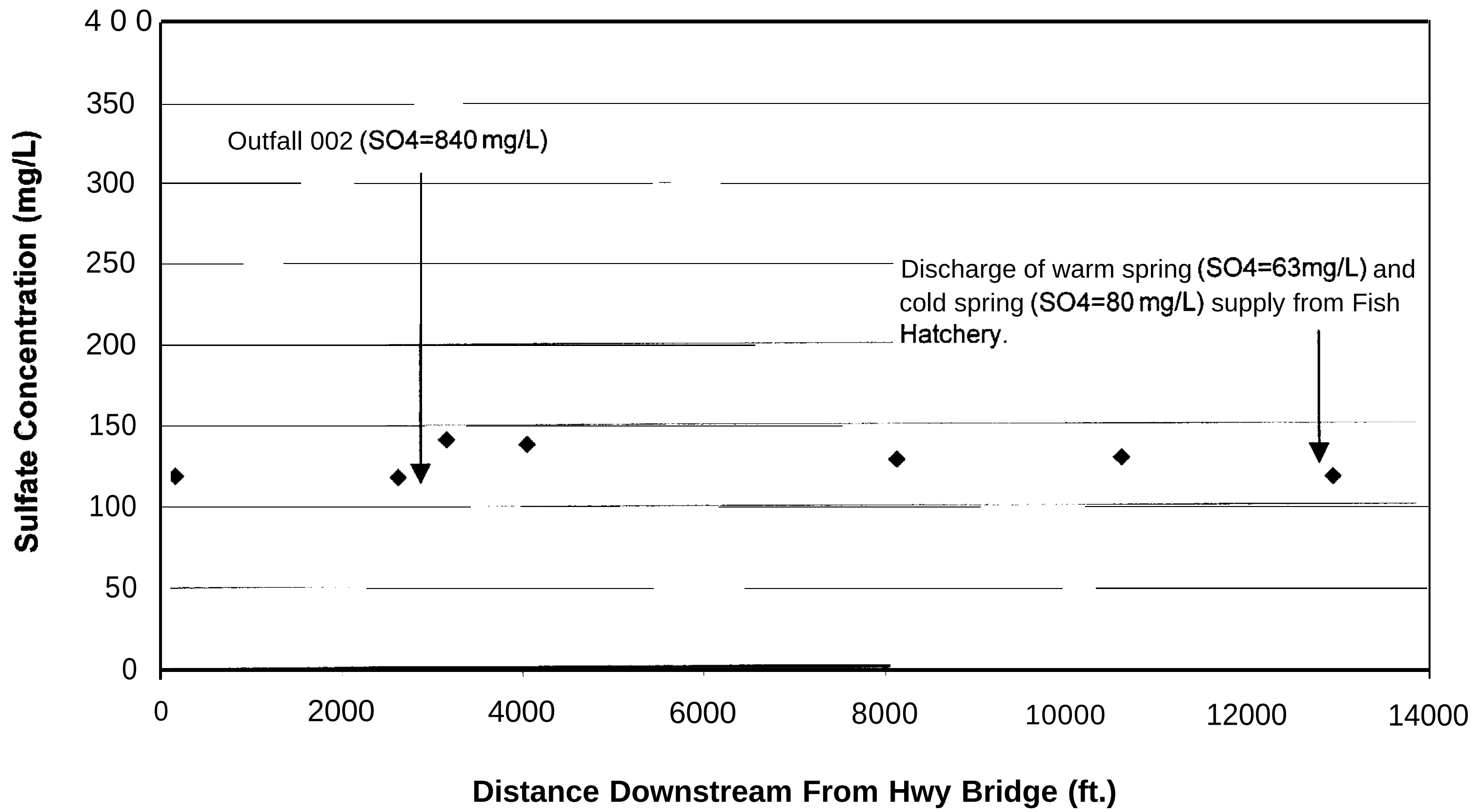
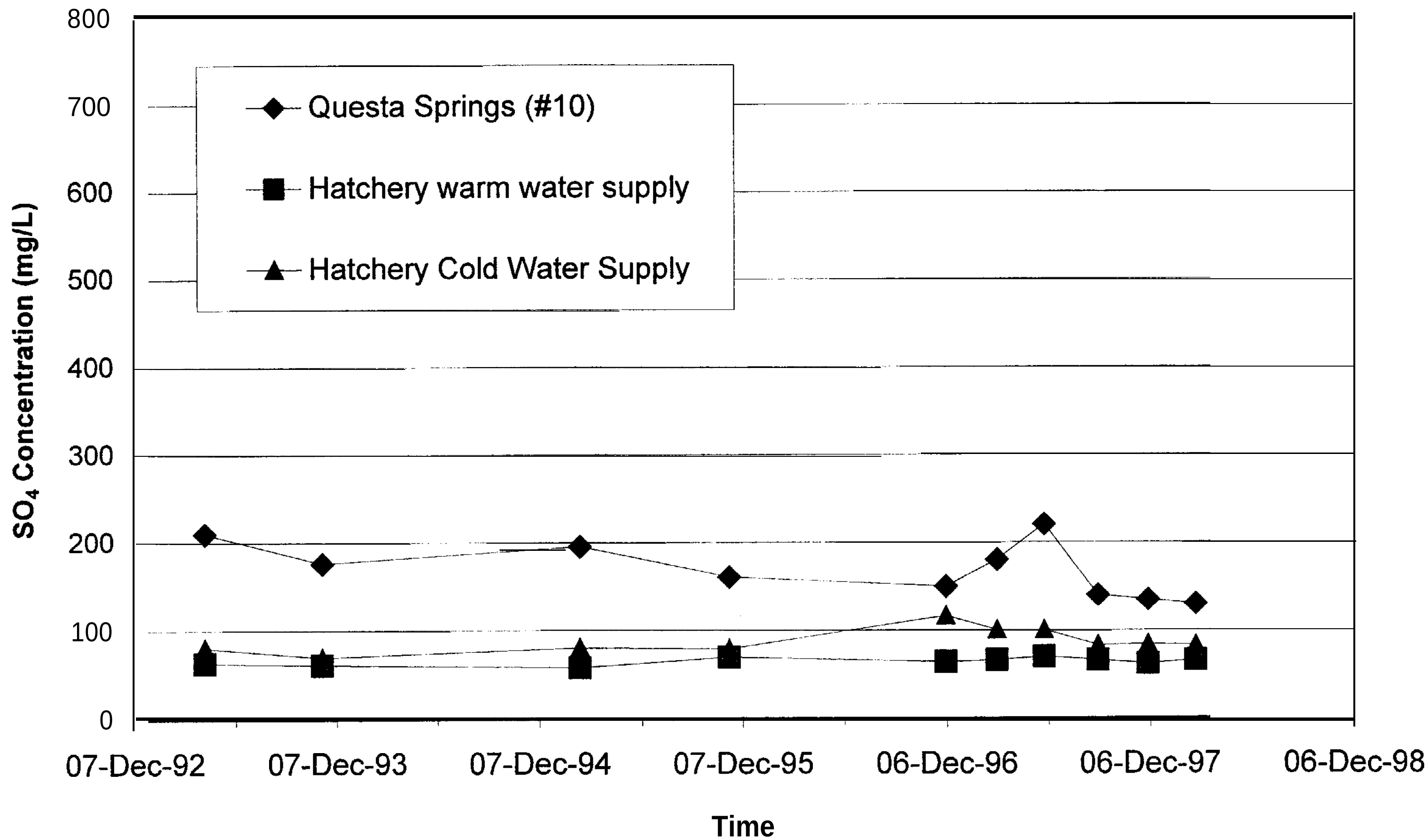
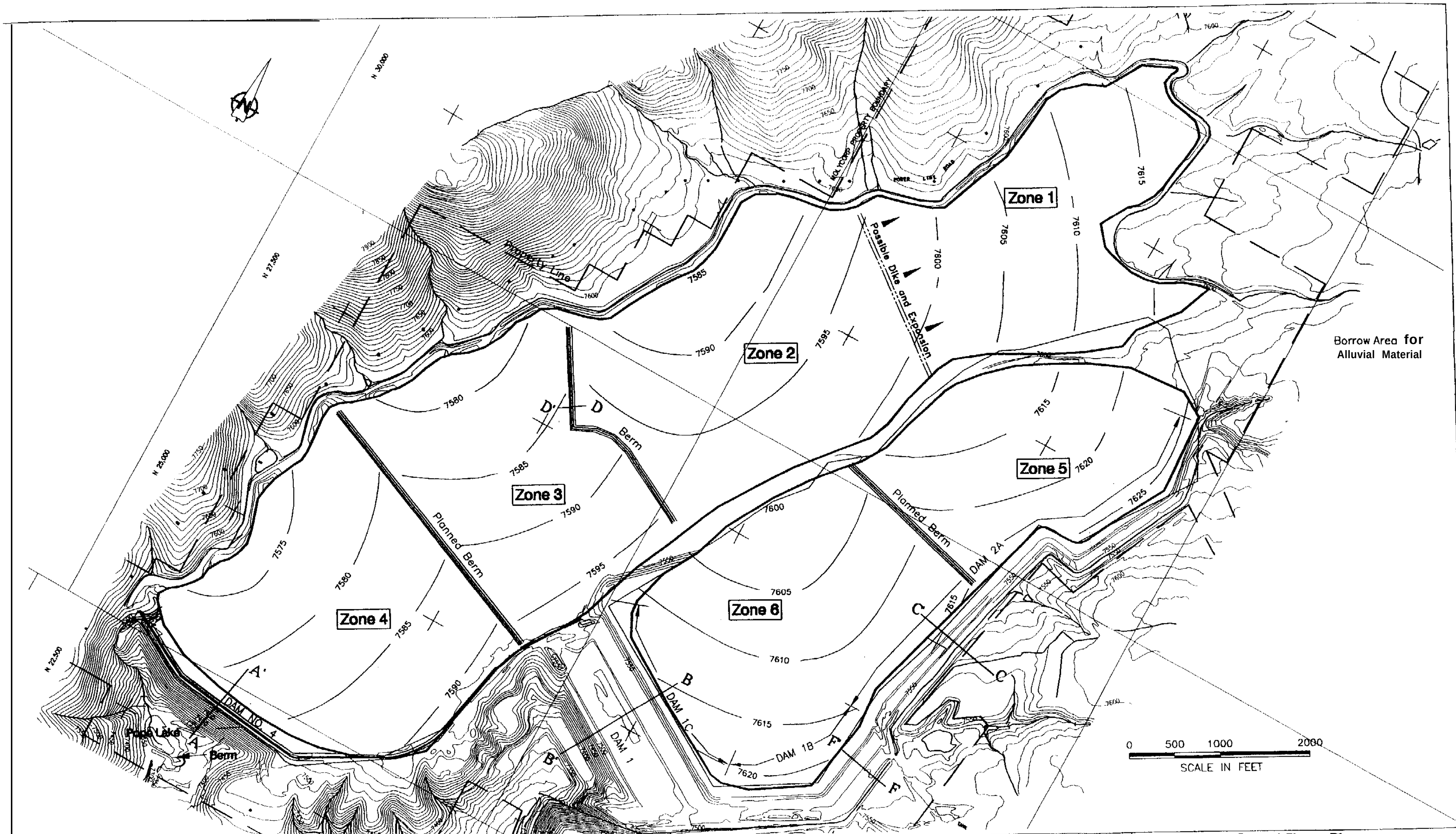


Figure 3-19
Sulfate Concentrations in Springs Flows vs Time.





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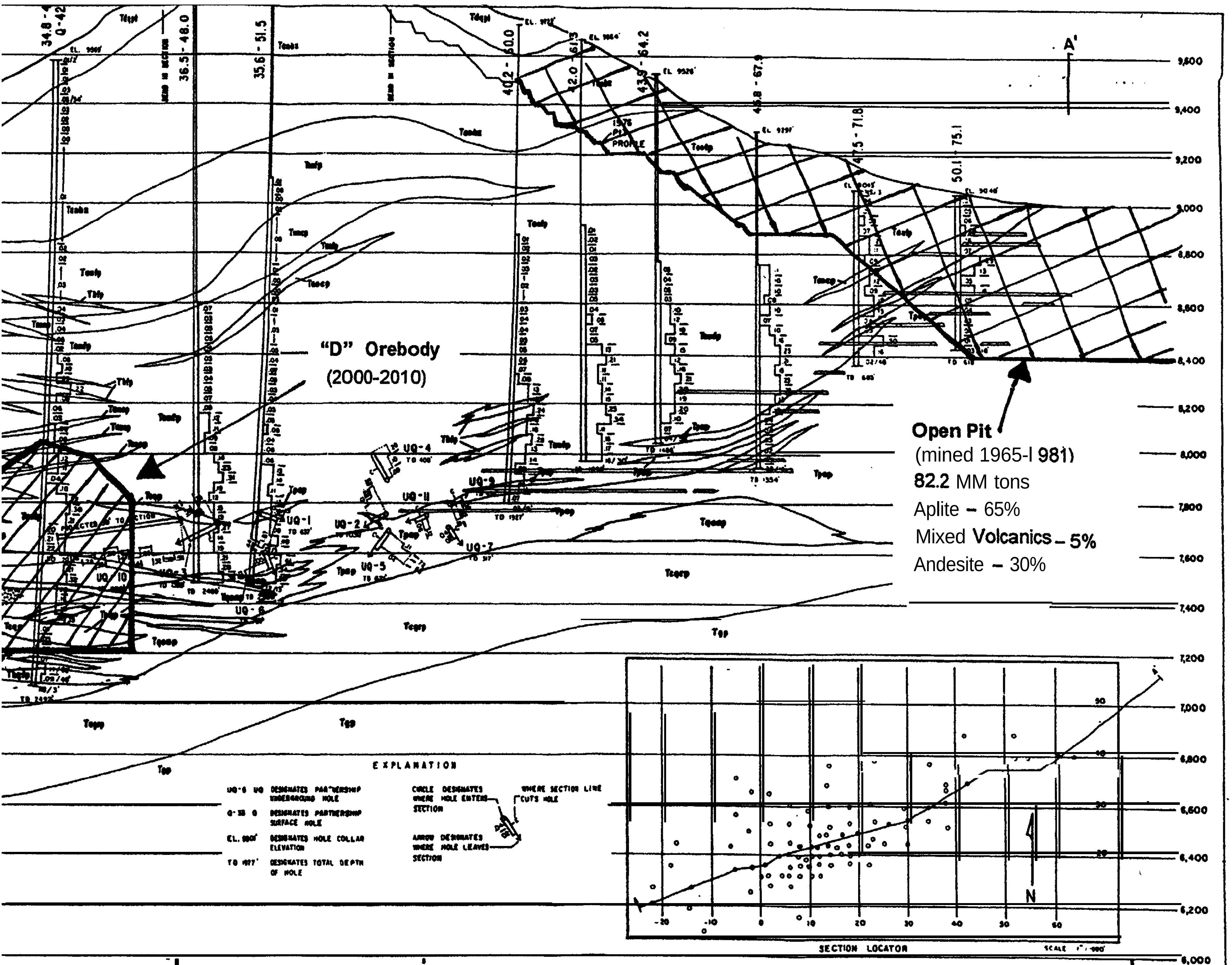
UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Future Tailings Surface

