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Assessment of Site located near Questa, New Mexico

prepared for
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June 27, 1994

001-03.SA

SOUTH PASS RESOURCES, Inc
SPRI

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SPRI DOCUMENT REVIEW SHEET

As part of South Pass Resources, Inc./SPRI's policy to provide complete and accurate reports to our clients, all reports are subject to a peer review for technical accuracy, validity of conclusions, and appropriateness of recommendation.

Report Prepared by: Jack Kepper, Associate Geologist — **Date:** 6-27-94

QUALITY ASSURANCE REVIEW

Editorial Review: Heidi Horten, Senior Editor — **Date:** 6-27-94

Peer Review: David A. Stephenson, Principal Hydrogeologist — **Date:** 6-27-94

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TABLE OF CONTENTS

INTRODUCTION

South Pass Resources, Inc. (SPRI) was requested by Molycorp/Questa Division to prepare a portion of a site assessment required for new and existing mining operations by the New Mexico Mining Act , Section 69-36-5NMSA 1978. This report on SPRI's site assessment presents:

- a description of the location and quality of surface and ground water at or adjacent to the mining operation and an analysis of the mining operation's impact on that surface and ground water;
- a description of the geologic regime beneath and adjacent to the mining operation; and
- a description of the piles and other accumulations of waste, tailings, and other materials and an analysis of their impact on the hydrologic balance and drainages.

This report is organized into two sections: **Tailings Ponds Area**, located 1 mile west of Questa, New Mexico, and **Mine Area**, located 6 miles east of Questa.

TAILINGS PONDS AREA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Tailings Ponds Area

Since 1965, Molycorp, Inc. has utilized an area about one mile west of Questa and north of the Red River for disposal of slurried tailings. There currently are two tailings ponds. Dam No. 1 and Dam No. 4, which support the two ponds, were constructed across arroyos that are tributary to the Red River. Alluvial material, the Santa Fe Foundation sedimentary rock, and various volcanic rock underlie the tailings ponds. The juxtaposition of these soil and rock types, which form the aquifer systems in the area of the tailings ponds, is controlled by high-angle faults. Site geology, including rock or soil type and structure, exerts a strong influence on the distribution of seepage from the tailings material.

HYDROGEOLOGY

Vertically-related hydrogeologic units are recognized in the area between the tailings ponds dams and the Red River. These units are:

- Upper Alluvium Unit (UAU)-- dominated by sand and gravel with some clay;
- Middle Alluvium Unit (MAU)-- characterized with a high percentage of clay;
- Lower Alluvium Unit (LAU)-- with significant sand and gravel; and
- Volcanic Unit -- basalt unit with interlayered volcanic gravel.

The UAU, LAU, and Volcanic Unit function as aquifers, while the MAU functions more as an aquitard (relatively low hydraulic conductivity).

Twelve (12) monitor wells (Figure T4) screened at various levels in the Santa Fe or in the volcanic unit are used to evaluate changes in ground-water chemistry. Localized perched water zones associated with clay lenses in the UAU are partially captured by seepage barriers below Dam No. 1 and east of Dam No. 4. Collected seepage water is piped to the 002 Outfall at the Red River. South of Dam No. 1, the water table in the lower UAU appears to be at the top of a major perched zone involving the lower UAU and some portion of the MAU. Much of the seepage from the tailings ponds has concentrated in the perched zones. Beneath the Dam No. 1 tailings pond and extending to monitor well MW-7 located near the toe of the dam, seepage has extended into the LAU. South of MW-7, in an area extending across the front of Dam No. 1, the upper LAU may be unsaturated.

WATER QUALITY

The water quality down-gradient of the tailings ponds is of good quality in many private wells (if the wells are screened in the LAU and/or underlying volcanic unit). Nevertheless, none of the private wells are used for domestic purposes since Molycorp connected the area to the community water supply system. Down-gradient of Dam No. 4, ground water is within volcanics and has relatively low sulfate and total dissolved solids (TDS) concentrations.

The fault that parallels the Dam No. 1 arroyo appears to extend to the Red River. A complex of springs (Big Spring Complex including Questa Springs) occurs at and just east of the fault. Spring waters are generally cool (8° to 10°C) but have widely varying TDS and sulfate concentrations. Springs fed by the deeper alluvial unit (LAU) or the underlying volcanic aquifer have low TDS and sulfate concentrations, whereas the springs believed to have come from shallower levels (UAU/MAU) have much higher concentrations of these constituents.

Upstream from the Big Springs Complex, the Red River shows a sulfate concentration of 119 mg/L of sulfate. Downstream of the 002 Outfall and the Big Springs Complex, the concentration rises to 138 mg/L. This concentration reflects a large amount of dilution here (compared to the shallow springs and the Outfall which show concentrations of 240 mg/L and 840 mg/L, respectively).

Springs (from the volcanic aquifer) in the upper part of the Red River gorge down-gradient from Dam No. 4 are warmer (10° to 14°C) and show a slightly elevated concentration of sulfate that is higher than the concentration at MW-11 which is closer to the dam.

There are several explanations for the higher sulfate in the springs along the gorge. Because springs on both north and south banks have similar concentrations, localized sulfide mineralization in the volcanics may be the source of the sulfate. It is possible that the spring water is older than the MW-11 water and records an earlier pulse of high sulfate water. If part of the shallow, southwesterly underflow in the volcanic aquifer extends beneath the river, then springs on the south side of the gorge could show some "north" side chemistry (such as localized mineralization or from Dam No. 4).

SEEPAGE CONTROL

Four extraction wells (Figure T11) are planned: one in the volcanic unit southeast of Dam No. 4, two immediately south of Dam No. 1 in the ground-water mound area, and one near the southeast edge of Dam No. 1. Existing monitor well systems will allow for evaluation of the effect of the extraction wells. In addition, site conditions are being evaluated with regard to the construction of a second east-west seepage barrier between the 001 Barrier and MW-2.

T-1 SITE DESCRIPTION

T-1.1 LOCATION AND GEOGRAPHIC SETTING

The tailings ponds are located about 1 mile west of Questa, New Mexico (Taos County) and 0.5 mile north of the Red River (Figure T1). The Town of Questa sits on a broad, westward-sloping alluvial plain bound on the east by the Sangre de Cristo Mountains (elevations in the 12,000-foot range) and on the west by the Guadalupe Mountains (elevations in the 8,700-foot range). In the site vicinity, the alluvial plain is a southern extension of Sunshine Valley but is topographically separated from the valley by a low divide near the Town of Cerro, about 3 miles north of Questa.

The Red River lies immediately south of Questa and is a perennial stream that flows westward from the Sangre de Cristo Mountains to the Rio Grande (5 miles west of Questa). From the front of the Sangre de Cristo Mountains to approximately 2 miles west of Questa, the river flows across the alluvial plain. From the end of the alluvial plain to the Rio Grande, the river channel is entrenched in a deep gorge developed in volcanic rocks on the south flank of the Guadalupe Mountains. The river gradient across the plain is approximately 0.014 foot per mile (ft/mi) increasing to 0.023 ft/mi in the gorge where the river erodes across the volcanic rocks.

West of the mountain front, most of the tributary drainages are intermittent to ephemeral. (The exception is Cabresto Creek, which heads within the Sangre de Cristo Mountains and is a perennial stream to its confluence with the Red River.) The Molycorp tailings ponds were built by constructing dams across two ephemeral tributary canyons located north of the Red River and west of Questa.

T-1.2 HISTORY OF THE OPERATION

The Molycorp-Questa open-pit mining began in 1965. Tailings disposal operations began with the construction of an earthfill starter Dam No. 1 in a large arroyo at the southern end of Section 36. Tailings slurry was piped westward approximately 8 miles along the Red River from the mill near the Molycorp molybdenum mine.

The upstream face of the dam was sealed with the slime faction of tailings. The water clarification pond was at the dam face. Clarified water was piped via decant structures raised on the upstream dam face, through culvert tunnels under the dam, and then by ditch to the Red River.

Raises and operation of Dam No. 1 continued until 1969 when a second dam (Dam No. 2) was constructed at the north end of Section 36. The clarification pond was then shifted to the north, and the existing decant structures were abandoned for a new overflow weir structure constructed in the bank alongside the new Dam No. 2. Clarified water overflowed the weir and traveled down a decant ditch cut around the west side of Section 35 to a small holding pond called Pope Lake (located at the southern end of Section 35). From Pope Lake, the water flowed over a Parshall flume (later called Outfall 001) and to the Red River. The final 7,520-foot and 7,525-foot elevation raises on Dam No. 1 were shifted upstream (west) of the existing dam and were constructed on tailings. These lifts were of compacted earthfill.

In 1971, additional tailings storage was created by constructing starter Dam No. 4 in Section 35. This dam and all its subsequent lifts were constructed of earthfill and had internal drain systems. The upstream dam face was also covered with an asphalt or plastic membrane. A decant weir was built to the north of the dam so that the clarification pond could be kept away from the dam face. Clarified water was released over the weir structure into the west ditch, from there to Pope Lake, and then to the Red River.

In 1974, east and west diversion ditches were constructed around both tailings storage areas in order to divert all natural drainage away from the impounded tailings. Diverted water re-entered the watershed below Dams Nos. 1 and 4.

In 1975, seepage barriers were constructed below Dam No. 1 and to the east of the ridge separating Dam No. 4 and Dam No. 1 areas. These barriers were excavated to clay, sealed on the downstream side, and filled with suitable drain material so that seepage from the tailings storage ponds could be collected and diverted around the dwellings situated downstream of the tailings storage area. This water was then piped to the Red River through Outfall 002.

Beginning in 1979, chemical stabilizers were applied to the exposed tailings surface to control wind-borne material.

In 1983, an ion exchange treatment plant (I-X) building was constructed along side Pope Lake. This plant processed all tailings decant water before it was discharged into the Red River.

In 1990, Dam No. 5A was constructed in the old west decant channel on the north side of Dam No. 3A to a 7,525-foot elevation. The dam is designed to be raised to a 7,540-foot elevation at a later date.

The disposal sites currently cover about 550 acres and have been maintained since the mine ceased underground operations in 1992.

T-1.3 GEOLOGIC SETTING

Regional Geology

The Molycorp-Questa site is located within the Rio Grande rift zone, a northeast-/southwest-trending fault-bound structural depression of Mid- to Late-Tertiary age, that extends across New Mexico into southern Colorado. The depression is composed of a number of structural subbasins including the San Luis Basin, which is located at the northern end of the rift. The San Luis Basin is bounded on the east by the Sangre de Cristo Range which was uplifted contemporaneously with the formation of the Basin along high-angle normal faults extending parallel to the west front of the range. The Basin fill contains coarser alluvial sediments along the range front. Farther to the west, the Basin fill consists of finer clays and silts (deposited in lakes) and finer alluvial material along the distal edge of alluvial fans.

Numerous volcanic fields developed as the result of the rifting and basin formation during Mid- to Late-Tertiary time. The volcanic units that underlie the Guadalupe Mountains along the west side of the site consist of lava flows and ash flow tuffs that range from rhyolite to basalt in composition. The volcanics were erupted onto older Basin-fill sediments from central vent and fissure eruptions (Winograd, 1959 and unpublished reports in the Molycorp files). Eastward toward the uplifted Sangre de Cristo Mountains, the volcanics intertongue with contemporaneous alluvial sediments. Figure T2 (modified from Winograd, 1959) illustrates these stratigraphic relationships. A younger (Pliocene) basalt unit, the Servilleta Basalt, overlies these older volcanic units and may intertongue with Basin-fill sediments. Winograd (1959) referred to the interlayered sedimentary and volcanic units filling the San Luis Basin in the Sunshine Valley areas as the Santa Fe Group. (Note that in the Santa Fe, New Mexico area, this type section of Basin-fill sediments is called the Santa Fe Formation. Elevation to Group status is related to heterogeneity and mappability of the rock units in the Sunshine Valley area.)