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=1000'		3-20



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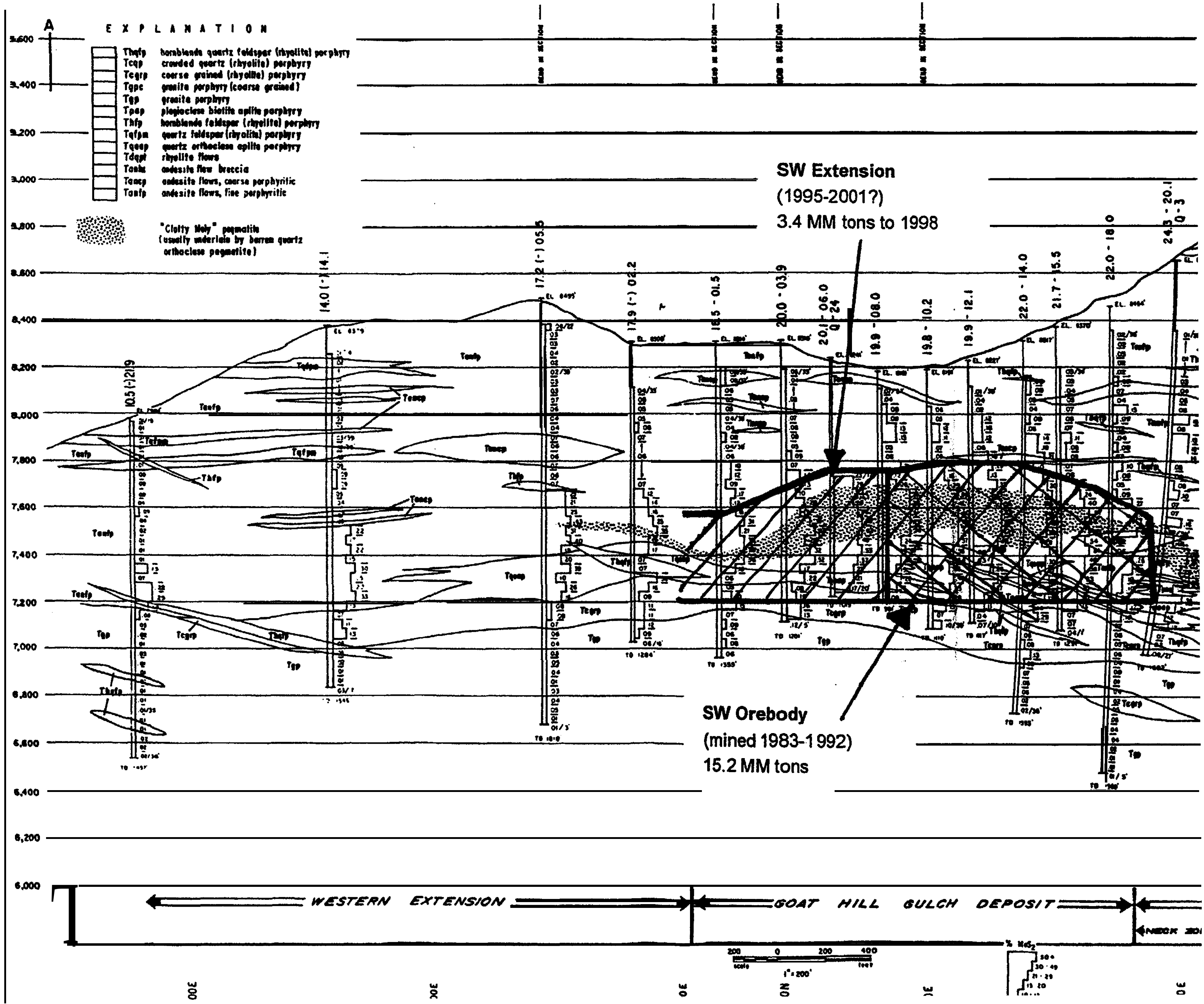
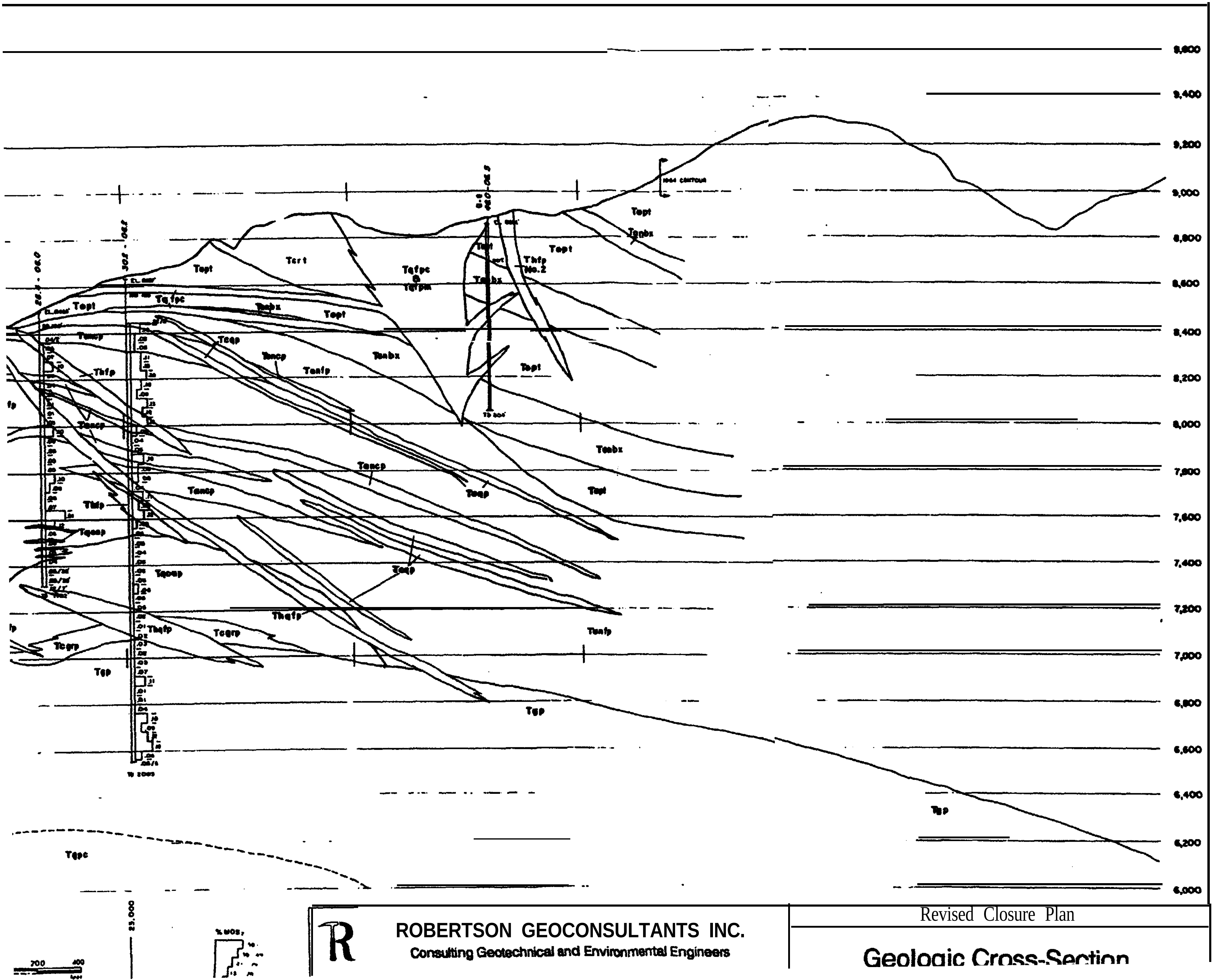
Revised Closure Plan

Longitudinal Section A-A'


A
EXPLANATION
Thqfp hornblende quartz feldspar (rhyolite) porphyry
Tcqp crowded quartz (rhyolite) porphyry
Tcgrp coarse grained (rhyolite) porphyry
Tgpc granite porphyry (coarse grained)
Tgp granite porphyry
Tpap plagioclase biotite aplite porphyry
Thfp hornblende feldspar (rhyolite) porphyry
Tqfpm quartz feldspar (rhyolite) porphyry
Tqoap quartz orthoclase aplite porphyry
Tdqpt rhyolite flows
Tanb andesite flow breccia
Tancp andesite flows, coarse porphyritic
Tanfp andesite flows, fine porphyritic
"Clotty Moly" pegmatite
(usually underlain by barren quartz orthoclase pegmatite)
SW Extension
(1995-2001?)
3.4 MM tons to 1998
SW Orebody
(mined 1983-1992)
15.2 MM tons
WESTERN EXTENSION
GOAT HILL GULCH DEPOSIT
% MoS2
1"=200'



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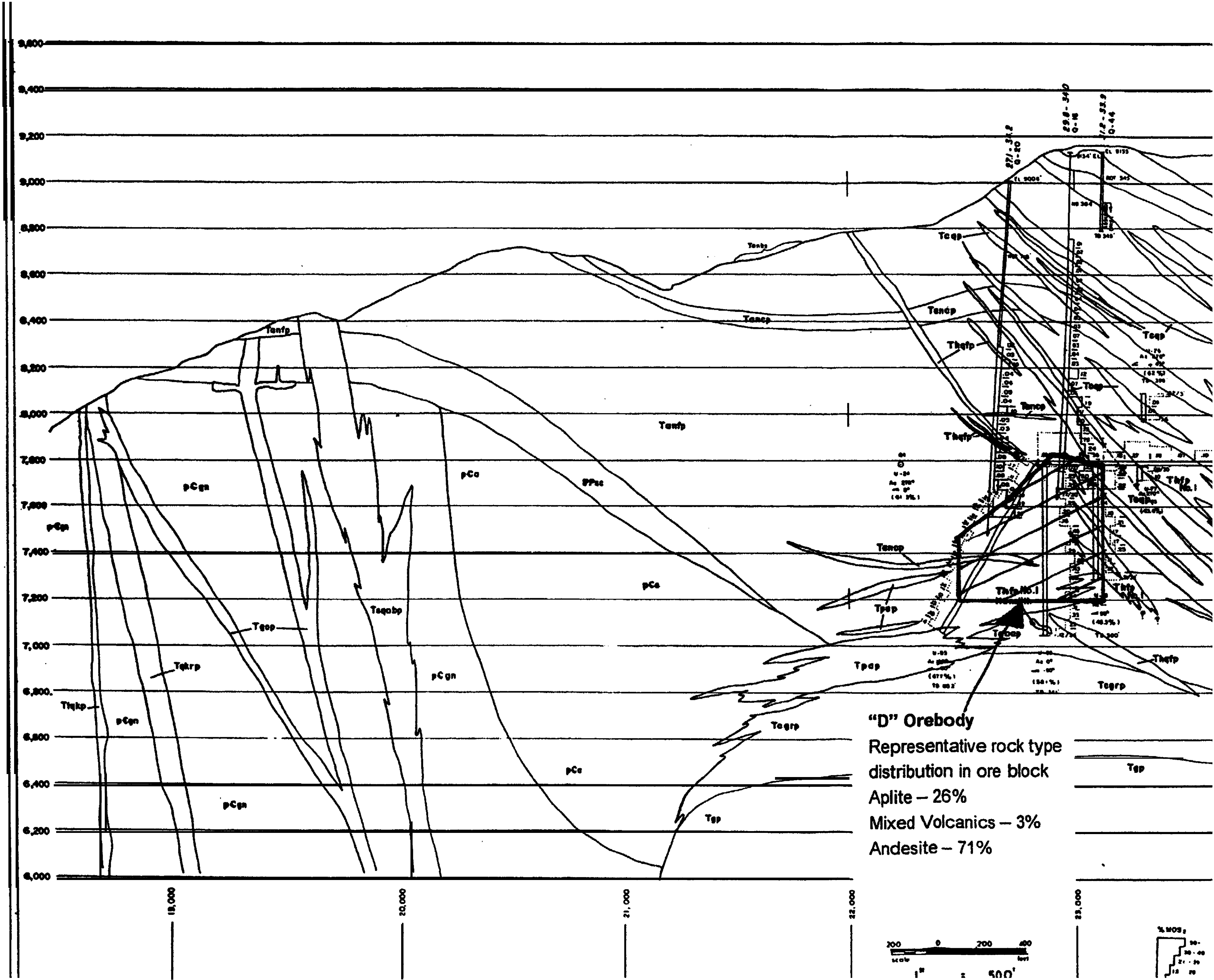
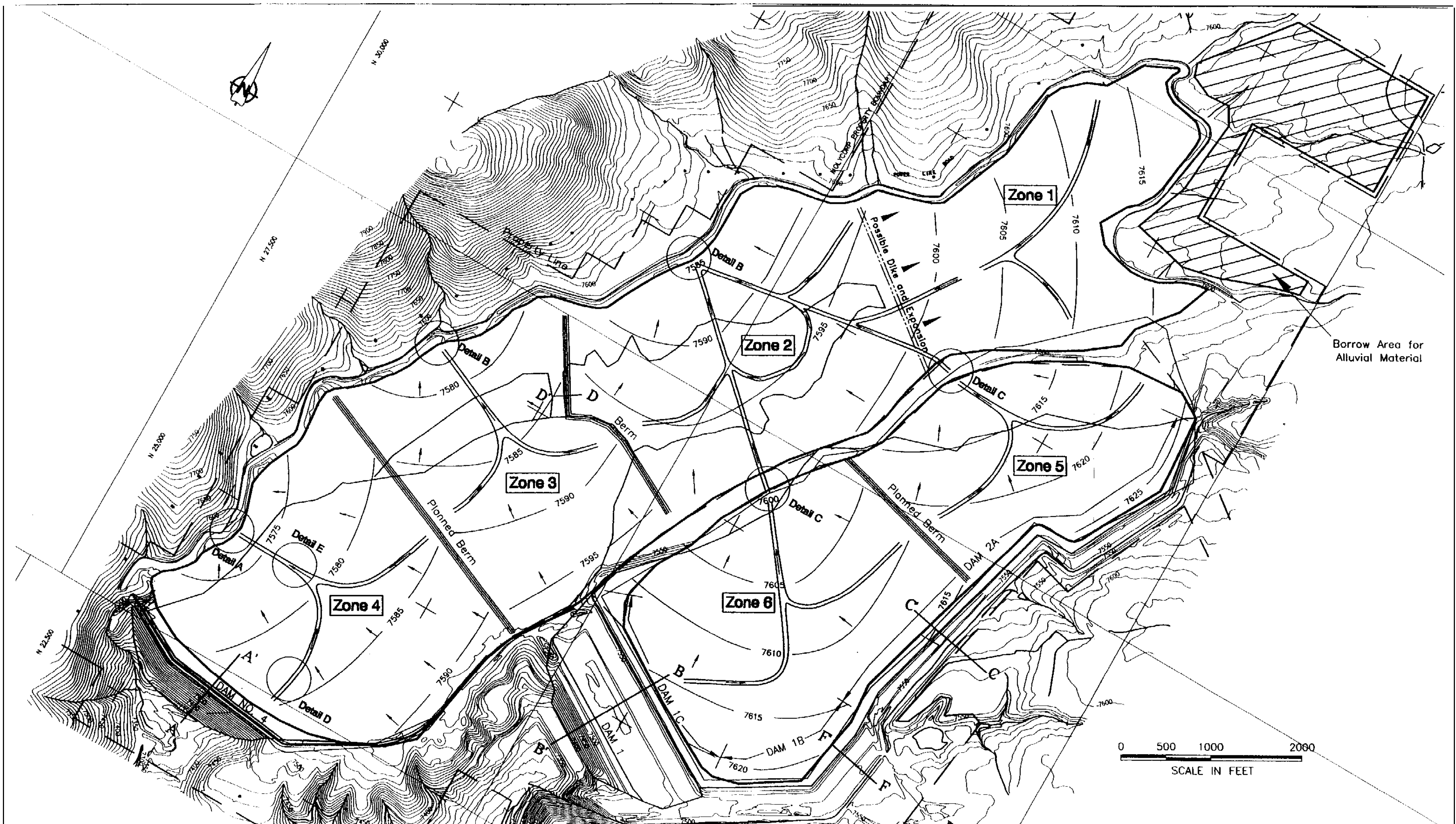
Revised Closure Plan