Site Geology

Stratigraphy

The stratigraphic sequence in the vicinity of the tailings ponds is based on nine borehole logs (Figure T3), data from field reconnaissance, and by unpublished geologic maps (Vail, 1987; Molycorp files) of the area. Much of the tailings ponds area is immediately underlain by gravel, sand, and clay assigned by SPRI to the Santa Fe Formation. Recent alluvial sediments appear to be confined to the bottom of the arroyos and are on the order of 20 feet or less in thickness (Dames and Moore, 1964, cross-section). A thin, distinctive sequence of coarse volcanic sand and volcanic conglomerate crops out along the southwest side of Dam No. 4 and appears in the top 29 feet of monitor well MW-11 in the same area. The stratigraphic relationship of this unit to the sedimentary beds elsewhere on the site is unresolved. Borehole data show that a basalt/andesite unit underlies the Santa Fe Formation from west to east across the site. A thin gravel (described as volcanic conglomerate at MW-8) is interlayered with the volcanics and is conceivably equivalent to the volcanic conglomerate that overlies the volcanics at the southwest toe of Dam No. 4. Volcanics along the eastern edge of the Guadalupe Mountains consist in part of ash flow tuffs and appear to be in fault contact with the basalts and the Santa Fe Formation. It is not known at this time whether these basalt flows are equivalent to the Servilleta Basalt or one of the older Miocene flow units. Ash flow tuffs are more typical of the Late-Oligocene to Mid-Miocene volcanics (Molycorp unpublished data) and may be older than the basalt/Santa Fe units in the tailings area.

Santa Fe Formation

Based on the borehole logs (Dames & Moore, 1964 and SPRI, 1993), the Santa Fe Formation in the area of the tailings ponds was found to consists of:

- an Upper Aquifer Unit (UAU) composed of brown sandy gravels and gravelly sands with a subordinate component of pale red brown silty, sandy clay.
- a Middle *Aquitard* Unit (MAU) in which pale red-brown clay and gravelly clay are the dominant sediments; and
- a Lower Aquifer Unit (LAU) composed of sandy or clayey gravel. Thin beds of tightly cemented sandstone were noted in MW-7 and MW-10.

These three lithologic divisions are based on dominant textural characteristics, but each unit contains subordinate amounts of the other lithologies (for example: clay beds occur within the UAU and LAU). There are no marker beds to establish lateral equivalence between borehole sections, such that parts of the MAU may be temporally equivalent to the lower part of the UAU, or the upper part of the LAU. In general, the internal structure of a sequence of alluvial or alluvial/lacustrine (lake) sediments is expected to be lensoid in character and have sand and gravel lenses intertonguing with clay-rich units (Galloway and Hobday, 1983). East of Dam No. 1 (in the direction of the Sangre de Cristo Mountains), the Santa Fe Formation coarsens and thickens (as demonstrated by the Change House Well bottoming at a depth of 250 feet in gravel and the Questa Well No. 2 bottoming at 500 feet in gravel).

Gravels range from very fine gravel (0.08 to 0.16 inch) to cobble sizes (2.4 to 10.24 inches), but most of the material appears to be below cobble size. Geotechnical drilling for Dam No. 1 (pre-dam cross-section along the proposed axis of Dam No. 1, Molycorp files) and the borehole for the Change House Well (located east of Dam No. 1) indicated boulder-size material is present in the UAU and LAU. Clast composition in the gravels indicates sources in the Sangre de Cristo Mountains to the east. A variety of volcanic rock types (flows, ash flow tuffs), intrusive igneous rocks (pegmatite, granite, quartz monzonite), and metamorphic rocks (gneisses) occur in the gravels.

A thin sequence of brown, silty, highly burrowed sands; black, coarsely grained volcanic sands; and gravelly clayey volcanic sands outcrop in the vicinity of MW-11. The gravels in this unit are entirely composed of volcanic clasts. Similar sediments were penetrated in the upper 29 feet of MW-11 and in several borings near the toe of Dam No. 4. This unit, shown separately (as T_{svs}) on the geologic map (Figure T4), may be equivalent to the volcanic conglomerate interlayered with the basalt/andesite unit.

Volcanic Units

Lithologic information for the volcanic rocks penetrated by the monitor wells comes primarily from cuttings descriptions. The flow rock is a finely crystalline olivine basalt or andesite containing brown millimeter-size phenocrysts of altered olivine and of pyroxene (possibly augite). White phenocrysts of feldspar were also noted. A few cuttings showed glassy textures which probably indicate the tops or bases of individual flows. Both vesicular, and to a greater extent, non-vesicular basalt are present in the section. Flow banding was observed in some cuttings. White and pale blue quartz/chalcedony fills some vesicules and occurs along a few fractures. Thin volcanic breccias consisting of black to gray angular volcanic fragments in a red volcanic matrix are interlayered with the flows. Exposures of the basalt along the walls of Pope Wash, south of MW-11, show that the basalt is highly fractured with sets of vertical fractures coupled with units showing a distinct horizontal parting. Volcanics observed along the east side of the Guadalupe Mountains were examined during a half-day reconnaissance of the area. These are dominantly medium gray ash flow tuffs characterized by flattened brown to tan pumice fragments and by the presence of black basal vitrophyres.

Geologic Structure

Reconnaissance mapping, combined with a description of subsurface geology based on borehole data, indicate the presence of four northeast-trending faults displacing Santa Fe Formation sediments relative to various volcanic units (see Figures T4, T5, and T6). The apparent movement along some of the faults is down to the east (a strike-slip component can not be ruled out).

Vail (1987 unpublished geologic map) mapped a northeast-trending high-angle fault along the east flank of the Guadalupe Mountains. This fault appears to follow the west side of a linear, northeast-trending wash, now largely covered by the tailings behind Dam No. 4. The ash flow tuffs along the east flank of the mountain are moderately tilted along the fault line and, in places, unconformably overlain by Santa Fe Formation or younger gravels. The Santa Fe volcanic sediments and the basalt unit south of Dam No. 4 lie east of the fault and appear to be truncated by the structure. The ash flow tuffs may correlate with volcanics that are either equivalent to the lower Santa Fe or older than the Santa Fe, suggesting that the fault block to the east has moved relatively downward.

In the Work Plan for the tailings ponds area study (GeoWest Group, 1993), the linear, northeast-trending pattern of the ridge between Dam No. 1 and Dam No. 4 and of the wash to the east of the ridge was identified. The wash between MW-1 and MW-2 was postulated to follow a high-angle fault because of the apparent displacement of the volcanic unit in MW-1 relative to the sediments (at the same elevation) in MW-2 (Figures T5 and T6) and because of the linearity of the wash. Wells MW-8 and MW-7, drilled 1,500 feet to the north of MW-1 and MW-2, show a similar structural relationship confirming a linear structure extending northeast along the wash. The volcanics were not encountered in MW-9, drilled to elevations well below the level of the volcanics in MW-1 (Figure T4). However, the volcanic unit does appear at deeper levels farther east in the lower part of a private well (P-4B), and in MW-10 (Figure T6). The driller's log for P-4B shows a gravel interbedded with the volcanic unit similar to the section at MW-1 (Figure T5). Using the gravel as a marker, it appears that the volcanic unit is offset along a fault that aligns with the wash and that the vertical displacement is on the order of 50 feet and down to the east. The eastern block may be slightly tilted to the west.

The cross-sections (Figures T5 and T6) suggest that a northeast-trending fault may also extend beneath the ridge that divides Dam No. 1 and Dam No. 4. This structure is based on the difference in elevation between the basalt outcrop immediately east of the I-X building and the top of the volcanic unit in MW-1 (a difference of 157 feet) and the linearity of the ridge. However, at the I-X outcrop, Santa Fe gravels unconformably overlie the basalt, and the basalt ridge could be an erosional feature. The presence of documented faults in the area that have the same trend and the linearity of the ridge -- when coupled with the Tertiary extensional history related to the Rio Grande Rift -- favors a fault interpretation.

The volcanic sediments outcropping below Dam No. 4 and noted in several boreholes appear to be truncated by the basalt unit unconformably overlain by the Santa Fe Formation immediately east of the I-X building. The volcanic sediments (T_{svs}) were not observed in the exposures of the Santa Fe Formation east of the I-X building. The apparent truncation of the stratigraphic units and the absence of the volcanic sediments are the basis for the fault shown east of the I-X building on the geologic map.

Both the borehole data and the field exposures are concentrated in a narrow band along the front of Dam No. 1 and Dam No. 4. The structure and the lithologic units, particularly the basalt unit, are believed to extend northward beneath the tailings ponds and southward at least to the Red River. The hydrogeologic significance of this condition is:

1) the extension of the basalt unit in an east-west direction entirely beneath the tailings ponds and at fairly shallow depths (Figures T5 and T6) means that any vertical seepage from the tailings ponds area can be adequately diluted by high rates of underflow before reaching the Red River; and

2) the northeast-trending structures juxtaposed lithologic units that have significantly different hydrogeological properties (for example: clay in fault contact with fractured basalt).

T-2 TAILINGS DAMS: STRUCTURE, HYDROLOGY, AND HYDROGEOLOGY

T-2.1 STRUCTURE AND HYDROLOGY

The tailings dams are earthfill structures constructed across two arroyos: Dam No. 1 in the Section 35 arroyo, and Dam No. 4 in the Section 36 arroyo. The UAU of the Santa Fe Formation (approximately 80 to 100 feet thick) underlies Dams No. 1 and occurs along the east side of Dam No. 4. Clays of the MAU underlie the UAU below Dam No. 1. The volcanic sandstone and conglomerate beds beneath at least the toe area of Dam No. 4 are very thin (approximately 50 feet thick) and rest on the fractured basalt/andesite unit. The pre-dam arroyo beneath Dam No. 4 is broader and the channel line approximately 80 feet higher than the pre-arroyo channel beneath Dam No. 1 (Questa and Guadalupe Mountain 7.5 Minute Quads., 1963). This condition is either the consequence of more erosionally resistant materiel beneath Dam No. 4 (volcanic-bearing sandstone and basalt) or reflects a longer period of erosion and/or higher volume of discharge through the Dam No. 1 arroyo.

The initial drainage of decant water at Dam No. 1 was carried by internal culverts directed to a still pond at the toe of the dam (elevation 7,290 feet) from which it flowed through a ditch southward to the Red River. Subsequent to this, the decant ponds were clarified upstream of the dam, and decant water was directed through a weir system to the west diversion ditch, to Pope Lake, and eventually to the Red River. Since 1983, the decant at Pope Lake was processed at an ion exchange (I-X) facility next to the lake prior to discharging to the Red River. Diversion ditches were constructed around both sides of the tailings ponds to divert all natural run-off away from the impounded tailings.

The drain system beneath both dams has evolved with time, but basically consists of chimney drains, that connect at the base of the dam with blanket and finger drain types of underdrains (Molycorp engineering drawings). The lowest elevation for the underdrain at Dam No. 1 is about 7,320 feet and at Dam No. 4 is about 7,344 feet. These drains would rest on the UAU beneath Dam No. 1 and probably the volcanic sandstone unit (based on pre-dam boring logs) at Dam No. 4.

Tails material was delivered to the pond as a slurry (38 percent solids and 62 percent liquid by weight). Sieve analyses of tails material (Molycorp files) indicate a range of size distributions with median values in the medium to fine sand classes and a <200 mesh fraction (silt and/or clay) that is less than 10 percent to as much as 50 percent of the sample. Slurry water that was not decanted or lost by evaporation infiltrated and was stored in the tailings material. The phreatic surface (top of saturated material) is monitored through a series of piezometers in the dam area and on the tailings surface. A comparison of the phreatic surface between Dam No. 1 and Dam No. 1c in 1983 with the 1993 surface indicates a decline in head of about 19 feet (1.95 feet per year based on 9.75 years). This value corresponds to a rate of decline of 0.005 feet per day.

Geocon (1983) used finite element code and water-level data from the piezometer between Dam No. 1 and Dam No. 1C to model a flow net consisting of equipotential (equal head) lines and flow lines. On their flow net cross-section, the phreatic surface slopes south toward the upstream face of Dam No. 1 at a gradient of 0.07 foot per foot (ft/ft). The 1983 gradient and SPRI's (1993) reported gradient of 0.22 ft/ft are not comparable: the 1983 phreatic surface extended only to the upstream face of Dam No. 1 and the 1993 gradient includes a piezometer point near the toe of the dam and the steeper gradient at the underdrain. The slope of the phreatic surface and the flow lines clearly show discharge to the underdrain system beneath Dam No. 1. The flow-line pattern also shows that flow is toward the bedrock base of the dam and that seepage will move into the underlying UAU. In their modeling effort, Geocon used an "interpreted" rate of outflow (shown as vertical seepage on their drawing) along the base of the tailings area of 0.003 cubic feet per day per square foot ($ft^3/day/ft^2$) or 0.022 gallons per day per square foot ($g/d/ft^2$). If the rate of decline in head (based on the change in the elevation of the phreatic surface between 1983 and 1993) is converted from 0.005 feet per day to a vertical seepage, the result is 0.037 $g/d/ft^2$, in fairly good agreement with the modeling. This description is an over simplification of the dewatering of the tailings because there is a component of horizontal flow toward the underdrain system at Dam No. 1. In other words, the head decline behind Dam No. 1 is a function of seepage through the underdrain system (some of which seeps out along the surface) and seepage through the UAU along the base of the tailings.

T.2.2 HYDROGEOLOGY OF DAM NO. 1 AREA

As indicated in the previous section on stratigraphy, the Santa Fe Formation is a heterogeneous lithologic unit. Logs from borings drilled along the axis of Dam No. 1 prior to its construction (Dames and Moore, 1964) and from monitor wells (SPRI, 1993) indicate that the UAU contains silty clayey gravels with lenses of clay and of relatively clean sand and gravel. The driller's log for the Change House Well just east of Dam No. 1 indicates some bouldery material is present in the UAU. Since the source of most of the alluvial material is from the Sangre de Cristo Mountains east of the site, the alluvial section becomes coarser in that direction and the clays pinch out (Winograd, 1959). The MAU is dominated by clay, but subordinate units of gravel and sand occur.

The downward change to the LAU seems to be gradational with increasing amounts of gravel and sand over clay. The Change House Well log shows some bouldery material at the top of the LAU.

Because of the relative low permeability clay beds, lateral hydraulic conductivity is probably significantly higher than the vertical conductivity within the Santa Fe Formation. Seepage water under hydraulic head driven by mounding within the saturated tailings has preferentially migrated laterally along the tops of the clay beds to form shallow perched zones. Monitor wells A, B, and C near the toe of Dam No. 1 and monitor well MW-9A record shallow water levels related to perched zones. MW-B is periodically dry, indicating the ephemeral nature of some of these perched zones. Seepage Barrier 002 along the east side of Dam No. 4 collects seepage from a perched zone in the UAU. At Seepage Barrier 001, much of the seepage is perched water related to the underdrain system beneath Dam No. 1. Head relationships, at least between the UAU and MAU, indicate a downward flow path. Seepage eventually reaches the water table, which currently is located near the UAU/MAU contact.

Prior to the construction of the tailings dams (pre-1965), there is some information on the subsurface units and depth-to-water for the private wells south of the Molycorp property and north of the Red River. The well locations are at the ¼ and $^1/_{16}$ section level in the northwest and northeast quarter of Section 1 and do not have measuring point elevations so they can not be used to calculate flow directions and gradients. Topographic contour data for well elevations and the approximate location on the Questa 7.5 Minute map indicate that the shallow wells (less than 100 feet deep) are probably screened in the UAU/MAU units. The water-level elevations for these wells are very close to elevations along the channel of the Red River.

Geocon (1989), in their response to EID's comments on the Guadalupe Mountain study, indicated that the original arroyo surface in the area of Dam No. 1 was typically wet with local springs and ponds. Whether this condition was related to perched water or the static water table is unknown. Long-time residents of the area recall cottonwood trees in the arroyo near the present dam and seepage water in one of the tributary arroyos. Within 300 feet of the Red River, there are numerous springs in the fields along the north bank.

Recent water-level data from the monitor wells constructed on Molycorp property north of the private wells indicate that the shallow, static-water level is close to the UAU/MAU contact (SPRI, 1993). A three-point solution for flow direction and gradient result in a direction of S47°W at a gradient of 0.02 ft/ft (SPRI, 1993). Contouring the available water-level elevation data for the shallow aquifer (Figure T7) shows that recharge occurs in the vicinity of the arroyo that extends southward from Dam No. 1.

SPRI (1993) reported a flow direction of S6°W at a gradient of 0.02 ft/ft for the LAU based on water-level measurements at MW-7C, MW-9B, and MW-10. The depth-to-water at MW-9B was measured at 143 feet below ground surface (bgs), resulting in a water-level elevation below river level and a flow direction to the south rather than to the west. Subsequent to the release of SPRI's 1993 report, measurement of water depth continued to give values in the 142 to 143 feet range at the bottom of the screen (total depth 145 feet). It appears that, at MW-9B, the LAU is dry (except for some seepage from a partially saturated LAU). The shallow, static-water levels for MW-2 and MW-3 (which bracket MW-9) may be for a perched water table associated with the clayey MAU. Calculations for ground-water velocity and dilution effects based on the original LAU gradient and flow direction data (SPRI, 1993) cannot be used.

MW-10 is screened in the LAU with a depth-to-water of 39 feet and a static water-level elevation of 7,314.2 feet. This is fairly close to the water-level elevation at nearby MW-4 which is screened in the lower UAU and upper MAU units. At MW-4, the water-level elevation is 7,319.93 feet, approximately 6 feet higher than the LAU. This suggests a downward gradient from the lower UAU with respect to the LAU. However, because of the composite screening at MW-4, head relationships between the LAU and the MAU in this area can not be established. The LAU water chemistry at MW-10 shows little evidence of the presence of seepage water whereas the overlying UAU/MAU at nearby MW-4 has high total dissolved solids (TDS)/sulfate concentrations.

Head relationships between the Santa Fe Formation and the underlying basalt/andesite unit are not well established. MW-1 and MW-8 are screened in the volcanic unit. At MW-1, the water-level elevation is about 10 feet above the top of the volcanic unit. This does not necessarily mean that there is an upward gradient since we do not know the water-level elevation for the overlying MAU. During the drilling of MW-8, the depth-to-water was measured on successive days at 132 feet when the casing drive unit was in the LAU, and later at 105 feet when the casing drive was in the volcanic unit. This well was drilled to a depth of 225 feet and was screened across the volcanic gravel unit that lies below a 30-foot interval of basalt (similar to the volcanic section at monitor well MW-1). The gravel unit at MW-8 appears to be a confined aquifer or in a discharge zone, which is the reason for the upward gradient between the volcanics and the overlying Santa Fe Formation (SPRI, 1993).

Unfortunately, casing collapsed at MW-8 during construction and the well was abandoned. A new MW-8 was located 5 feet west of the original (abandoned) MW-8 and was drilled to a depth of 185 feet. This well was screened in the basalt above the volcanic gravel. Although the initial water level was at 160 feet, the water level never recovered above a depth of 181 feet after bailing. Subsequent measurements after well construction show the well to be dry. Reconstructing the drilling experience at both wells suggests that the MAU water level in the original MW-8 may have been for a perched water table and that the basalt above the volcanic gravel (and possibly some portion of the overlying LAU) are unsaturated. If this is the case, the unsaturated zone in the LAU at MW-9 may extend westward across the front of Dam No. 1 (see discussion in Section T-2.4, page T-14). This condition may be a further indication that tailings water from Dam No. 1 may largely be concentrated in a perched zone involving the lower UAU and some portion of the MAU.

A three-point solution for the volcanic unit utilizing MW-1, -8 *(original MW-8)*, and -11 resulted in a flow direction across the front of Dam No. 4 of S55°W at a gradient of 0.0229 ft/ft.

An aquifer pumping test was conducted at MW-10 to measure the transmissivity of the LAU. The test was not successful since the well pumped dry at 2 gallons per minute after 70 minutes and most of the water was probably from borehole storage. Several measurements of saturated vertical hydraulic conductivity (Kv) were made from samples collected from the MAU at MW-9 (SPRI, 1993). These values ranged from 0.01056 g/d/ft^2 for a clay rich unit to 73.3 g/d/ft^2 gravelly silt. Since horizontal hydraulic conductivity commonly exceeds vertical conductivity by a factor of 10 or more (Freeze and Cherry, 1979), some of the gravelly units in the Santa Fe Formation south of Dam No. 1 would be expected to have higher conductivity and may be fairly productive but at low pumping rates because of their thinness and lens-like character.

T-2.3 HYDROGEOLOGY OF DAM NO. 4 AREA

Monitor well MW-11 is located just east of the fault zone that runs along the western edge of Dam No. 4 and south of the toe of the dam (Figure T4). The well is screened in the basalt/andesite unit. Aquifer pumping tests conducted at the well resulted in hydraulic conductivities in the range of 6,833 g/d/ft^2 (specific capacity calculation) to 14,103 g/d/ft^2 (recovery test). Dames and Moore (1986) calculated an hydraulic conductivity of 2,400 ft/day (17,952 g/d/ft^2) from a pumping test conducted in volcanics at test well GM-5. These values are all well within the published values for permeable basalts (Freeze and Cherry, 1969). A three-point solution for flow direction and gradient resulted in a flow direction of S55°W and 0.029 ft/ft. An earlier study utilizing the three-point method at Guadalupe Mountain (west of Dam No. 4) by Dames and Moore (1986) resulted in a flow direction of S30°W and a gradient of 0.003 ft/ft. (Elsewhere in their report, a range of gradients from 0.003 to 0.015 ft/ft was given.) In the case of the Guadalupe Mountain study, the wells are more than 3 miles apart such that the water-level elevations may be a function of the position of the well with respect to the flow path (gradient over such a distance may not be uniform). In contrast, the monitor wells south and east of Dam No. 4 are less than 1 mile apart and were screened in the upper part of the volcanic section. The three-point solution across the front part of Dam No. 4 is also an approximation. It is possible that the fault zone immediately west of MW-11 is a discharge zone that would lower the water-level elevation and cause a local steepening of the gradient. For purposes of calculating ground-water velocity and dilution effects, the gradient and flow direction across the point of Dam No. 4 are reasonable values.

The depth-to-water at MW-11 at the time of the pumping test was 193.89 feet resulting in a water-level elevation of 7,153.23 feet. MW-11 is about 200 feet south of the toe of the dam. It appears that the unsaturated zone below the dam is on the order of 190 feet in thickness (50 feet of Santa Fe Formation and 140 feet of variably permeable basalt).

The elevation of the Red River at a point 180 feet south of the well is between the 7,160- and 7,200-foot contours (Guadalupe Mountain 7.5 Minute Quad). Static water level at MW-11 is at 7,153.23 feet, slightly lower than the river. MW-1, also screened in the volcanic unit, has a water-level elevation of 7,233 feet which is just about river level. For the segment of the Red River between Big Springs and Pope Lake, the water table in the volcanic unit appears to be just above river level. In the vicinity of Pope Lake, across the fault zone, there may be some ground-water discharge into the fractured volcanics. The water table gradients may steepen slightly across the fault zone, bringing the static water level below river level. Since the river elevation is higher than the water table, there probably is some recharge or loss of flow from the river (but not enough to impact the overall gain recorded by stream gauges). In the Red River Gorge, the river has steepened its gradient and, at some point, river elevations are below the water table. The point where the water table in the volcanic unit rises above river level probably lies between the Pope Lake area and the Fish Hatchery. There may be a segment of the river in the upper gorge along which ground water flows away from the river.

T-2.4 WATER QUALITY

This discussion of ground-water chemistry is based on the analytic results of monitor well water samples collected as split samples with the New Mexico Environmental Department on August 17 and 18, 1993. The results of the chemical analyses are presented in Tables T1, T2, and T3. Additional chemistry data from documents in Molycorp files or from other consultants' reports are also presented in this discussion.

Figure T8 shows a series of STIFF diagrams comparing the ground-water chemistry of the monitoring wells. MW-10, MW-11, and MW-CH belong to a different set of water quality measurements than the rest of the monitoring wells. Wells MW-10 and MW-11, which are located down-gradient from the tailings ponds, produce high quality water (Table T1) and are characterized by low TDS and low sulfate content. Water from these wells is of higher quality than a recently (April 1993) collected water sample from the Red River upstream of Questa Springs which showed a TDS at 268 milligrams per liter (mg/L) and sulfate at 141 mg/L. The third well of this group, the Change House Well (MW-CH), appears to be screened in the MAU and LAU (based on depth of the perforated intervals and the lithologic log). This well has a slightly higher TDS, a lower sulfate, and a higher sodium, potassium, and bicarbonate content compared to the other two wells. MW-CH is located east of the tailings pond behind Dam No. 1 and, based on flow directions for the shallow aquifer, may be indicative of some of the up-gradient water chemistry. The water chemistry at the remaining monitoring wells can be characterized as a high TDS, calcium-sulfate water.