Geologic Cross-Section



"D" Orebody
Representative rock type
distribution in ore block
Aplite – 26%
Mixed Volcanics – 3%
Andesite – 71%
9,600
9,400
9,200
9,000
8,800
8,600
8,400
8,200
8,000
7,800
7,600
7,400
7,200
7,000
6,800
6,600
6,400
6,200
6,000
20,000
21,000
22,000
23,000
Tanfp
pCgn
pCa
Tgop
Tgkrp
Tgqnbp
Tancp
Tcqp
Thqfp
Tpap
Tcgrp
Tgp
Tqqp
Thfp No.1
Thqfp
1" = 500'



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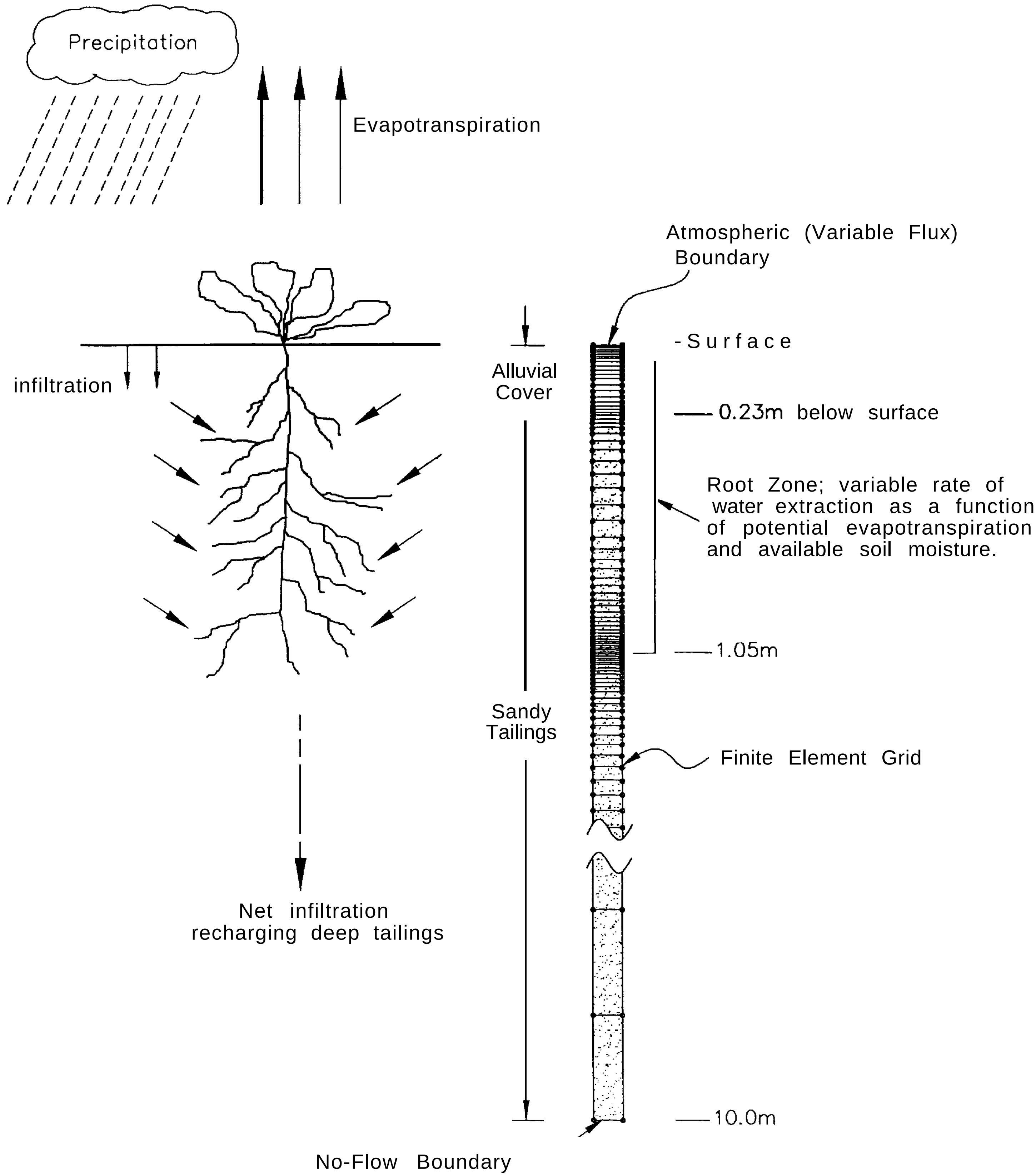
UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Final Tailings Shaping Plan

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	March 1998	1"=1000'		4



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UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

Conceptual Model of Storage Cover and Numerical Implementation

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	N.T.S.		4-2

acad_questa\Questa-Final Report\4-2-ConceptualStorageCover Tue Apr 14 13: 19: 45 1998 L. duToit

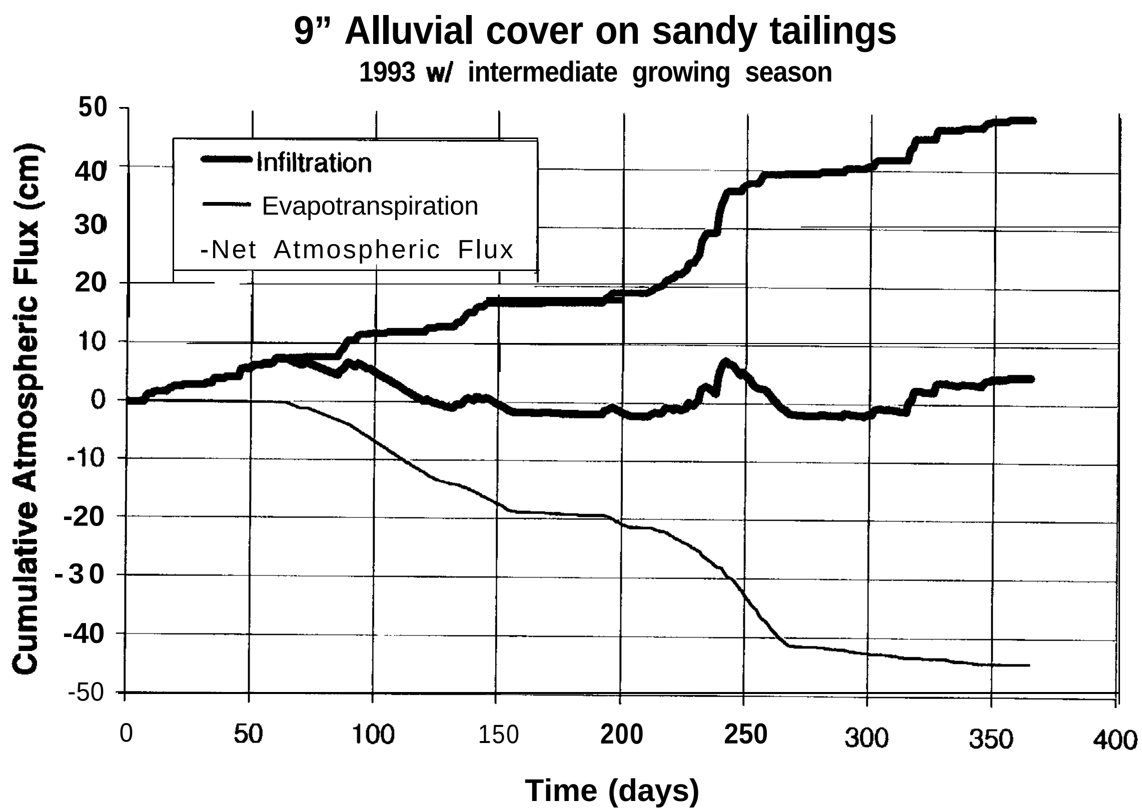
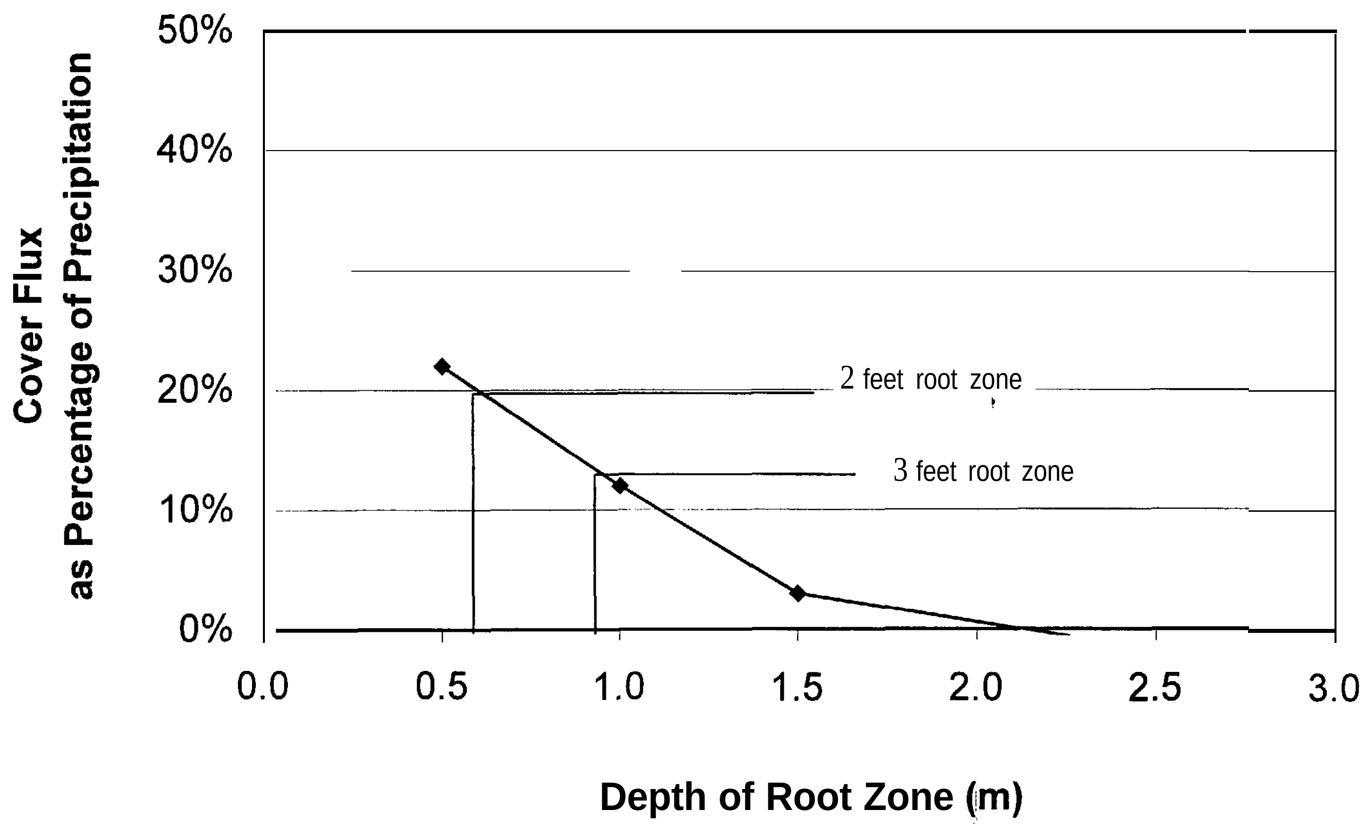
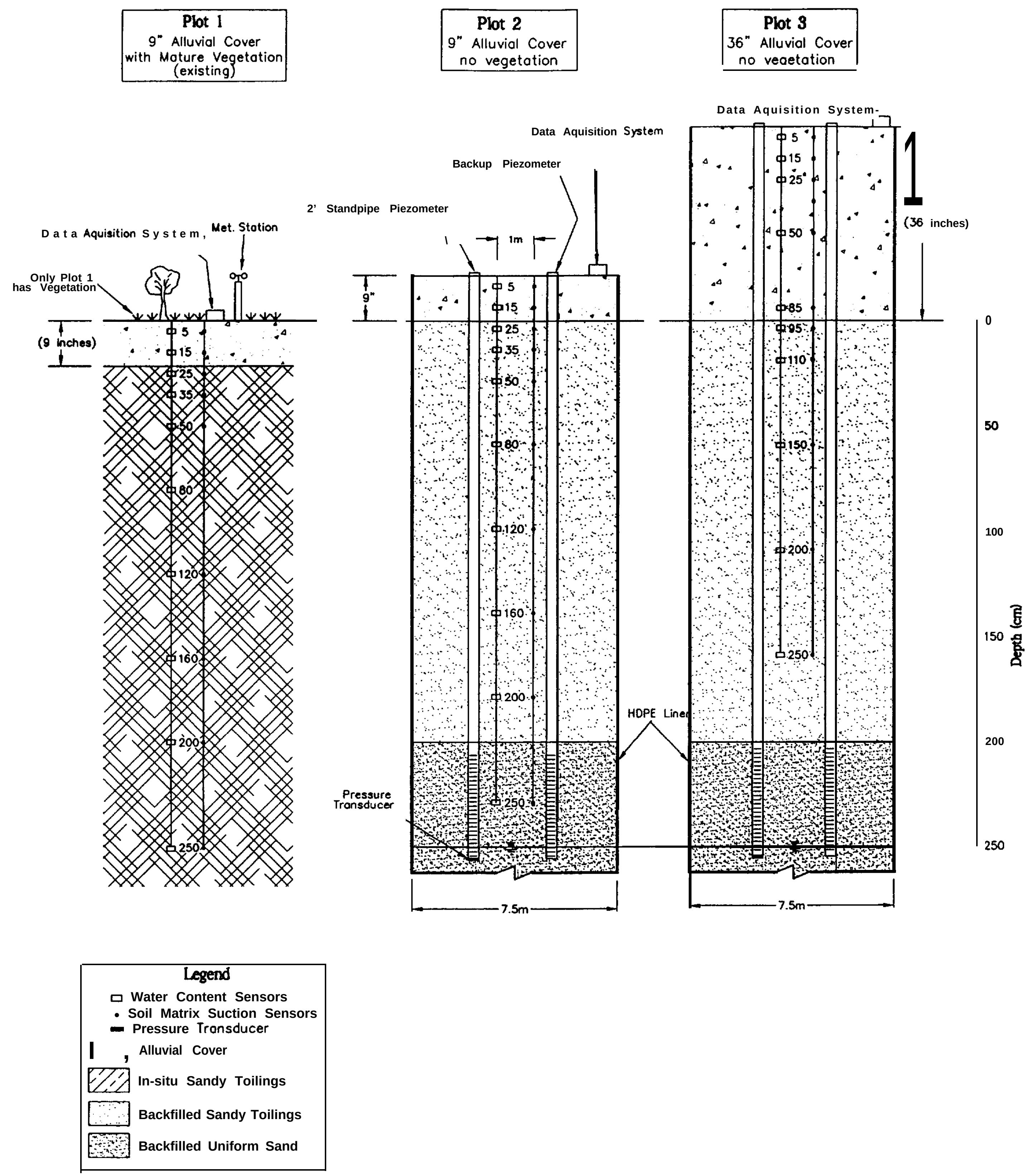


Figure 4-3.
Simulated Atmospheric Fluxes for Run 1 (for year w/ exceptionally high precipitation)

Figure 4-3a

Simulated Net Infiltration through a Storage Cover vs. Root Zone Depth (for exceptionally wet year)





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UNOCAL 76

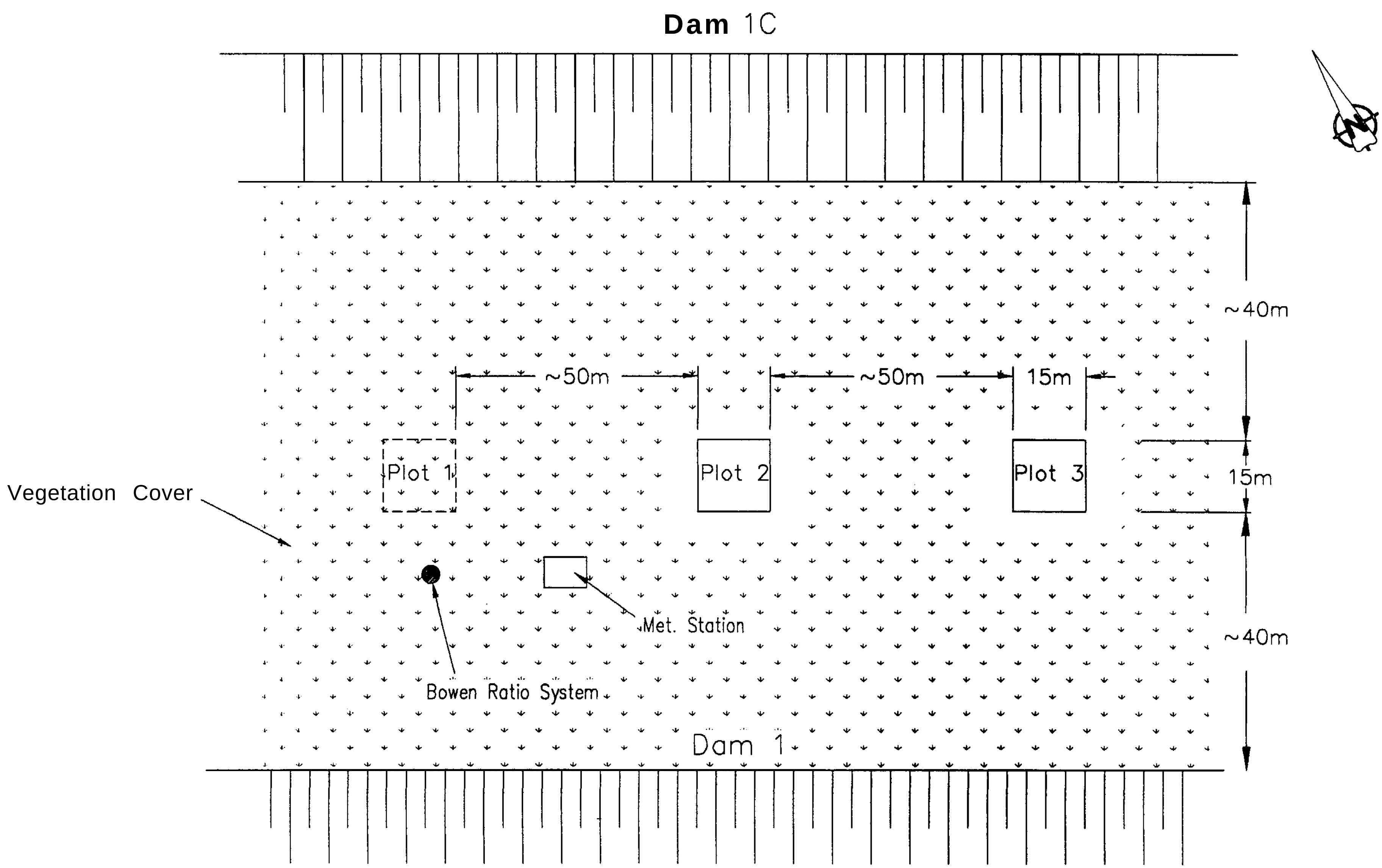
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Generalized Section Through Cover Test Plots

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	N.T.S.		4-4

\acad_questa\Questa-Final Report\4-4 CoverPlotsSection Tue Apr 14 13: 59: 34 1998 L. du Toit



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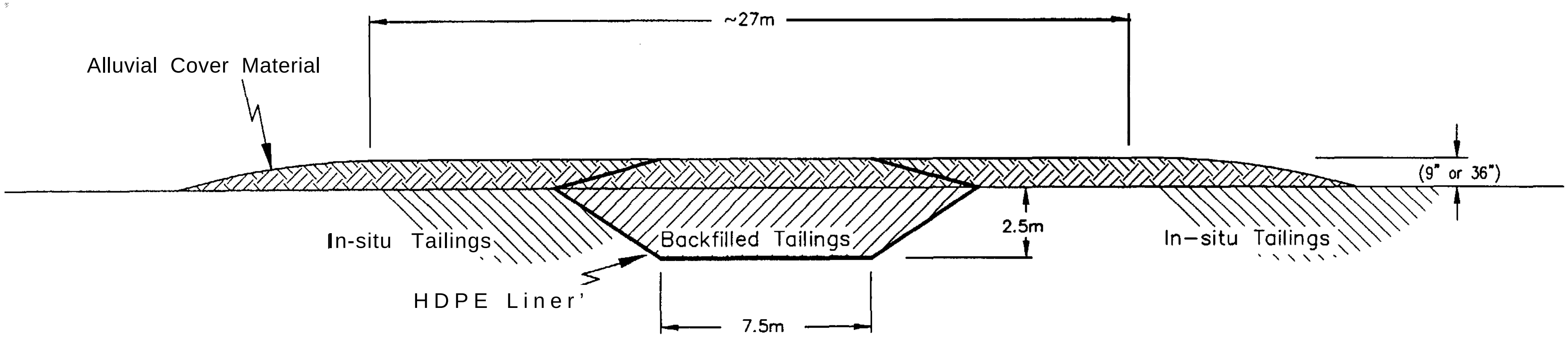
UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised Closure Plan

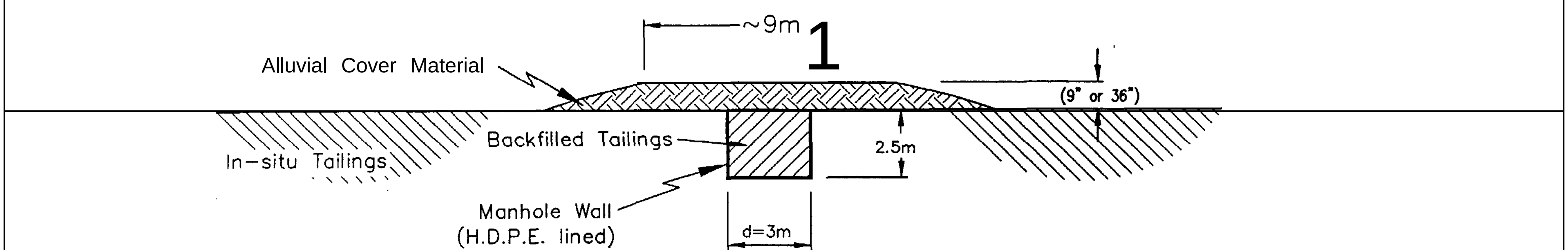
Cover Test Plots - Plan View

PROJECT NO.	DATE	SCALE	APPROVED	
052004	April 1998	N.T.S.		Y - 5



Option 1

Lined and Backfilled Excavation with Sloped Side Walls

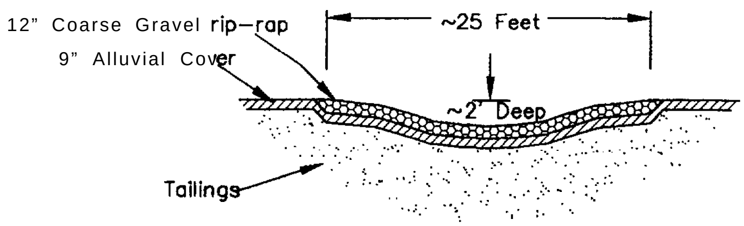


Option 2

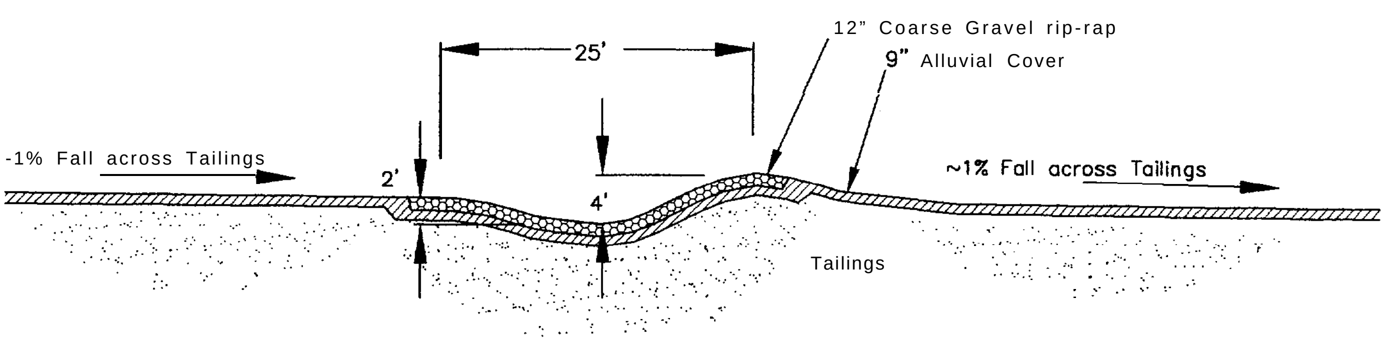
Backfilled Manhole with Vertical Side Walls

ROBERTSON GEOCONSULTANTS INC. **Consulting Geotechnical** and Environmental **Engineers**	Revised Closure Plan
UNOCAL 76 — MOLYCORP Questa, New Mexico	**Alternative Conceptual Designs for Lysimeter Test Plots (Cross-section)**

PROJECT NO.	DATE	SCALE	APPROVED	
052004	April 1998	N.T.S.		T - 6



Section - Detail E



Section - Detail D

ROBERTSON GEOCONSULTANTS INC.
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UNOCAL 76

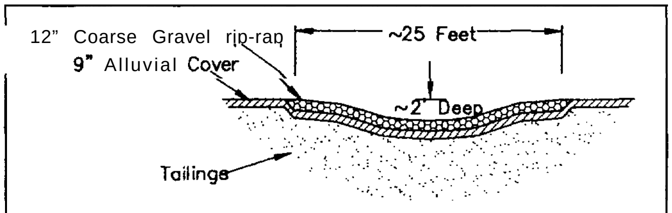
MOLYCORP
Questa, New Mexico

Revised Closure Plan

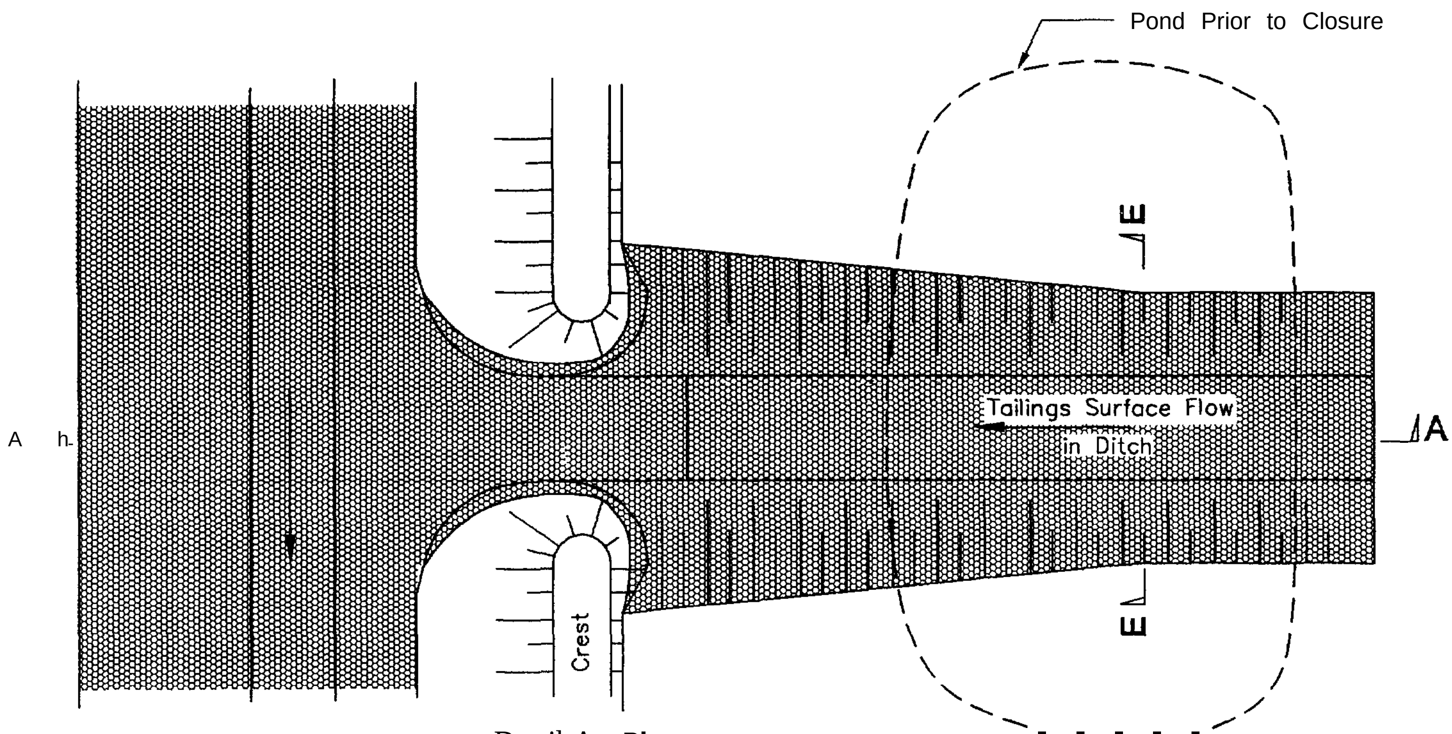
Tailings Surface Drain Sections
(Locations on Dwg. 4-l)

PROJECT NO.	DATE	SCALE	APPROVED	
052004	April 1998	1"=15'		T - 7

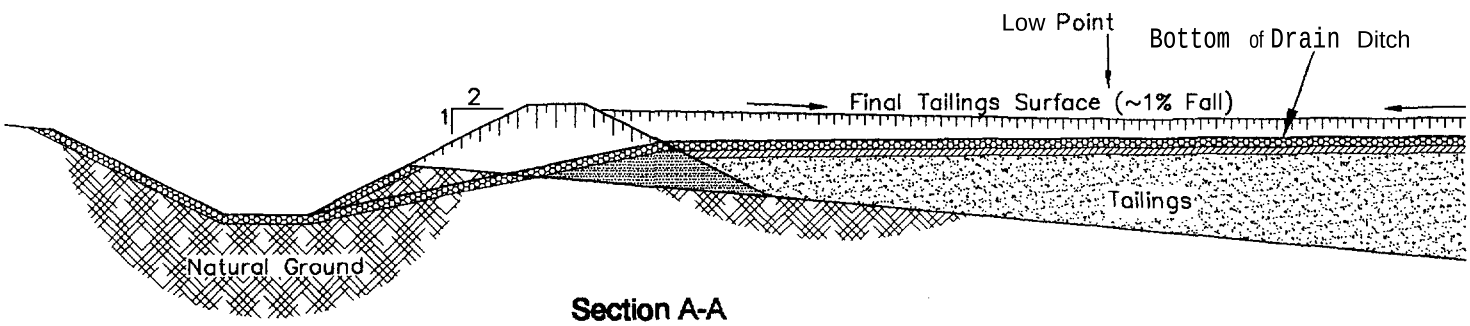
\acad_questa\Questa-Final Report\4-7 TailingsDrainSections Mon Apr 27 19:34:45 1998 L. du Toit