The principal components of the tailings pond leachate that exceed New Mexico State Standards are TDS and sulfate. The higher concentrations of TDS and sulfate occur in wells located east of Dam No. 4 and south and east of Dam No. 1 (Figure T8). TDS and sulfate concentrations are high in the UAU and MAU units over the same area.

Although the water chemistry from the LAU at MW-10 and from the deeper private wells south of Molycorp property show little or no evidence of seepage water, the LAU water quality at MW-7C (near the toe of Dam No. 1) has an elevated TDS/sulfate concentration. Head relationships at MW-7 indicate a downward gradient between the LAU and MAU. This condition suggests that heads in the UAU and MAU beneath the tailings ponds are higher than those in the underlying LAU. Some tailings water may be migrating downward into the LAU and flowing in a southerly direction within the saturated LAU beneath the ponds. MW-10 has high quality water because it is east of the flow path of LAU water from the area beneath the ponds and probably because of an upward gradient preventing tailings water in the UAU/MAU (MW-4) from moving downward.

SPRI (1993) reported that water collected from the bottom of the deep piezometer at MW-9 (MW-9B) had a conductivity of 230 microhms similar to the measurement at MW-10 (240 microhms). Subsequent to that report, water-level measurements indicated that it remained close to the bottom of the screen. It appears that the LAU may in fact be unsaturated here and that the water in the bottom of this well is seepage from a vadose zone. The conductivity reading indicates that the water is not from the overlying UAU/MAU units (MW-9A, MW-2, and MW-3), which have high TDS, high sulfate water. The extent of an unsaturated zone involving the LAU is unknown. Both MW-2 and MW-3 are close to MW-9, but are screened in saturated lower UAU and part of the MAU. As indicated in the discussion on page T-12, an unsaturated zone involving the LAU may extend entirely across the Dam No. 1 arroyo. It is possible that as tailings leachate moved downward beneath the tailings pond that the bulk of the flow moved out laterally along perched zones in the UAU and close to the UAU/MAU contact. With the exception of MW-7C, influenced by its location at the toe of Dam No. 1, the LAU along the south side of the Molycorp property may be free of pond leachate because of a combination of reasons:

1. upward gradient between the LAU and MAU south of MW-7;
2. MW-10 is east of the LAU flow path; and
3. possible existence of an unsaturated zone involving the LAU in an area extending from MW-9 westward to MW-8.

Figure T10 illustrates a series of histograms showing changes in TDS and sulfate for the period 1988 to 1993, for MW-1 through -4 and for MW-A, -B, and -C. Except for a decline in these components at MW-1, the changes at MW-2, -3, and -4 seem to fluctuate. This fluctuation may be a function of head changes in the pond area possibly related to year-to-year variations in natural recharge from melting snow. In contrast, MW-A and MW-C show a trend of increasing concentration with time. These increases occur in the shallow UAU, in wells constructed near the toe of Dam No. 1. The rising concentration may also result from changes in head. If the head within the pond material declines with time because no new tailings are accumulating, then residence time for the water within the pond sediment increases and concentrations may rise. Shallow wells near the toe of the dam would be particularly responsive to such changes.

South of Dam No. 4, monitor well MW-11 (screened in the basalt aquifer) shows very low concentrations of TDS (267 mg/L) and sulfate (78 mg/L). This sulfate concentration is lower than that in the Red River east of Questa Springs (141 mg/L) according to unpublished data from Vail (1993). If tailings leachate is moving down into the basalt aquifer, it is rapidly diluted by the southwesterly underflow in the basalt, and the monitor well near the toe of the dam produces high quality water (for example, see STIFF diagram, Figure T8).

Southeast of Dam No. 4, monitor well MW-1 is screened in the volcanic unit. This well has slightly elevated TDS (1,051 mg/L) and sulfate (540 mg/L) with respect to State standards. Head relationships between the volcanic unit and the overlying sediments are unknown here and it is possible that water from the overlying units has moved down into the aquifer. However, the head in the sedimentary section above the basalt at MW-8 was lower (132 feet bgs) than the head in the screened basalt (105 feet bgs) at the time of well construction. The water-level elevation for the basalt can not be confirmed because the PVC casing partially collapsed and the well was abandoned. If these head relationships are correct, this would indicate the basalt is confined or in a discharge zone east of Dam No. 4 and leachate-impacted water would be derived from up-gradient sources where higher heads beneath the pond might cause a downward gradient. It is also possible that, given the evidence for recharge to the shallow water table (recharge zone south of Dam No. 1, Figure T7), some ground water having high TDS/sulfate concentrations might move across the fault zone into the basalt. Farther to the west, the tailings pond concentrations are diluted by normal underflow in the basalt.

There is some evidence that the fault east of MW-1 may exert some control on the movement of ground water toward the Red River. The projection of this fault to the river would approximately correspond to the Questa Springs area and the springs may be directly related to the structure. Water from the Questa Springs area is piped to the Fish Hatchery (approximately 4.5 miles downstream from the springs). Questa Springs area water has a TDS of 173 mg/L and a sulfate concentration of 80 mg/L (Vail, 1993), which are comparable with LAU or volcanic aquifer water. It is possible that, with a southwesterly flow direction in the saturated LAU, there is a component of flow parallel to the structure. The temperature of this water (8.3°C) is perhaps more compatible with shallow ground water than the temperature (16°C) of the deeper flow system in the volcanics (Vail, 1993).

T-3 IMPACT OF THE TAILINGS POND LEACHATE ON PRIVATE WELLS AND THE RED RIVER

T-3.1 IMPACT ON PRIVATE WELLS

South of Dam No. 1 Arroyo

The deeper private wells (P-4B and P-5) south of the tailings ponds have good quality water in terms of TDS and sulfate (Table T2). Well P-4B is a deep well (175 feet bgs), is partly screened in the volcanic unit, and is partly in the overlying sedimentary material. Well P-5 is 131 feet deep, which is enough to be into the LAU (perforated interval unknown). Well P-5 may be located east of an LAU flow path from the tailings area.

For the shallower wells (P-1: 67 feet bgs, and P-8: 90 feet bgs), the high concentrations of TDS and sulfate may result from these wells being largely screened in the MAU. Drillers' logs for these and other shallow private wells, when compared to the more detailed log at MW-9, suggest that the lower part of the screens may be in the top of the LAU. However, the high TDS/sulfate may reflect MAU water rather than LAU water. The shallow aquifer water-level map (Figure T7) indicates recharge along the axis of the arroyo that passes beneath Dam No. 1 and suggests that much of the tailings leachate is focused in the area of the arroyo that includes the down-gradient private wells.

Vail (1993) recorded a sulfate concentration of 504 mg/L from a field spring in the vicinity of Big Springs (Table T3). In Vail's report, the cold spring water piped to the Fish Hatchery came from Questa Spring (part of the Big Spring Complex). However, Vail (personal communication, 1994) indicates that the source of the Fish Hatchery cold water is a spring in the fields just east of the Questa Springs. This spring water has a sulfate concentration of 80 mg/L. It appears that the shallower alluvial units (UAU/MAU) are the probable sources of the poorer quality water and that some of the spring water comes from deeper sources in the Santa Fe Formation (LAU). All of these springs are located east of the fault zone identified in the tailings area (east of MW-1 and MW-8). Water may migrate upward along fractures from different levels in the Santa Fe Formation.

As indicated earlier in this report, seepage from the east side of the pond at Dam No. 4 is partially captured by Seepage Barrier 002. The high sulfate and high TDS concentrations in MW-1, however, may be related to Dam No. 4 or to southwesterly flow from the shallow ground water from Dam No. 1.

South of Dam No. 4 Arroyo

South of the face of Dam No. 4, monitor well MW-11 (located on the west flank of the arroyo that passes beneath the dam) contains high quality water. SPRI (1993) calculated very high rates of discharge (5 to 15 cfs) in this zone of highly fractured basalt near a fault zone. A combination of a locally steep gradient coupled with higher than normal hydraulic conductivity and porosity can result in such high discharge figures. However, over a larger section of basalt, discharges may be considerably lower. Flow conditions in a sequence of volcanic flows vary widely because much of the ground water flows along permeable zones near flow contacts. Vertical flow depends on high angle joint systems and fault zones that extend across the volcanic sequence. Fault zones can divert flows in directions at sharp angles to the regional flow directions. Porosity and permeability within individual flows can vary as a function of vesicularity, frequency and interconnection of joints and flow parallel parting. The result is that it is difficult to estimate flow rates and even flow directions, except in a general way, within the volcanics between tailings Dam No. 4 and the Red River.

Based on the depth-to-static-water level at MW-11, the unsaturated zone beneath Dam No. 4 is on the order of 190 feet thick. The obvious effect of a thick vadose zone would be to increase travel time for seepage water. However, for a conservative evaluation, the vadose zone is ignored and the tailings pond is assumed at the water table, it is possible to estimate the underflow in the volcanic unit using a mixing equation. Geocon (1983) estimated pond seepage rate to be between 0.5 to 1.5 cfs. The sulfate concentration of the seepage water is 840 mg/L and of the ground water at MW-11 is 78 mg/L. Using the more conservative seepage rate of 1.5 cfs and a conservative figure for ambient sulfate concentration based on Winograd (1959) of 20 mg/L, it is possible to solve for the underflow rate that would reduce the 840 mg/L concentration to 78 mg/L (Hem, 1970):

$$C_m = \frac{\sum_{1}^{n} C_n Q_n}{\sum_{1}^{n} Q_n}$$

where	C_m	=	sulfate concentration, in mg/L, of the river
	C_n	=	sulfate concentration, in mg/L, of tributary sources
	Q	=	flow rate, in cfs
	n	=	number of sample points

$$78 = \frac{(840)(1.5) + 20Q_2}{1.5 + Q_2}$$

$$1143 = 58Q_2$$

$$Q_2 = 19.7$$

The resulting rate is 19.7 cfs, which is between the 11.7 and 21.4 cfs underflow rates calculated by Dames and Moore (1987) in the Guadalupe Mountain study. However, the 19.7 cfs underflow appears to be too high when compared to the estimated 10 cfs/mile accretion from the volcanic aquifer to the Rio Grande between Cerro and the mouth of the Red River (Dames and Moore, 1986). Explanations for the sharp reduction in sulfate concentration south of Dam No. 4 include:

- The conservative vertical seepage rate of 1.5 cfs is too high. Using the lower estimated rate of 0.5 cfs, the underflow would be 5.9 cfs.
- There may be some attenuation of sulfate in the thick vadose zone.
- The sulfate concentration of the tailings water in storage below Dam No. 4 is less than the seepage outfall figure of 840 mg/L (combines Dam No. 1 and Dam No. 4 seepage).

T-3.2 IMPACT ON RED RIVER

Data from two U.S. Geological Survey stream gauges have been used to evaluate the impacts of tailings water on the Red River: one at the Ranger Station 1.5 miles east of Questa, and the other at the confluence of the Red River with the Rio Grande River—a separation of 8.1 miles. The section of the Red River that may be impacted by the tailings ponds is 1.84 miles (roughly from the 002 Outfall west to the area of the Fish Hatchery). Water levels for wells near the river are close to, but above, river level which indicates that the Red River is a gaining stream.

A number of attempts have been made to estimate accretions from tributary sources to segments of the river between the gauges (Wilson and Associates, 1978; Water Resources, 1987; Dames and Moore, 1987; and Vail, 1993). The different studies generally conclude that the net gain between Questa and the confluence is roughly 30 cfs. Vail (1993) provides the most recent and detailed set of estimates for tributary source discharges and their sulfate concentrations (see Figure T9 for sample locations and Table T3 for the water chemistry) to the Red River. For the area from the Big Springs Complex (which includes Questa Springs) eastward to the highway bridge over the Red River (the alluvial segment), the estimates are given below.