Section E-E



Detail A - **Plan**

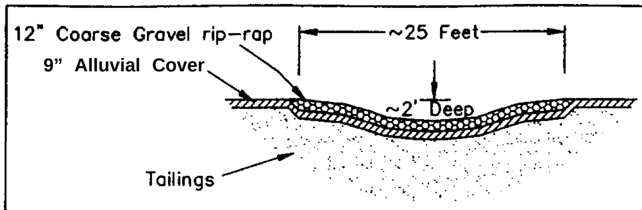


Section A-A

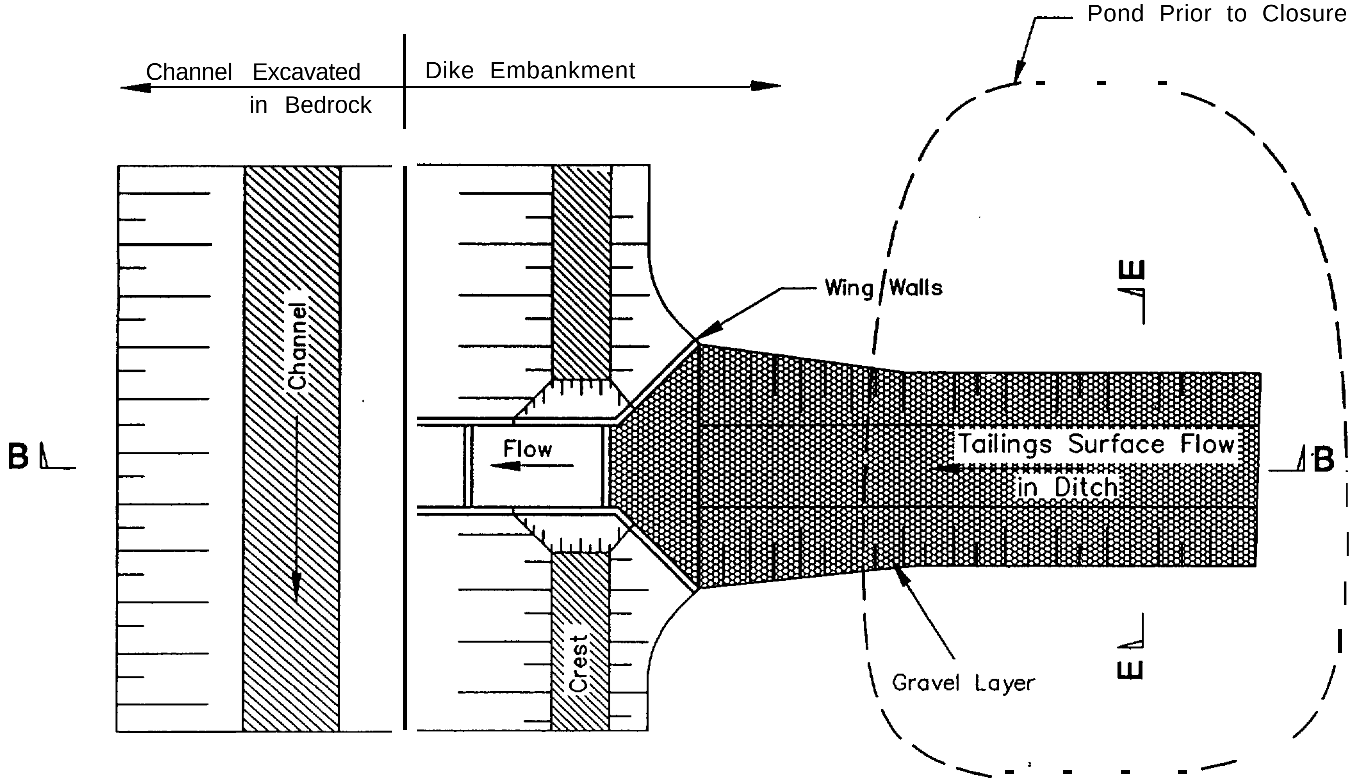
ROBERTSON GEOCONSULTANTS INC. **Consulting Geotechnical** and **Environmental** Engineers	Revised **Closure** Plan
UNOCAL 76 — **MOLYCORP** Questa, New Mexico	**Outlet Structure Detail - Type "A"**

NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=20'		4-8A

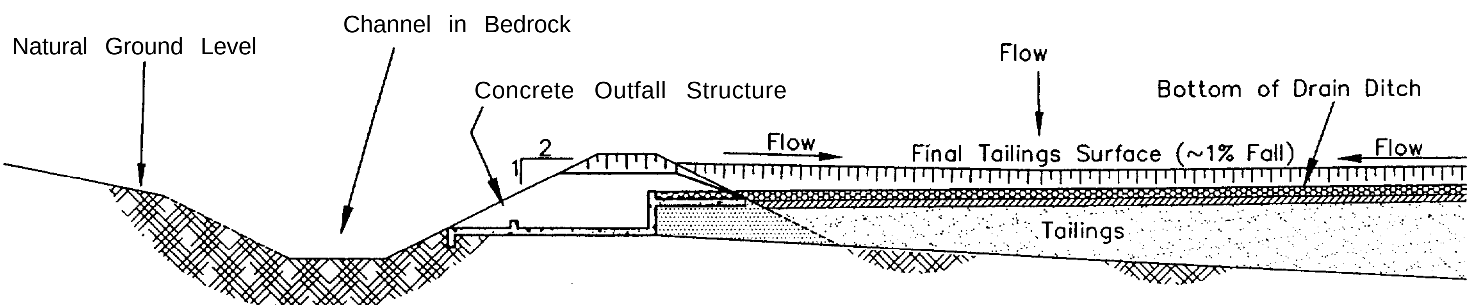
\acad_questa\Questa-Final Report\4-8A Outfall-Structure-A Mon Apr 27 21:02:28 1998 L. du Toit



Section E-E



Detail B - Plan

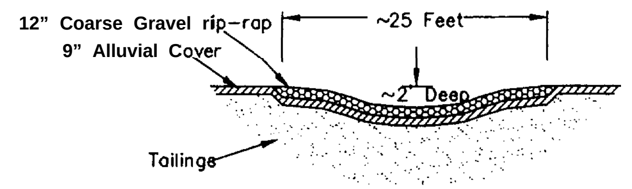


Section B-B

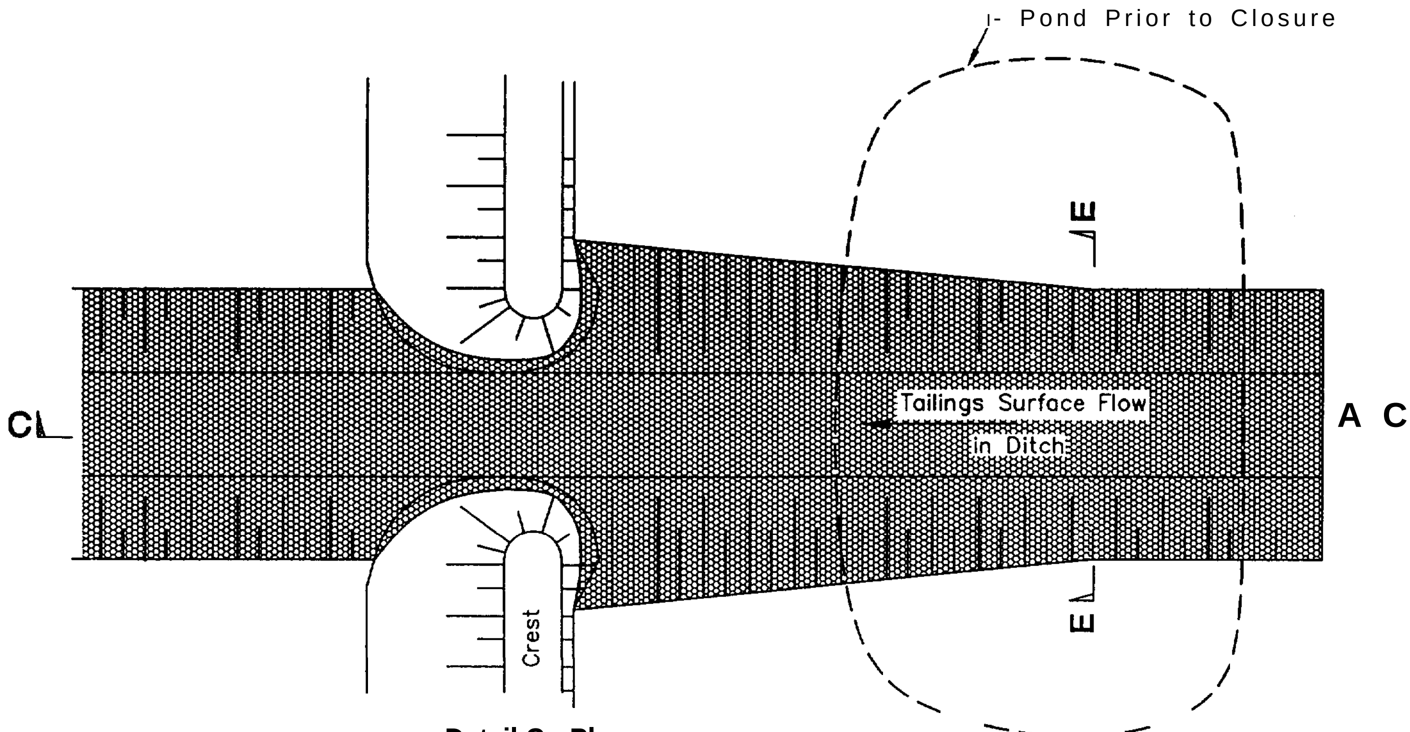
ROBERTSON GEOCONSULTANTS INC. Consulting Geotechnical and Environmental Engineers	Revised Closure Plan
UNOCAL 76 — MOLYCORP Questa, 'New Mexico	**Outlet Structure Detail - Type "B"**

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=20'		4-8B

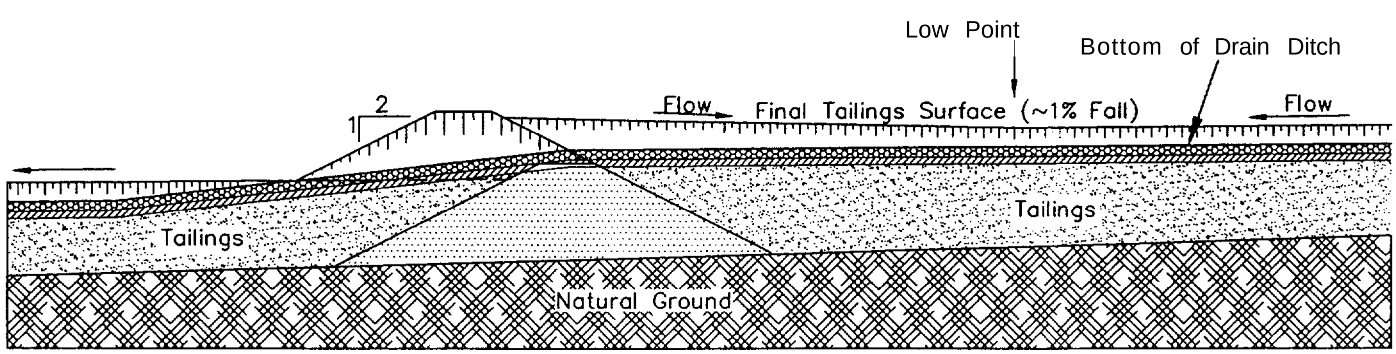
\acad questa\Questa-Final Report\4-8B Outfall-Structure-B Tue Apr 14 14:26:07 1998 L. du Toit



Section E-E



Detail C - Plan



Section C-C

ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

UNOCAL 76

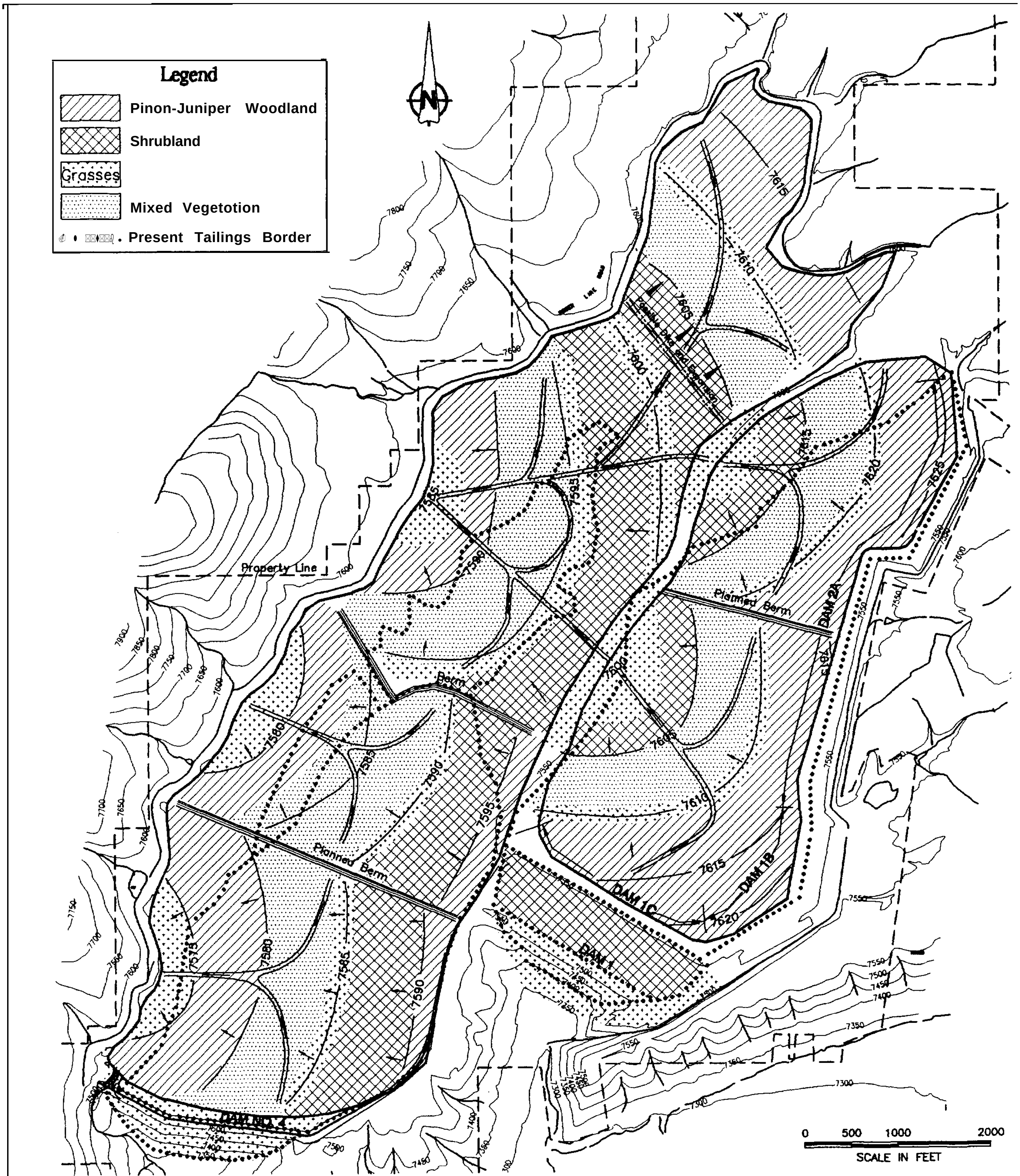
MOLYCORP
Questa, New Mexico

Revised Closure Plan

Outlet Structure Detail - Type "C"

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	April 1998	1"=20'		4-8C

\acad_questa\Questa-Final Report\4-8C Outfall-Structure-C Tue Apr 14 14:33:13 1998 L. du Toit



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UNOCAL 76

MOLYCORP
Questa, New Mexico

Revised **Closure** Plan

Tailings Conceptual Revegetation Plan

PROJECT NO.	DATE	SCALE	APPROVED	FIGURE
052004	Feb. 1998	1"= 1400'		4-9

:\acad_questa\Questa-Final Report\4-9 RevegetationPlan Tue Apr 28 08:14:22 1998 L. du Toit