	Flow Rate (Q) (cfs)	Sulfate Concentration (C) (mg/L)
Cold springs from alluvium east of Red River Gorge		
piped to Fish Hatchery	2.7	80
directly to Red River	0.4	80
Field drainage (probably includes seepage from springs east of Big Springs)	2.76	240
002 Outfall (seepage from 001 and 002 barriers)	0.6	840

The estimated rate of flow for the Red River just upstream of the "alluvial" segment at the highway bridge is 46 cfs and the sulfate concentration is 119 mg/L. Using the estimates above, the calculation for mixing is:

$$C_m = \frac{\sum_1^n C_n Q_n}{\sum_1^n Q_n}$$

$$\frac{(46)(119) + 2.7(80) + 0.4(80) + 2.76(240) + 0.6(840)}{46 + 2.7 + 0.4 + 2.76 + 0.6} = 131.3$$

Based on this calculation, the tributary sulfate input to the Red River directly from the alluvial segment would be diluted to 131.3 mg/L sulfate. A water sample from the Red River taken 500 feet west of Big Springs Complex has a sulfate concentration of 138 mg/L.

Estimates for tributary sources along the north side of the Red River Gorge (from Big Springs Complex to the Fish Hatchery) are based on estimates of warm spring flow (the assumption, as noted earlier, is that warm water is derived from ground water moving through the volcanic pile).

	Flow Rate (Q) (cfs)	Sulfate Concentration (C) (mg/L)
Warm springs from volcanics directly to the river		
Warm springs potentially influenced by seepage	1.65	120
Warm springs not influenced by seepage	2.18	20

Adding the inflows from the alluvial segment between the highway bridge and the head of the gorge results in a flow to the upper portion of the gorge on the order of 52 cfs (assuming 138 mg/L sulfate for the Red River below Big Springs). Using the mixing equation and spring flows directly to the river:

$$C_m = \frac{\sum_{1}^{n} C_n Q_n}{\sum_{1}^{n} Q_n} = \frac{(138)(52)+(120)(1.65)+(2.18)(20)}{52+1.65+2.18} = 132.86$$

The sulfate is diluted to 132.86 mg/L. The two Red River samples measured in this segment of the river have sulfate concentrations of 126 and 129 mg/L.

Sulfate concentration in water samples collected from springs in the upper Red River Gorge are:

- 115 mg/L for Sample Location 12;
- 126 mg/L for Sample Location 14; and
- 20 mg/L for Sample Location 15.

The water temperatures for these springs were 15.3° C, 14.5° C, and 16.4° C, respectively. Red River water in the same area has a temperature of 10.3 to 11.2 °C. The spring temperatures seem to indicate that the springs' source is ground water that is derived from the volcanic pile and not river water recharged to the volcanic aquifer near Pope Lake. The question here is: since the springs are down-gradient from MW-11 (near the toe of Dam No. 4, sulfate concentration 78 mg/L), how can the springs have a higher sulfate concentration? There are at least two possible answers to this question:

1) There was an earlier pulse of seepage water that had higher sulfate than presently measured such that the spring samples represent older water than MW-11.

2) There is some iron-sulfide in the basalt that oxidizes in the vadose zone and releases some sulfate to the ground water. The spring at Sampling Location 14 is located on the south side of the Red River and it has a sulfate concentration of 126 mg/L. It could be possible that localized iron sulfide mineralization in the fracture volcanics on both sides of the river is supplying sulfate.

Ground water in the regional volcanic aquifer flows to the southwest beneath the tailings ponds. The deeper part of the system (with low sulfate concentrations) probably flows beneath the river (underflow). The shallower part discharges to the river at some point below the head of the gorge (near Pope Lake) and upstream of the Fish Hatchery. Some portion of this shallow system may extend south of the river and is exhibited in the spring chemistry. The sulfate at Sampling Location 14 could have a north side source (tailings pond or local mineralization).

The spring at Sampling Location 15 has a very low sulfate concentration (20 mg/L). It is possible that the higher sulfate springs are discharging water that lies close to the water table and that the water at Station 15 comes from a deeper source.

T-4 ADDITIONAL PLANS FOR SEEPAGE CONTROL

The major cause for the high TDS and sulfate levels in the shallow private wells south of the Molycorp property is seepage of tailings pond leachate through the alluvial deposits of the Santa Fe Formation into the shallow ground water (partially perched) south of Dam No. 1. To address this issue, three (3) extraction wells will be drilled into the Santa Fe Formation and one (1) into the volcanic unit (Figure T11). In addition, Seepage Barriers 001 and 002 will be extended, and the utility of an additional barrier north of MW-2 to collect UAU seepage will be evaluated.

TAILINGS POND AREA
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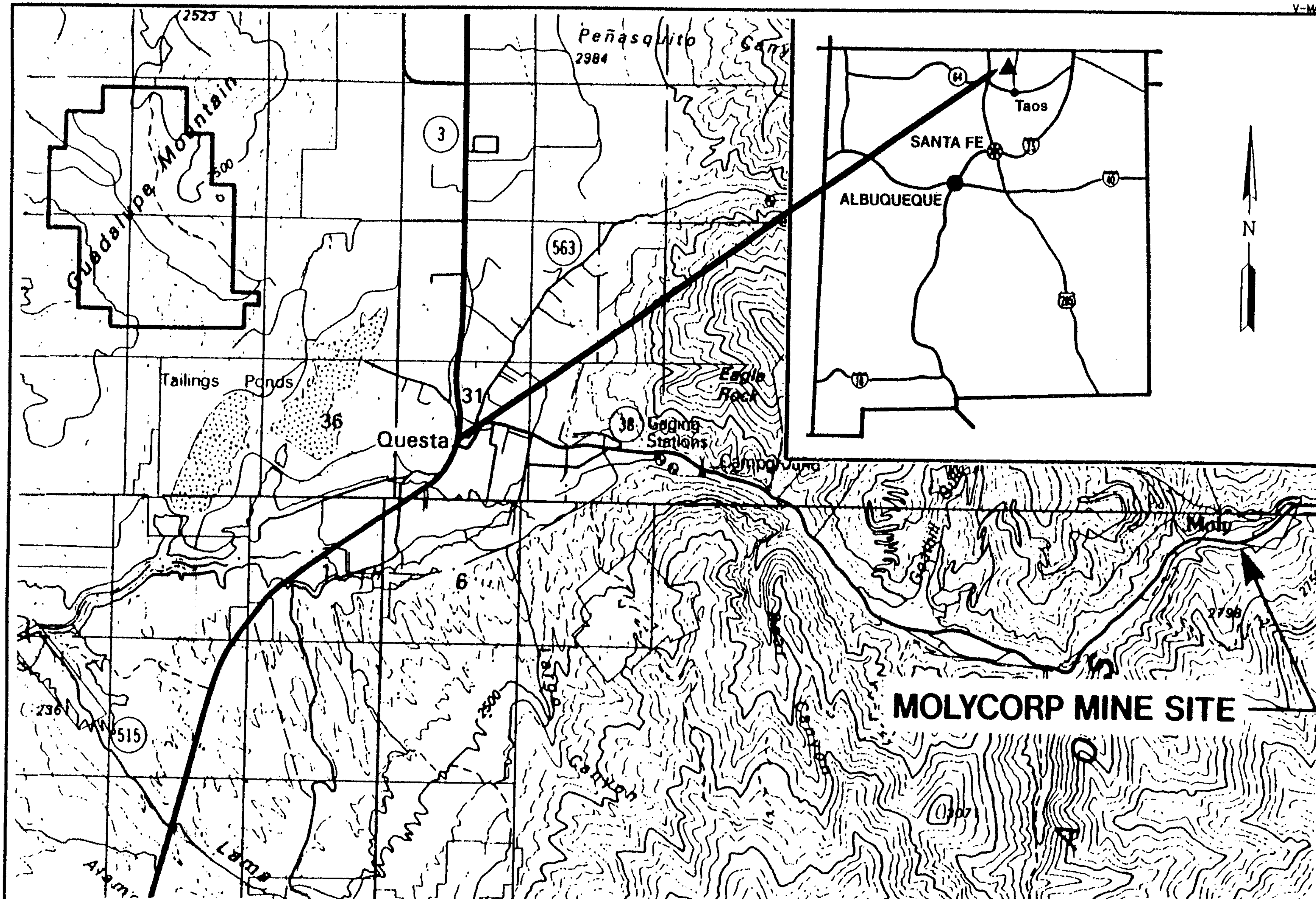
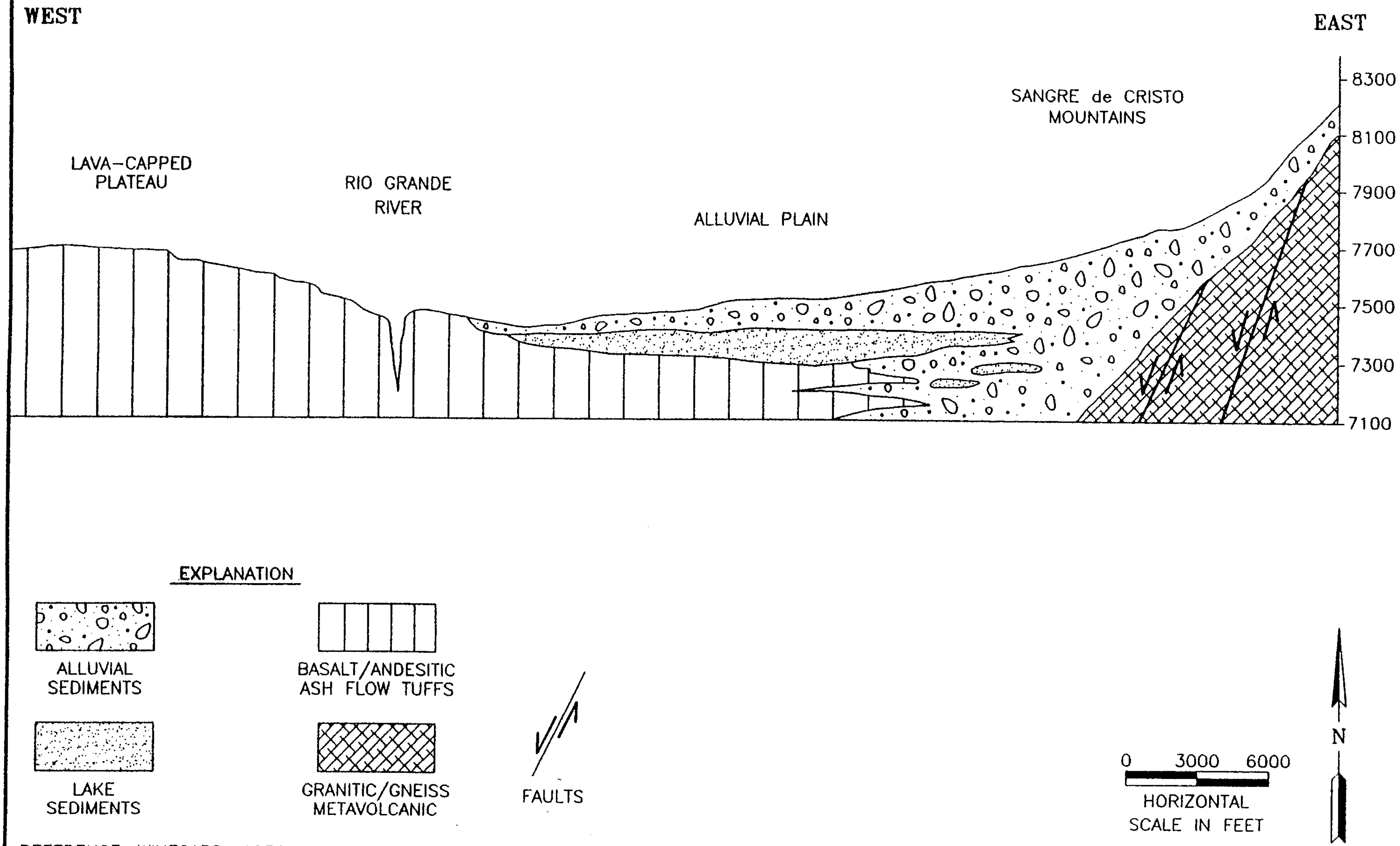


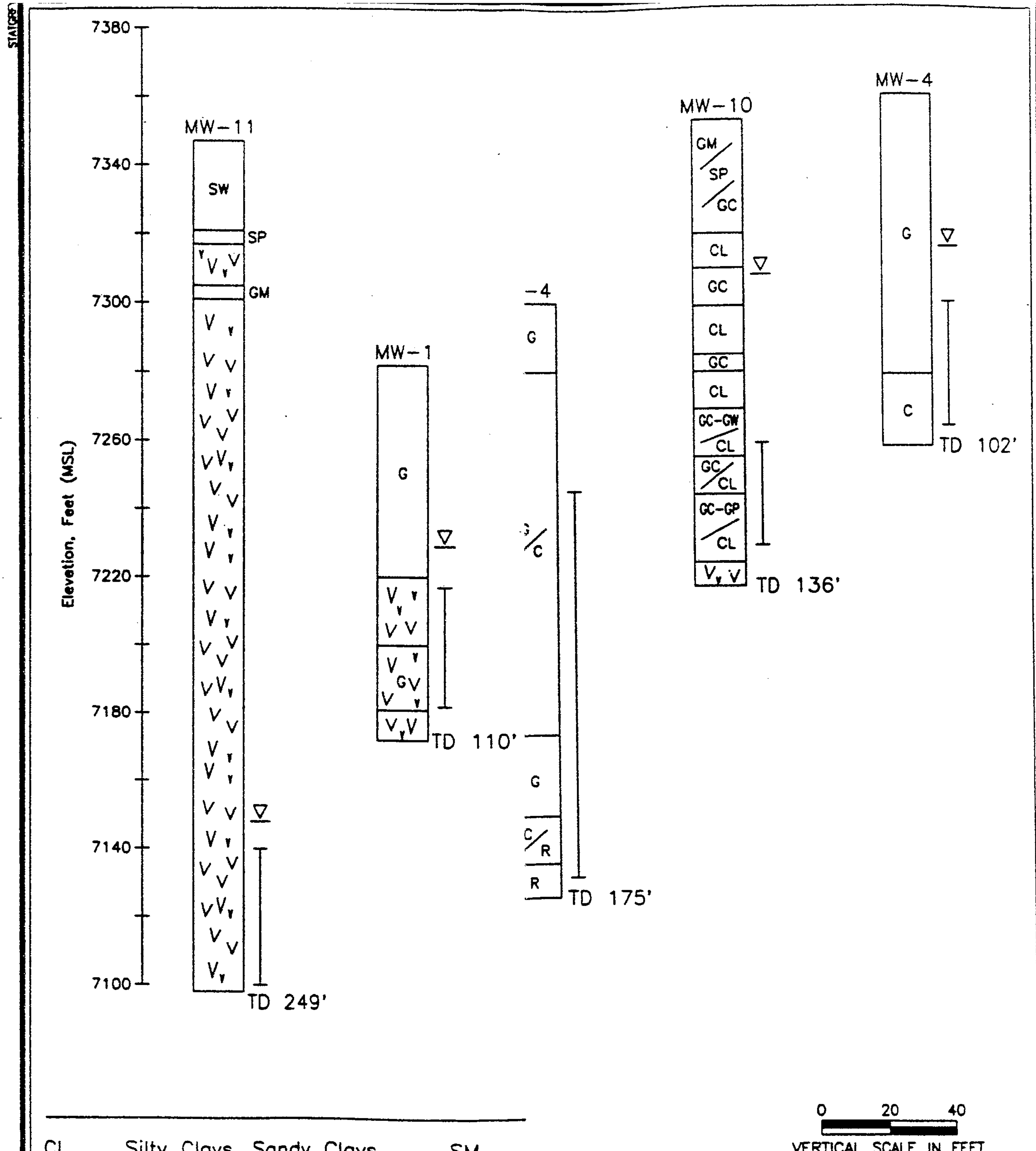
FIGURE: T1	SOUTH PASS RESOURCES, Inc.				LOCATION MAP Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

GENERALIZED GEOLOGIC CROSS-SECTION
SUNSHINE VALLEY, TAOS COUNTY NEW MEXICO



REFERENCE: WINEGARD, 1959.

FIGURE: T2	SOUTH PASS RESOURCES, Inc.				GENERALIZED GEOLOGIC CROSS-SECTION Molycorp , Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

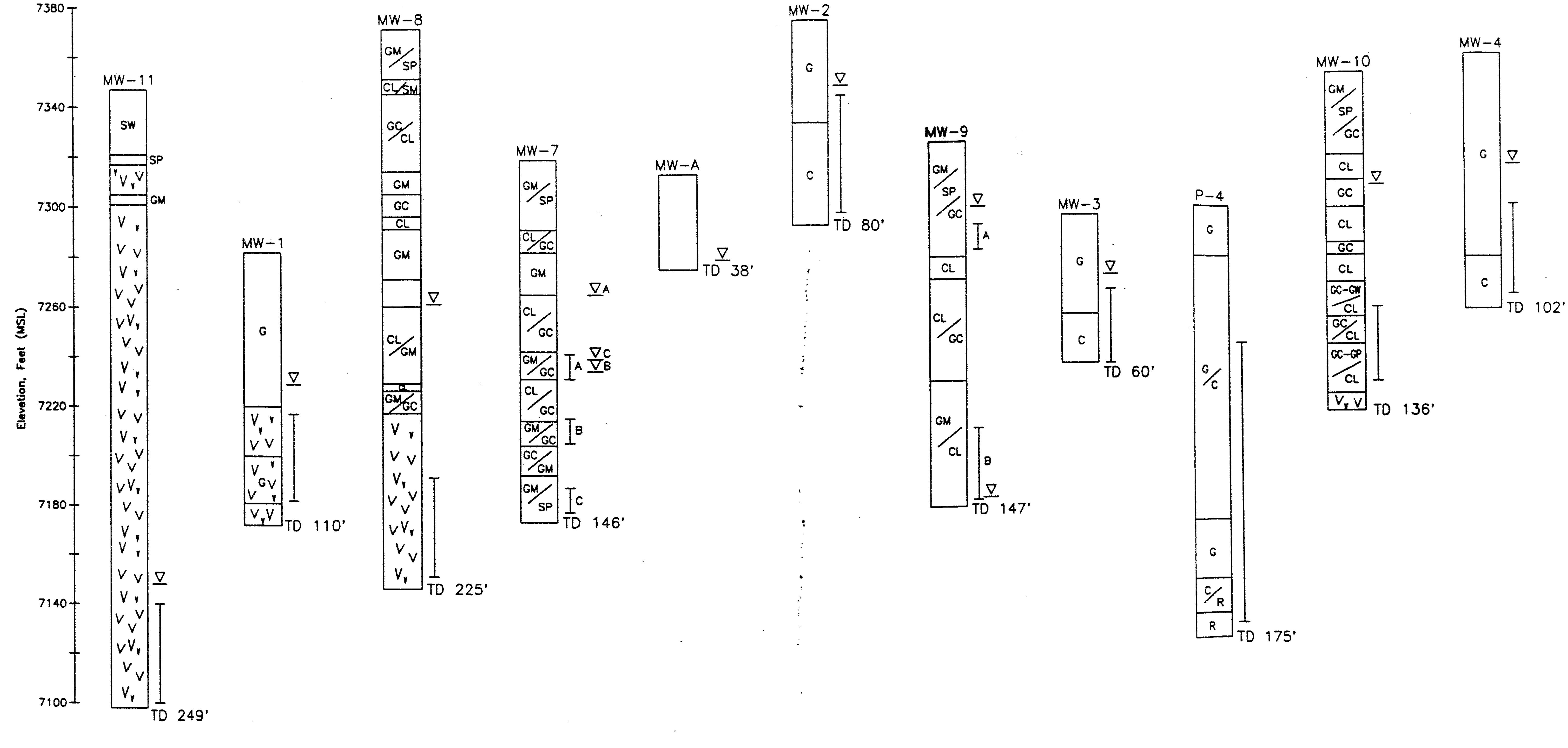


CL	Silty Clays, Sandy Clays Gravelly Clays	SM
		SP
GC	Clayey Gravel	
GM	Sandy Gravel	SW
GP	Poorly Graded Gravels (narrow size range) less than 5% Fines	GM/CL
GW	Well Graded Gravels (wide range if sizes) less than 5% Fines	V

BOREHOLE STATIGRAPHY
TAILINGS PONDS AREA
Molycorp, Inc.
Questa, New Mexico

SOUTH PASS RESOURCES, Inc.

PROJECT NO.:	DATE:	AUTHOR:	DRAWN BY:	FIGURE:
001-03	6/13/94		M.O'M.	T3



LEGEND

- CL — Silty Clays, Sandy Clays Gravelly Clays
- GC — Clayey Gravel
- GM — Sandy Gravel
- GP — Poorly Graded Gravels (narrow size range) less than 5% Fines
- GW — Well Graded Gravels (wide range if sizes) less than 5% Fines
- SM — Silty Sand
- SP — Gravelly Sand to Poorly Graded Sand
- SW — Well-Graded Sand
- GM/CL — Unit with Interbedded Sandy Gravel and Gravelly Clay and/or Clay (top unit more abundant)
- V — Volcanic Unit
- C — Clay (1979 well)
- G — Gravel (1979 well)
- R — Rock, possible Volcanic Unit
- MW-11 — Monitor Well
- P-4 — Private Well, 1964 no current water level
- ∇ — Water Level
- I — Position of Well Screen Letter refers to a Piezometer in a Multiple-Completion Well

BOREHOLE STATIGRAPHY TAILINGS PONDS AREA

Molycorp, Inc.
Questa, New Mexico

SOUTH PASS RESOURCES, Inc.

PROJECT NO.:	DATE:	AUTHOR:	DRAWN BY:	FIGURE:
001-03	6/13/94		M.O'M.	T3

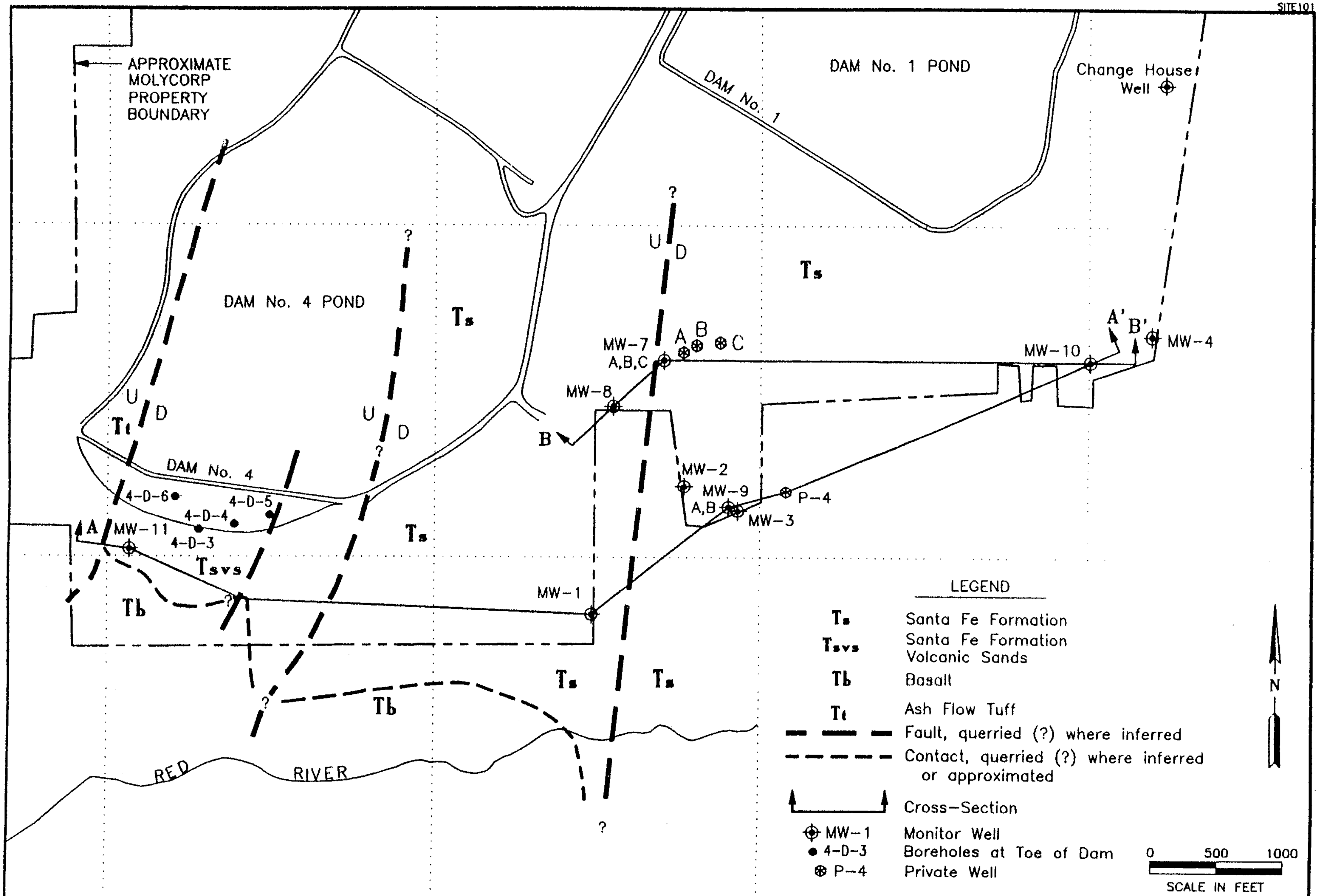


FIGURE: T4	SOUTH PASS RESOURCES, Inc.				GEOLOGIC MAP – TAILINGS PONDS AREA Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