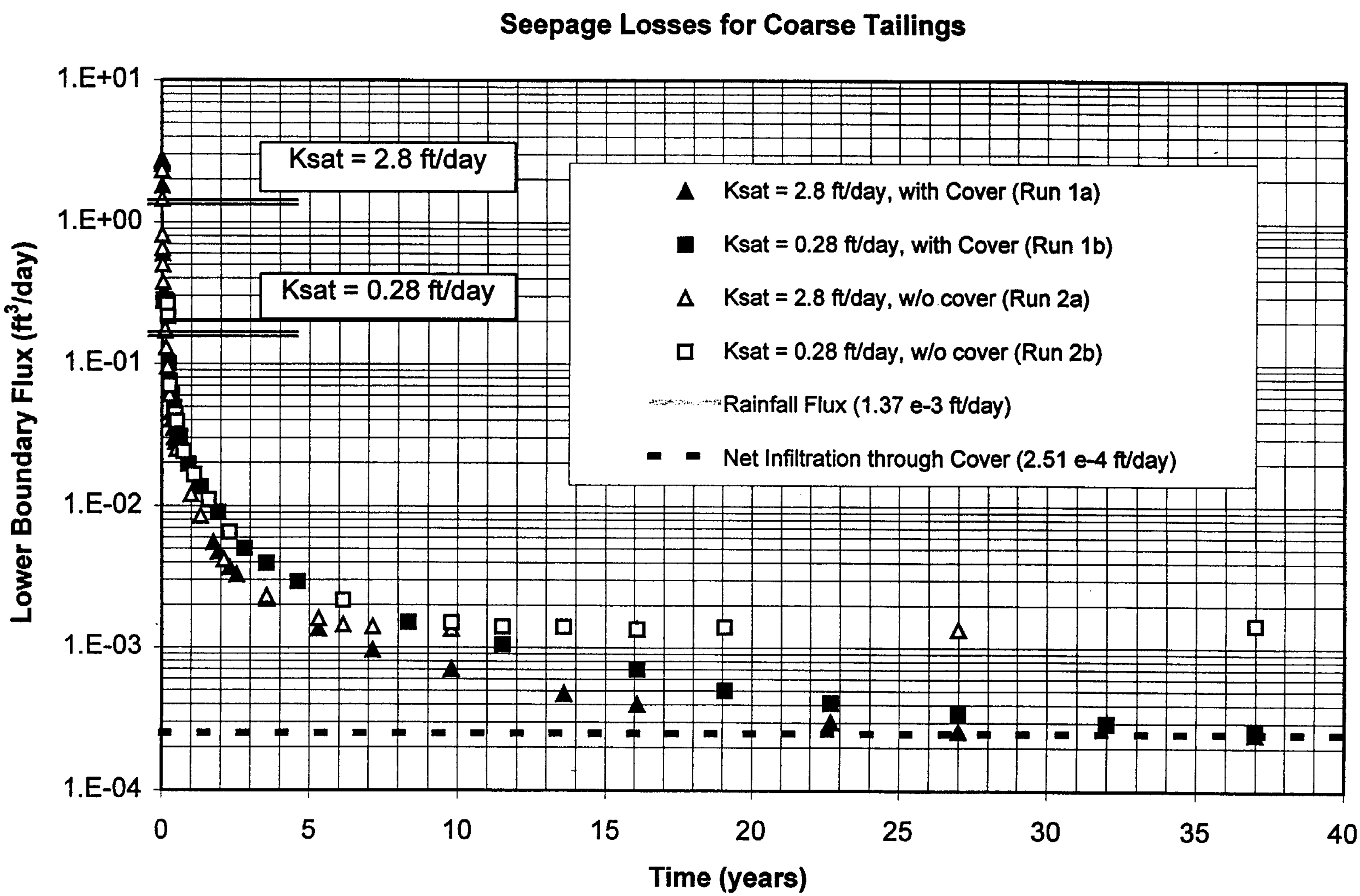

Figure 4-10a.
Simulated Seepage Losses from the Coarse Tailings of Section 35 over Time.

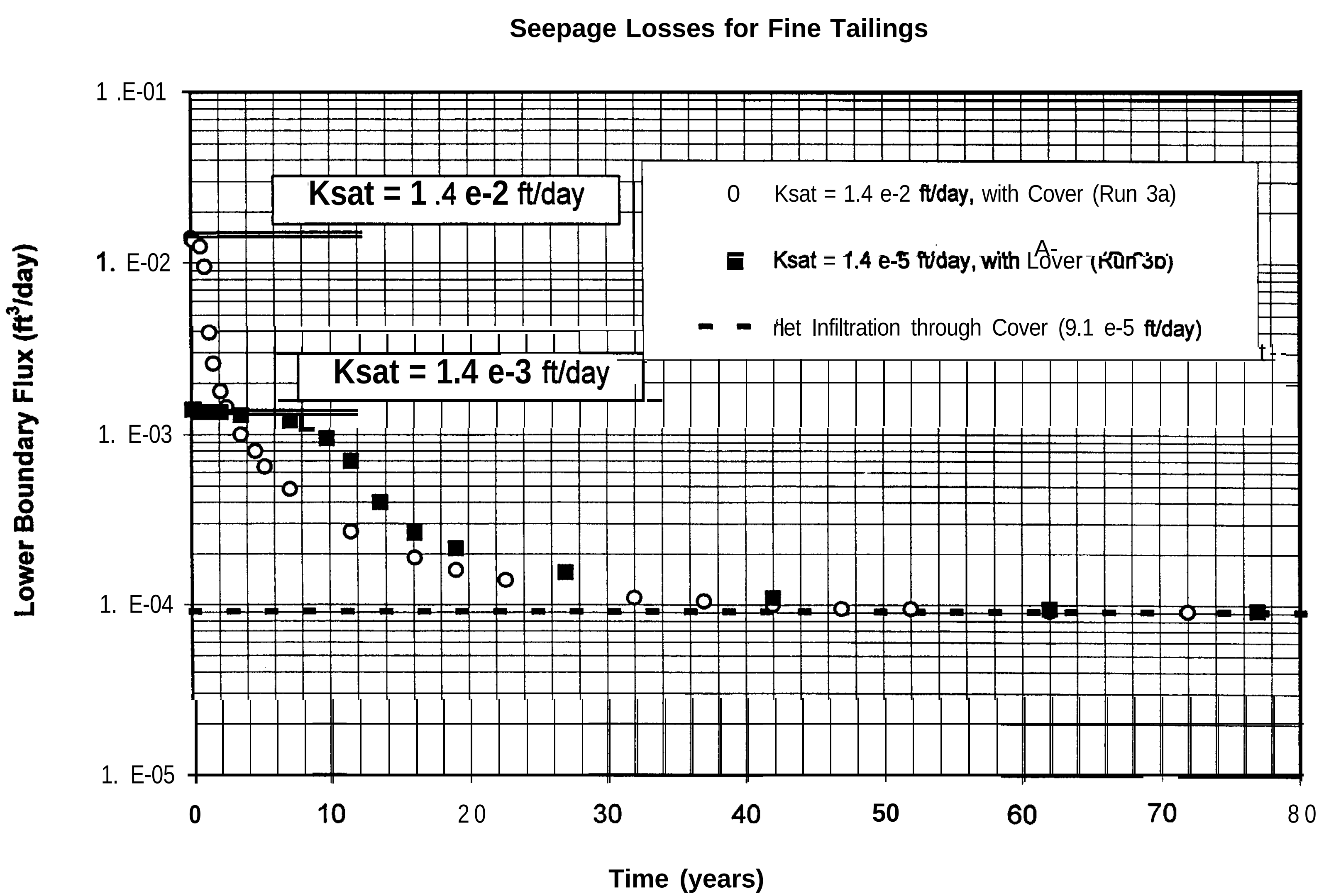

Figure 4-10b.
Simulated Seepage Losses from the Fine Tailings of Section 35 over Time.

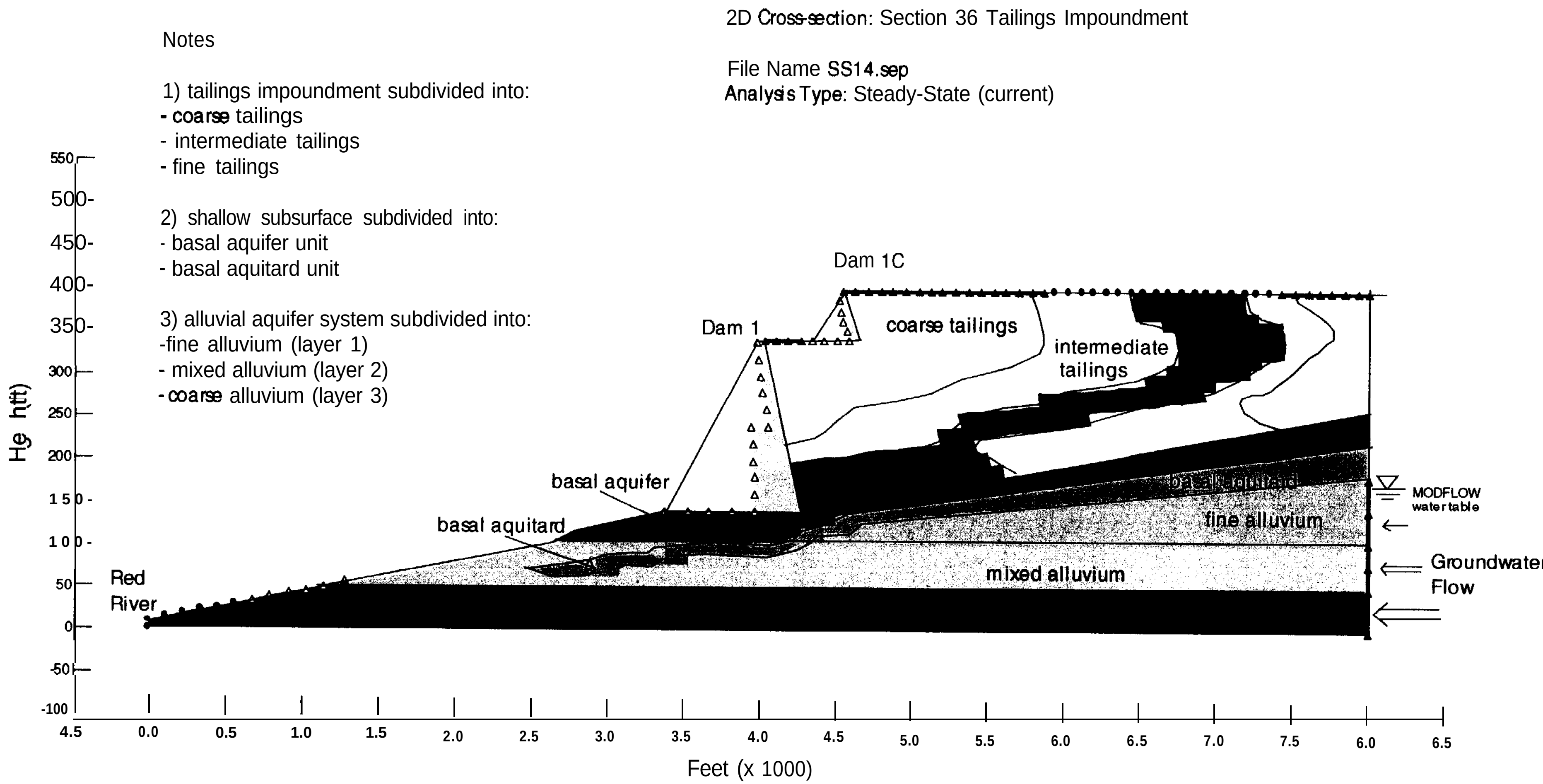

Figure 4-11.
Cross-sectional Model used to simulate Seepage in Section 36 Tailings Impoundment.

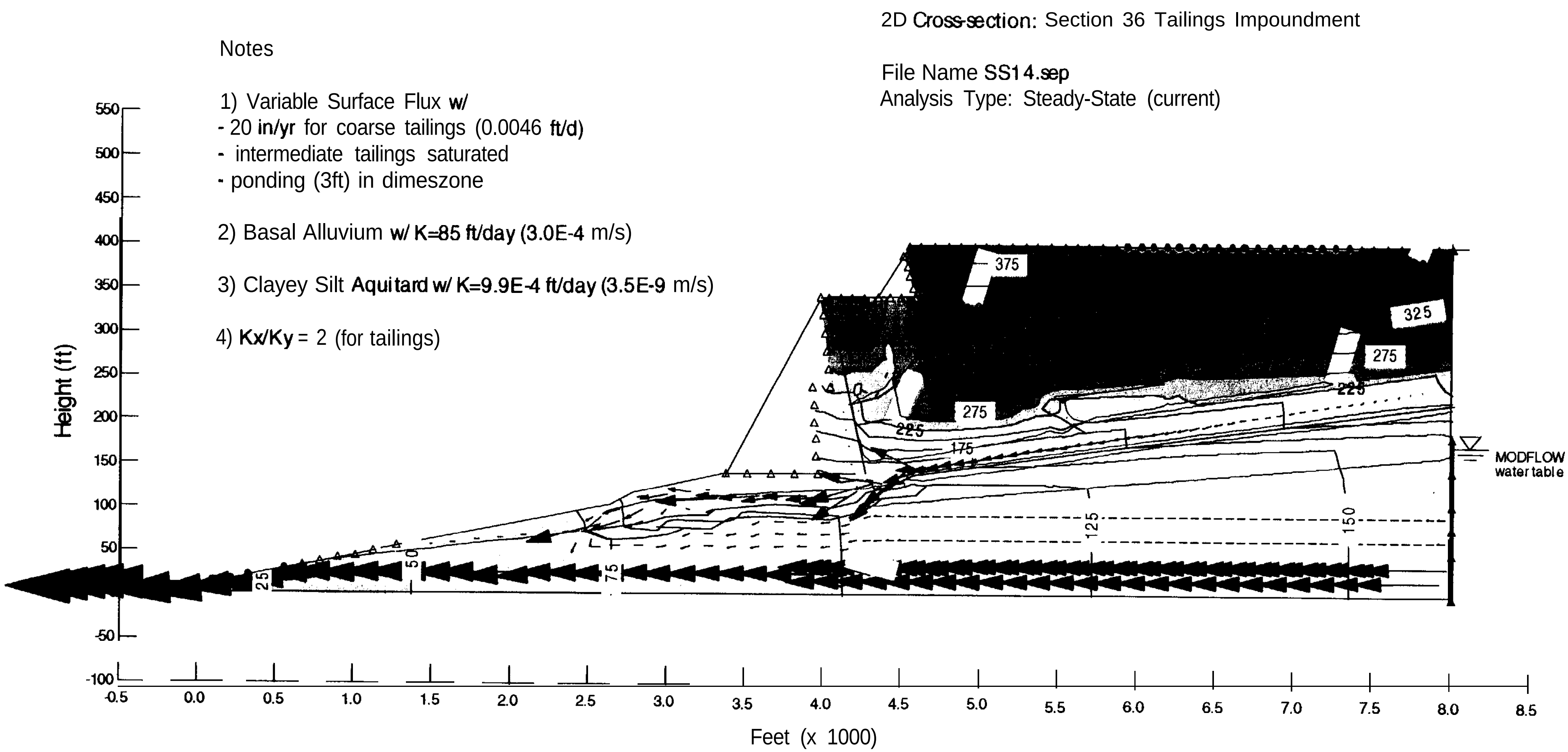

Figure 4-12.
Simulated Hydraulic Head for Calibrated Steady-State Seepage Model.

Figure 4-13.
Simulated Tailings Seepage Fluxes using Transient 2D Seepage Model.

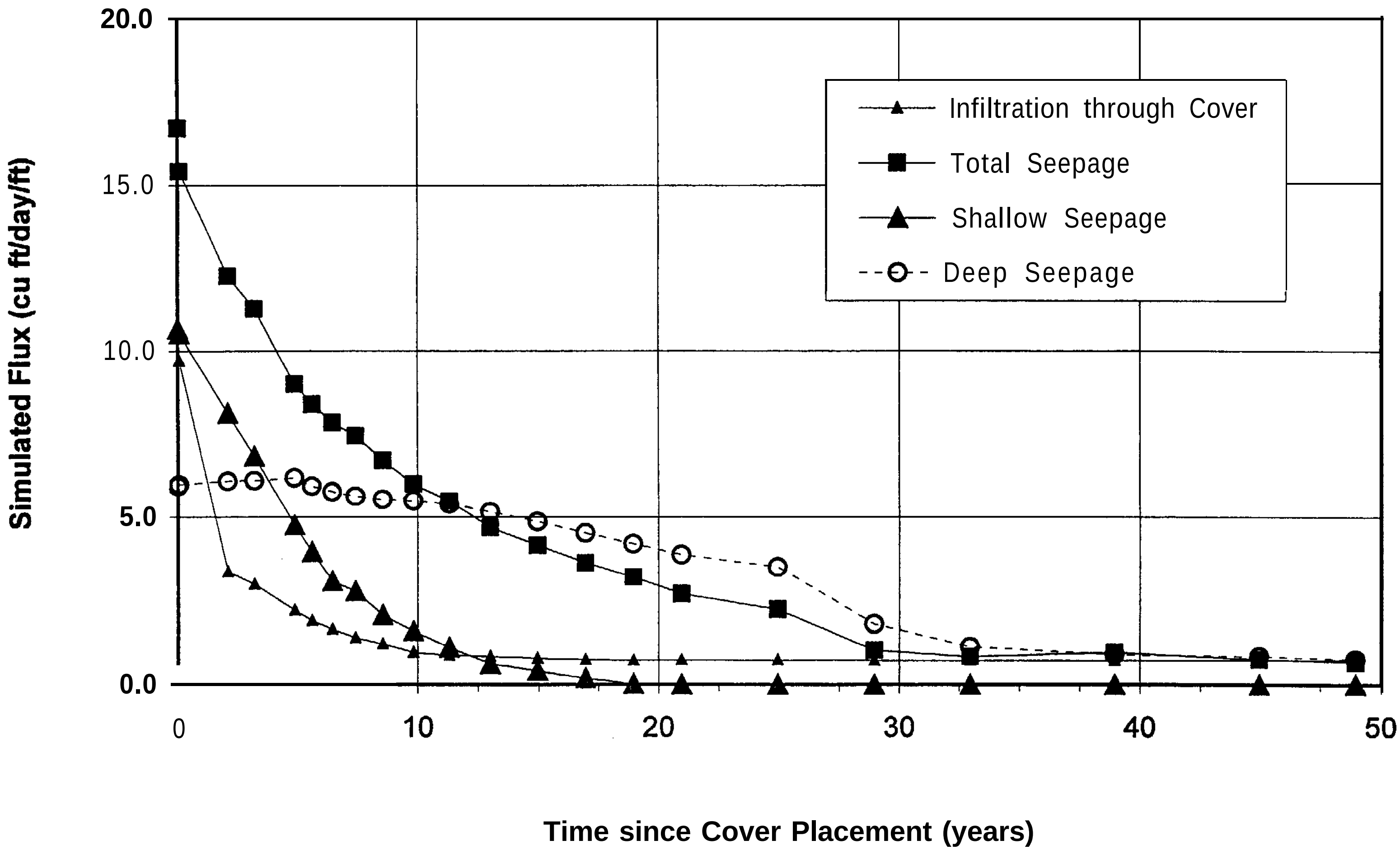

Figure 4-14a.
Simulated [SO_4] in Shallow Seepage versus Time.

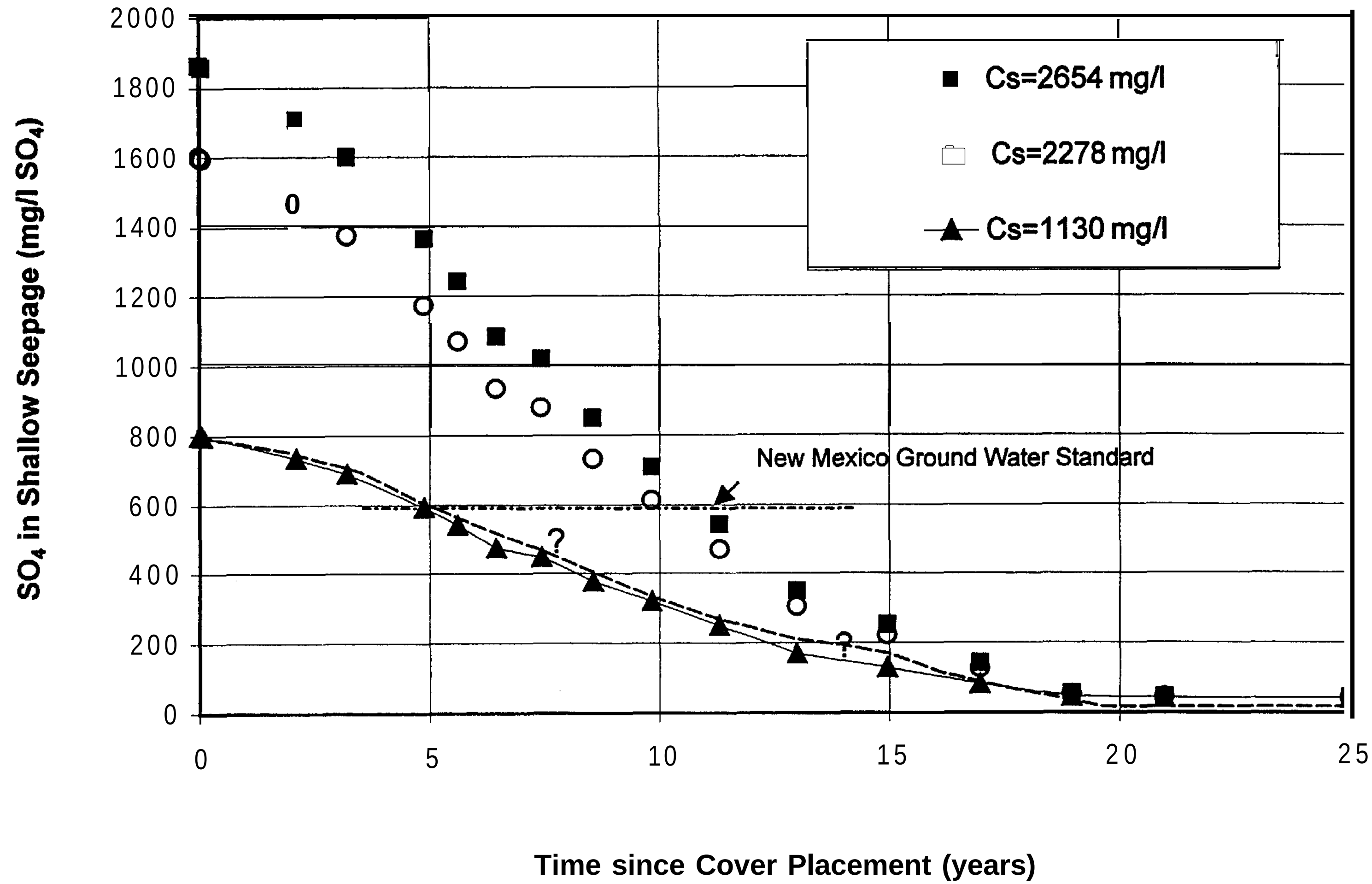

Figure 4-14b.
Simulated [Mo] in Shallow Seepage versus Time.

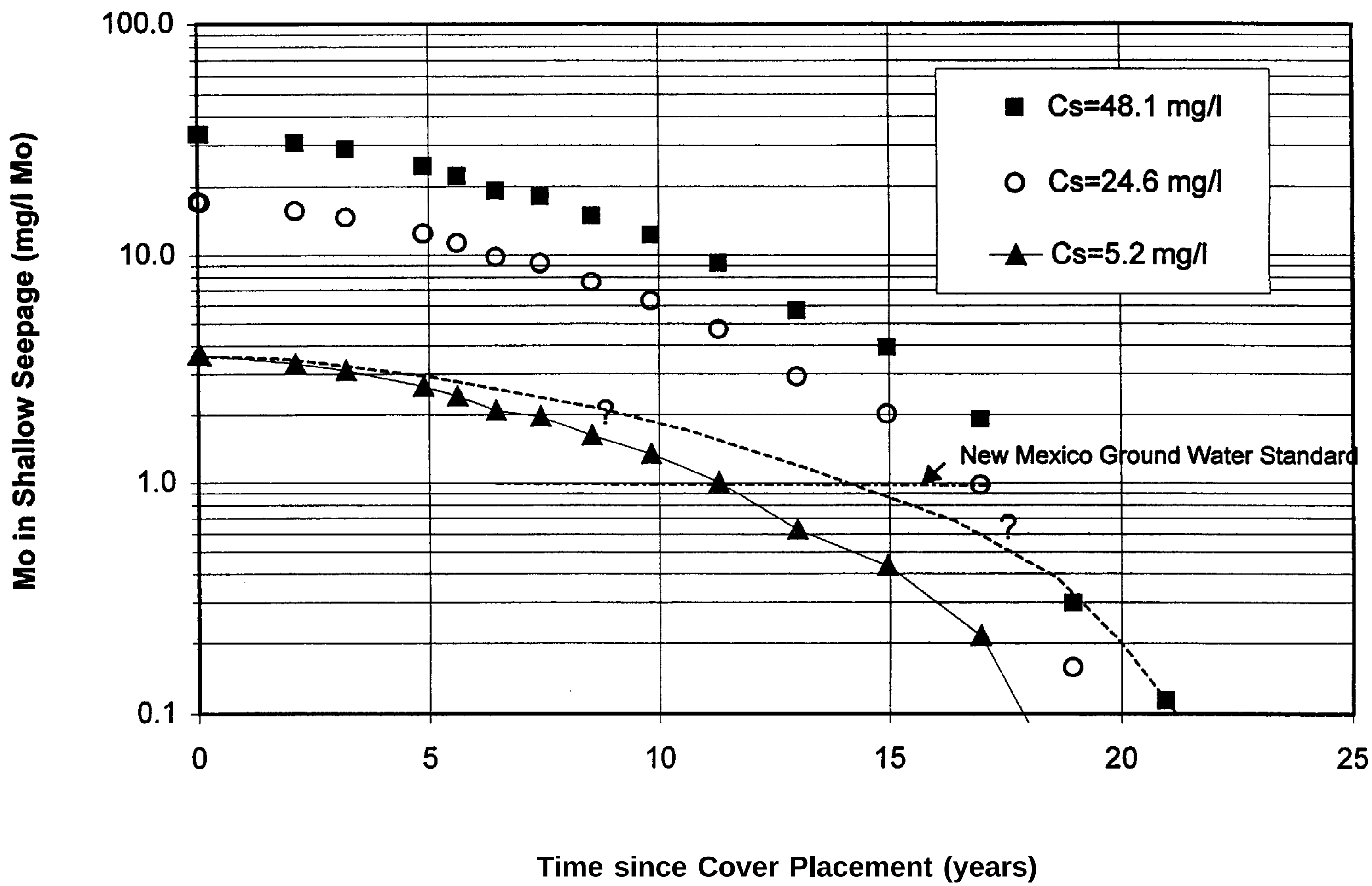

Figure 4-l 4c.
Simulated TDS in Shallow Seepage versus Time.

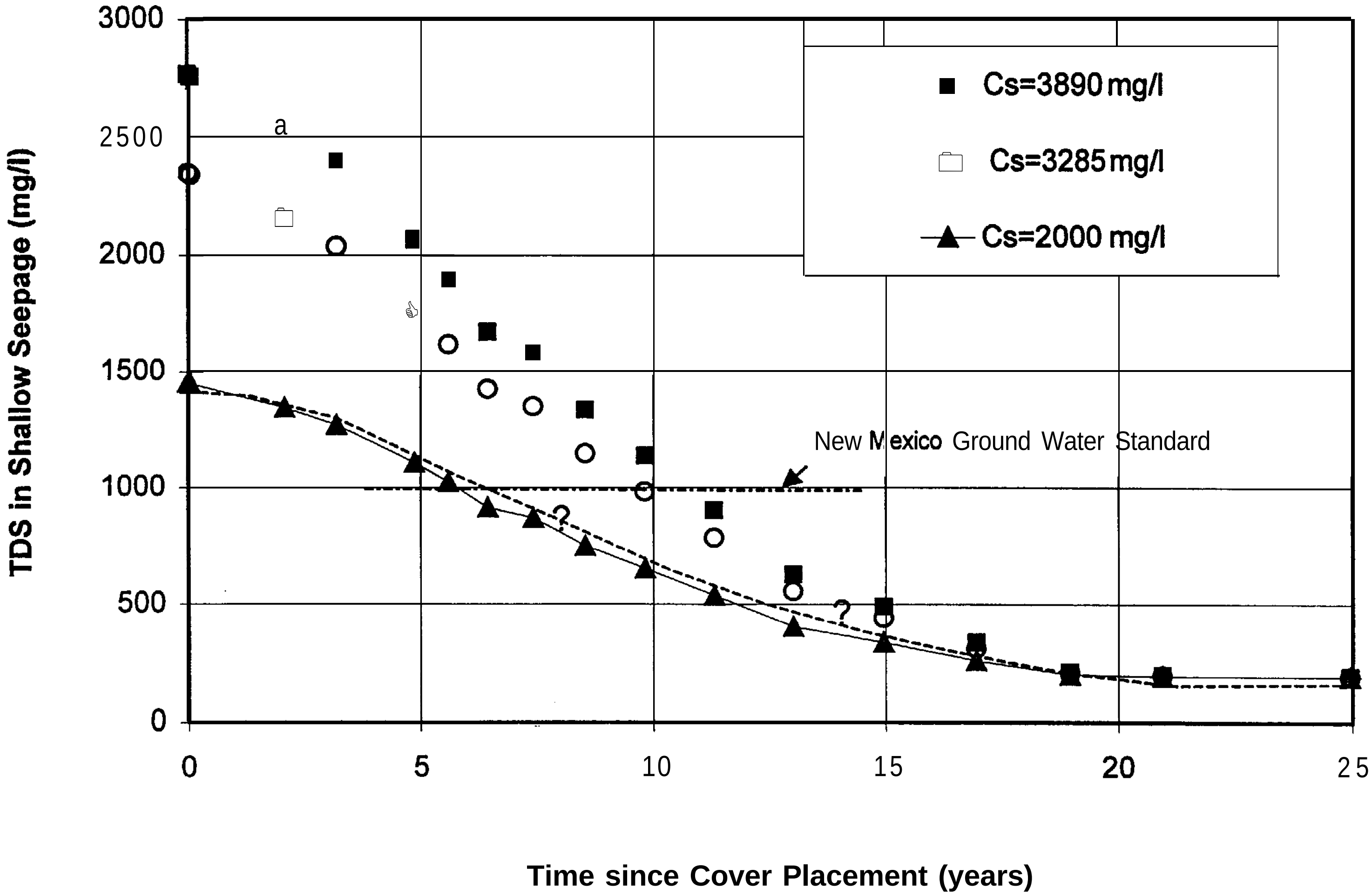

Figure 4-15a.
Simulated [SO_4] in Deep Seepage versus Time.