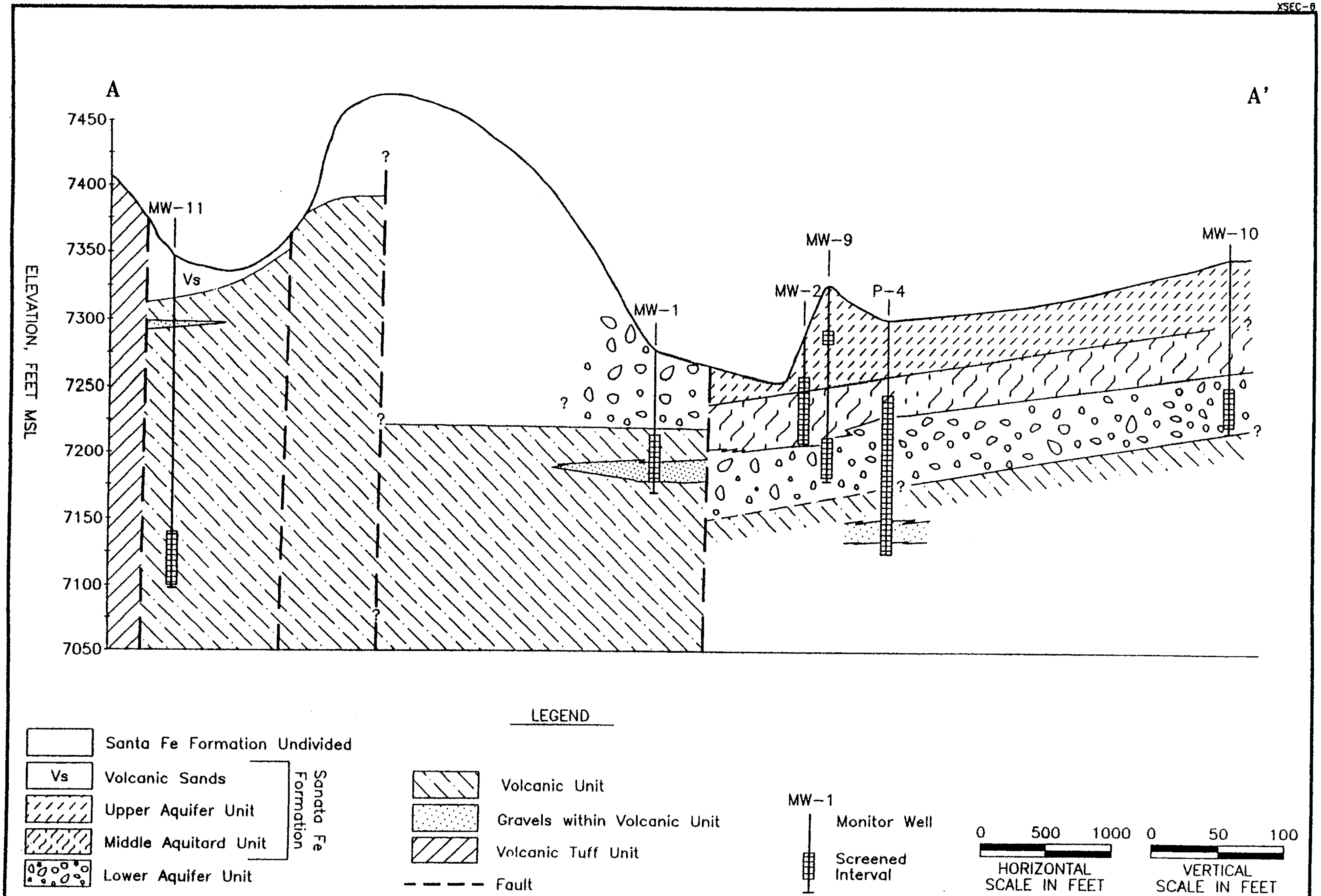


FIGURE: T5	SOUTH PASS RESOURCES, Inc.				GEOLOGIC CROSS-SECTION A – A' Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

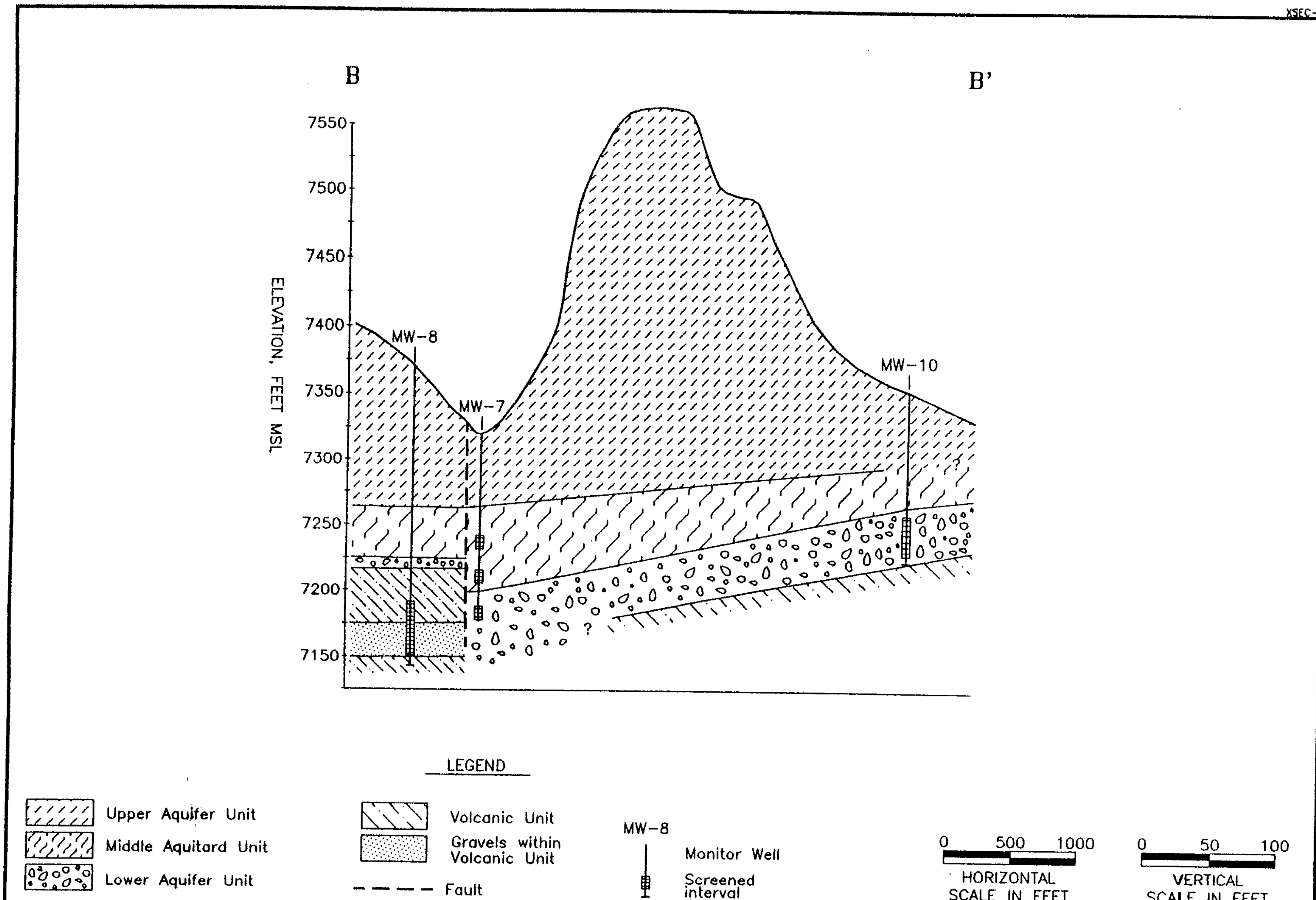


FIGURE: T6	SOUTH PASS RESOURCES, Inc.				GEOLOGIC CROSS-SECTION B – B'
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico