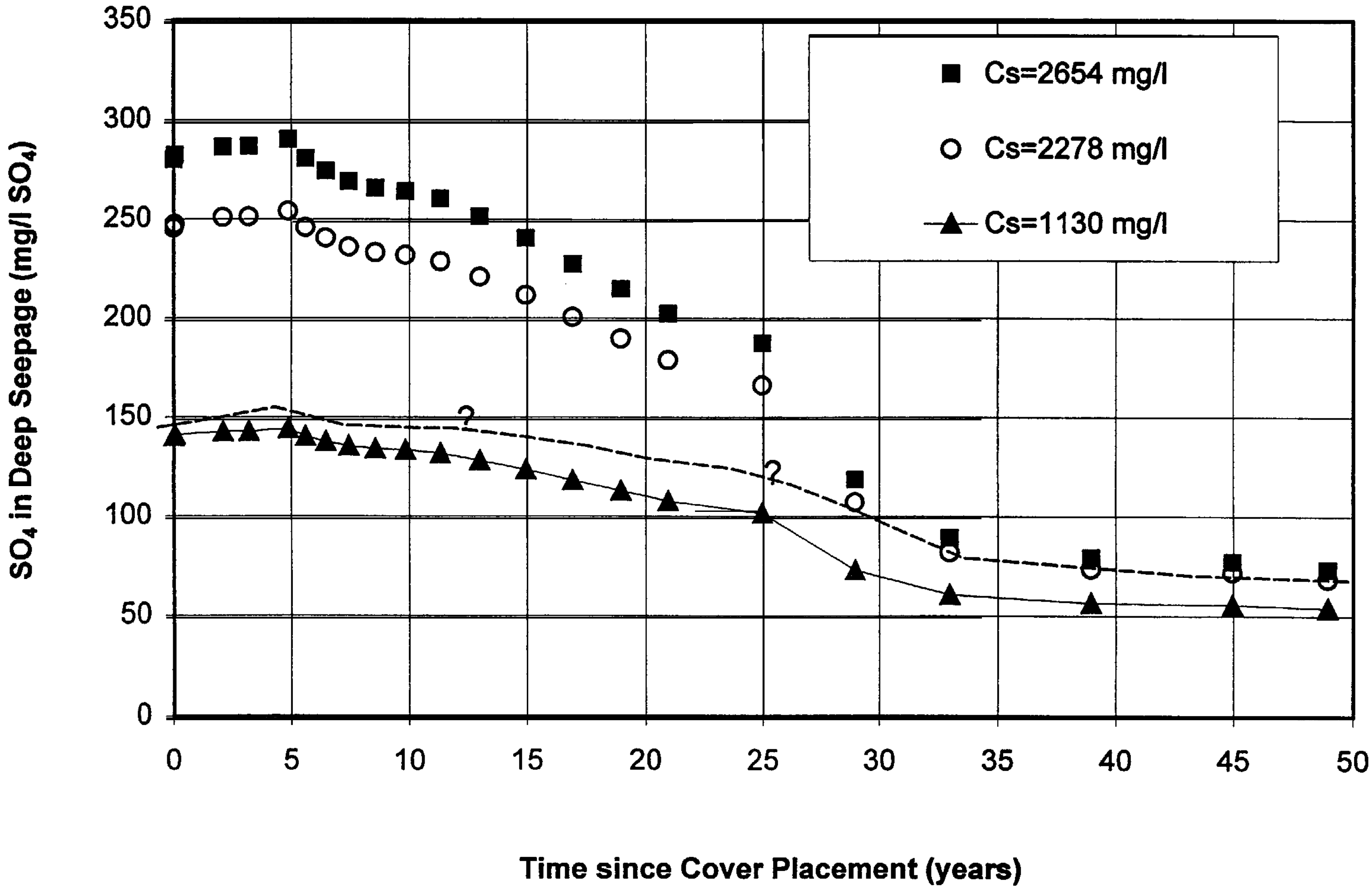

Figure 4-l 5b.
Simulated [Mo] in Deep Seepage versus Time.

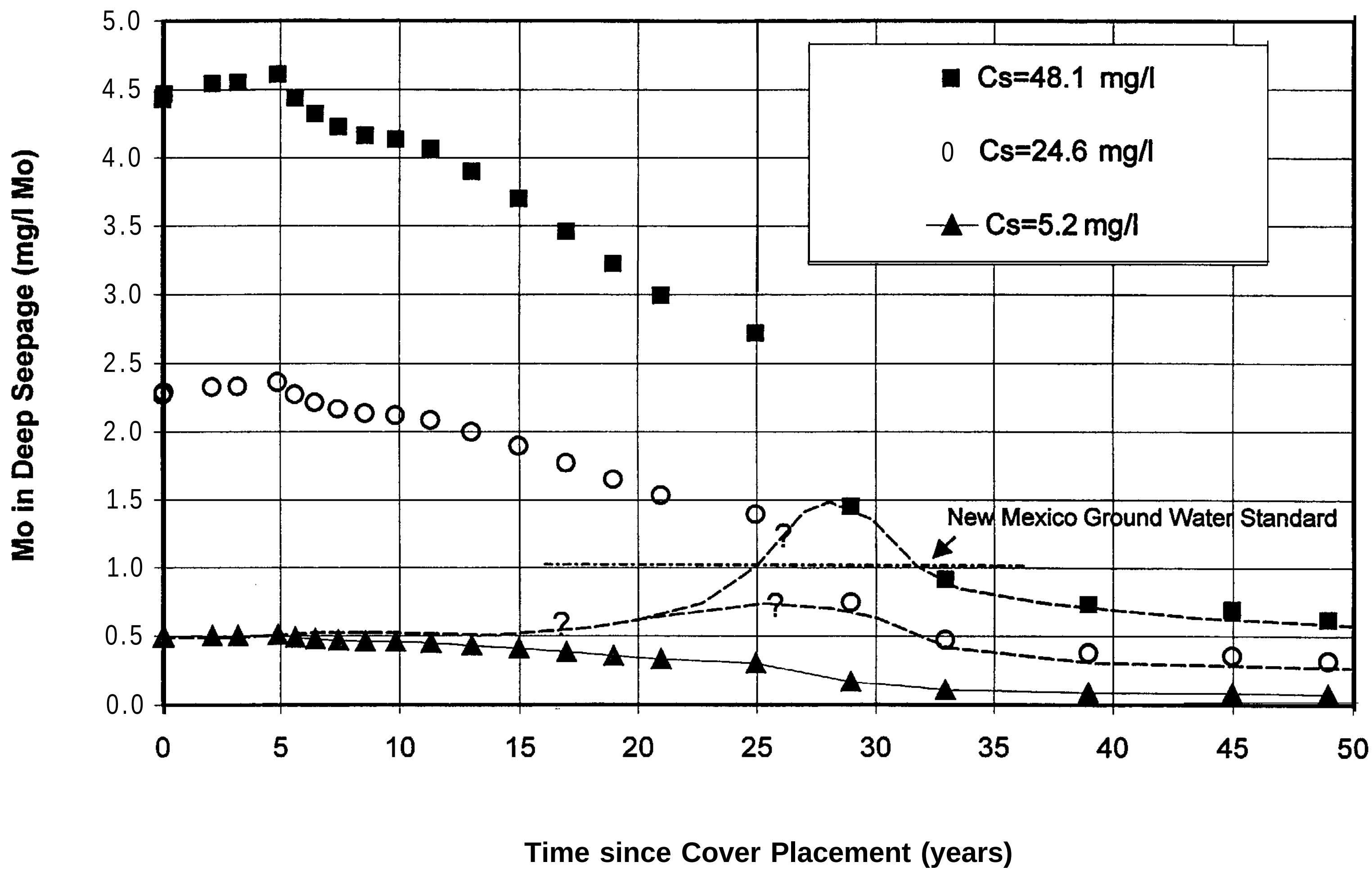

Figure 4-15c.
Simulated TDS in Deep Seepage versus Time.

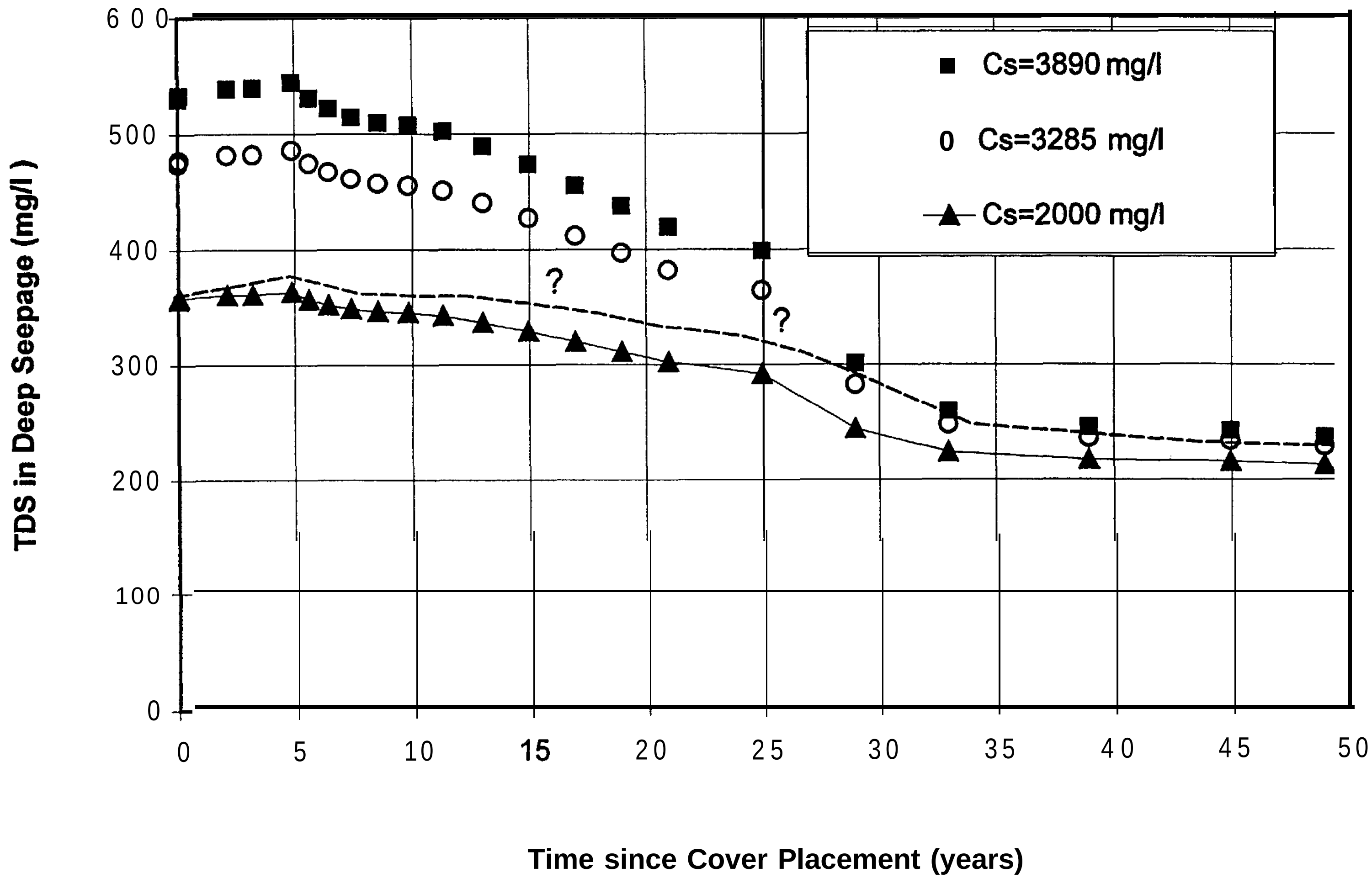

Figure 4-16a.
Comparison of Predicted [SO_4] in Shallow Seepage for Alternative Cover Types

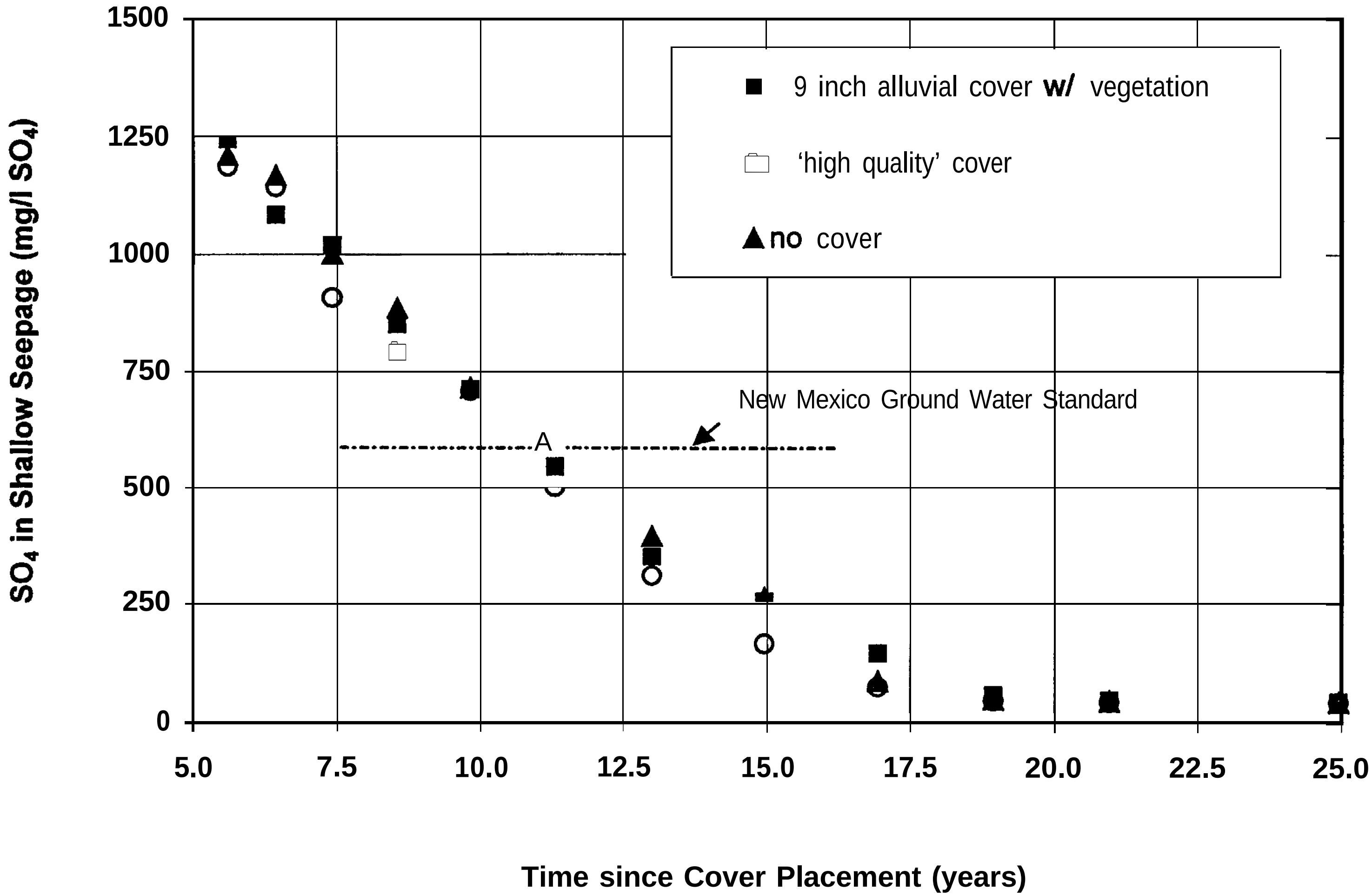

Figure 4-l 6b.
Comparison of Predicted [SO_4] in Deep Seepage for Alternative Cover Types