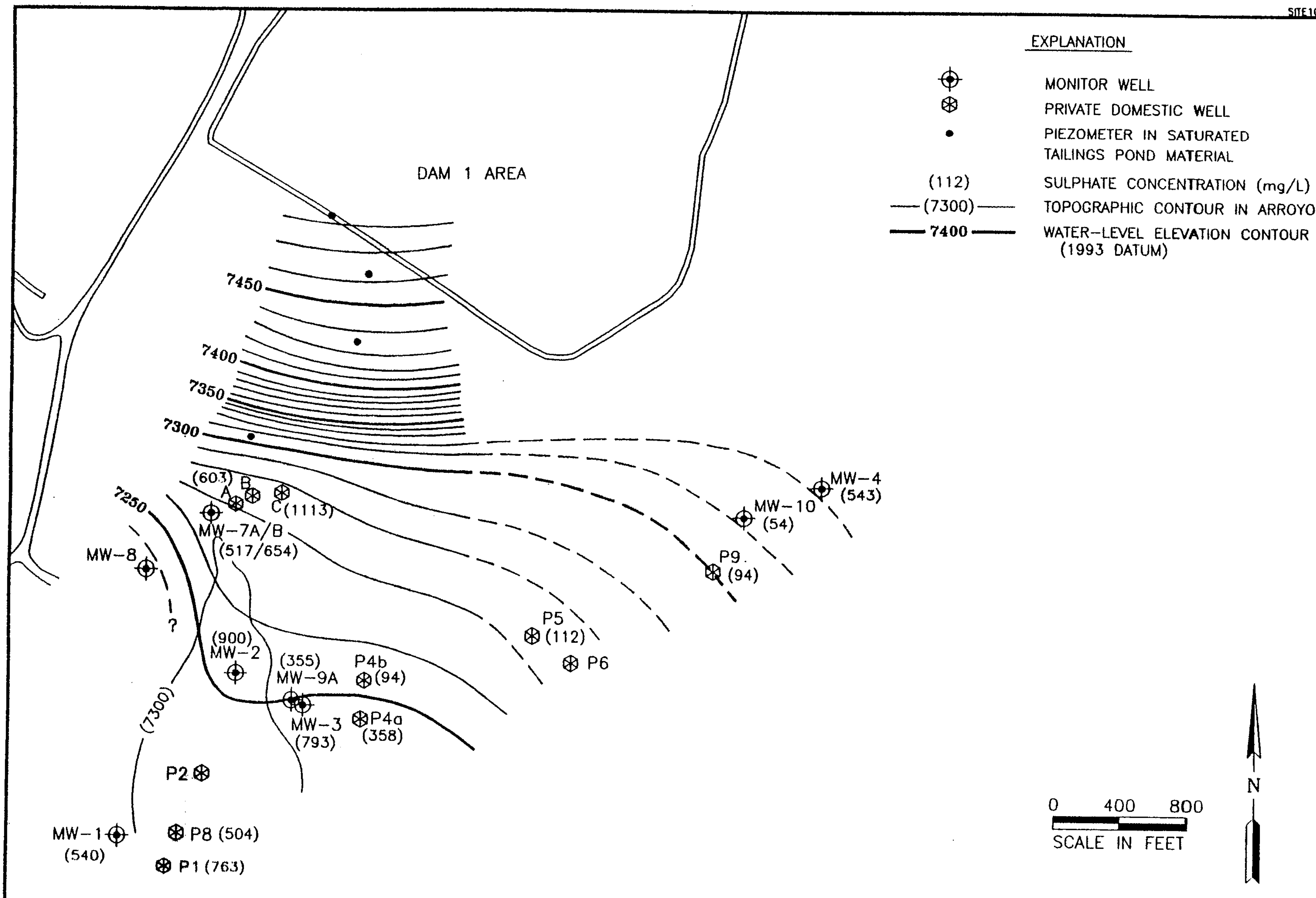
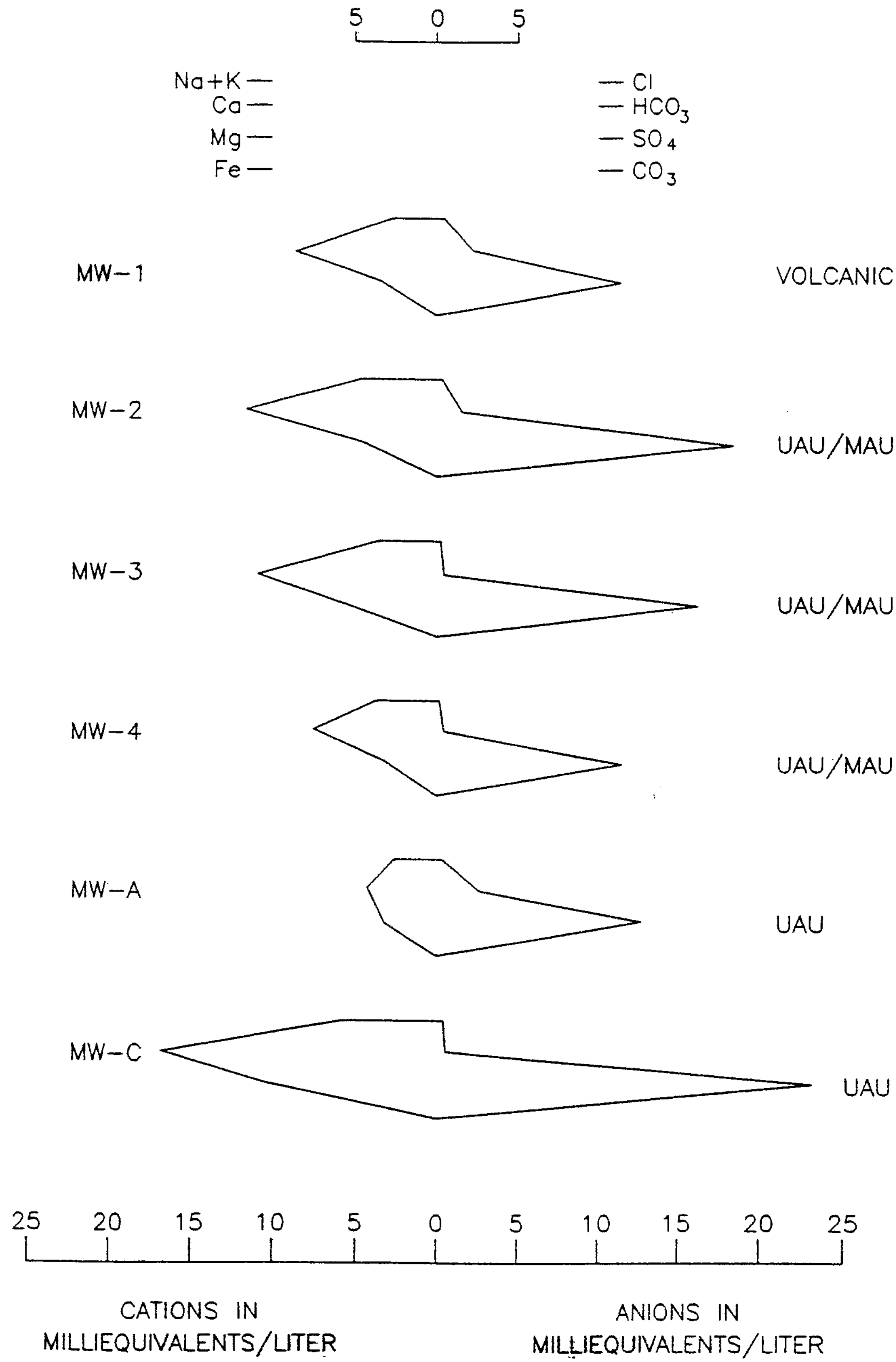
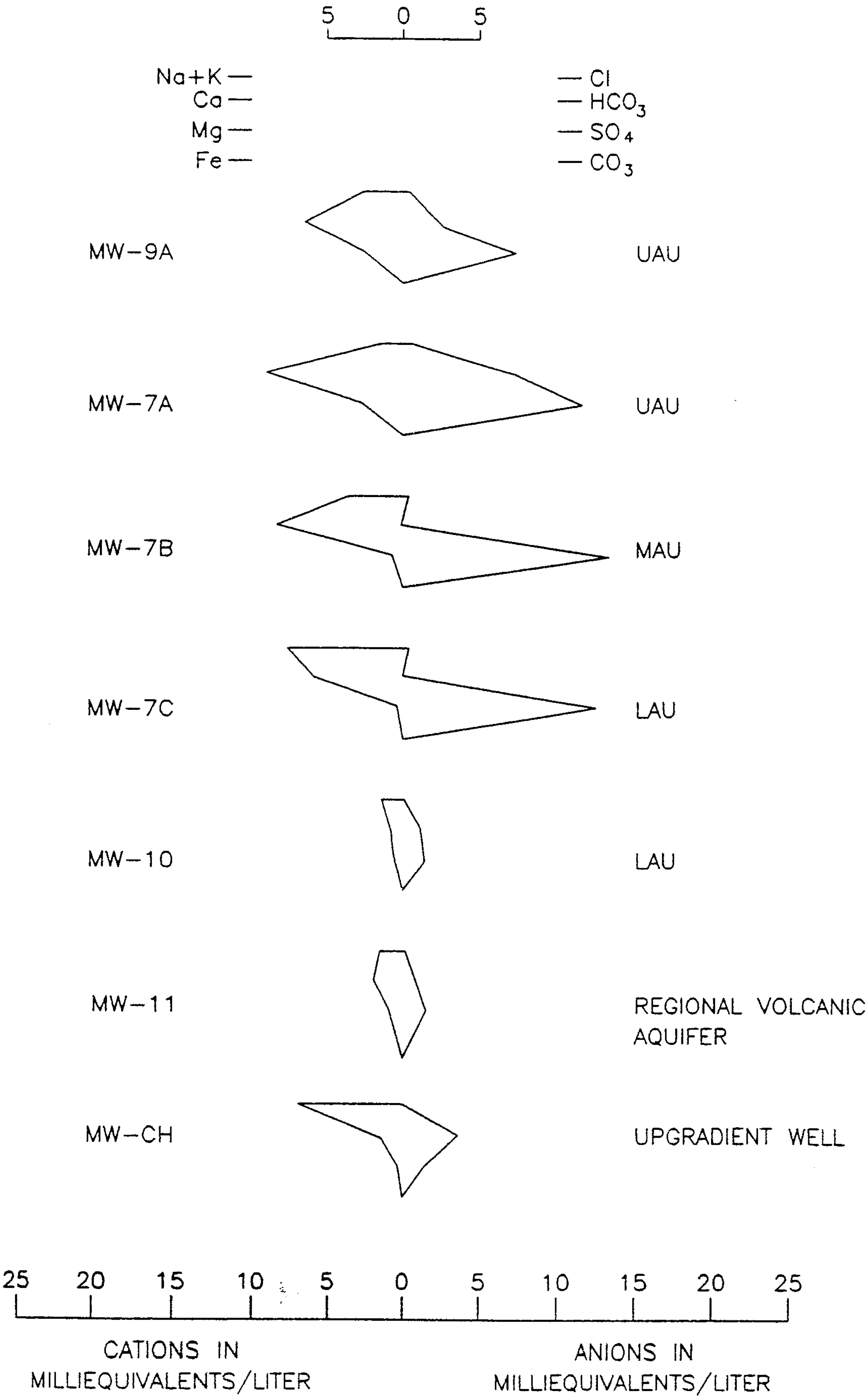


FIGURE: T7	SOUTH PASS RESOURCES, Inc.				WATER-LEVEL RELATIONSHIPS Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	



SOUTH PASS RESOURCES, Inc.				STIFF DIAGRAMS Molycorp, Inc. Questa, New Mexico	FIGURE: T8
PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.		



SOUTH PASS RESOURCES, Inc.				STIFF DIAGRAMS Molycorp, Inc. Questa, New Mexico	FIGURE: T8a
PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.		

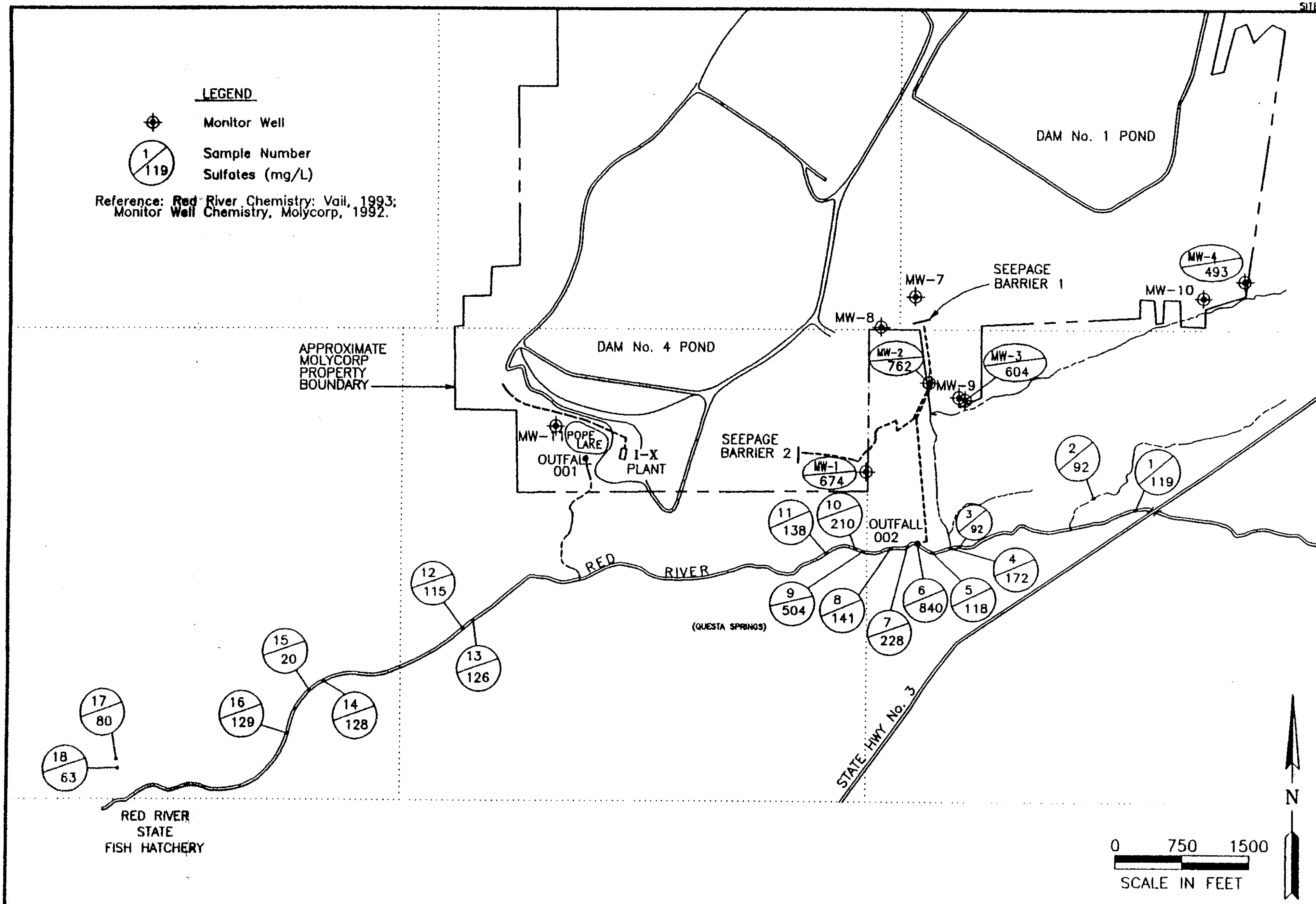
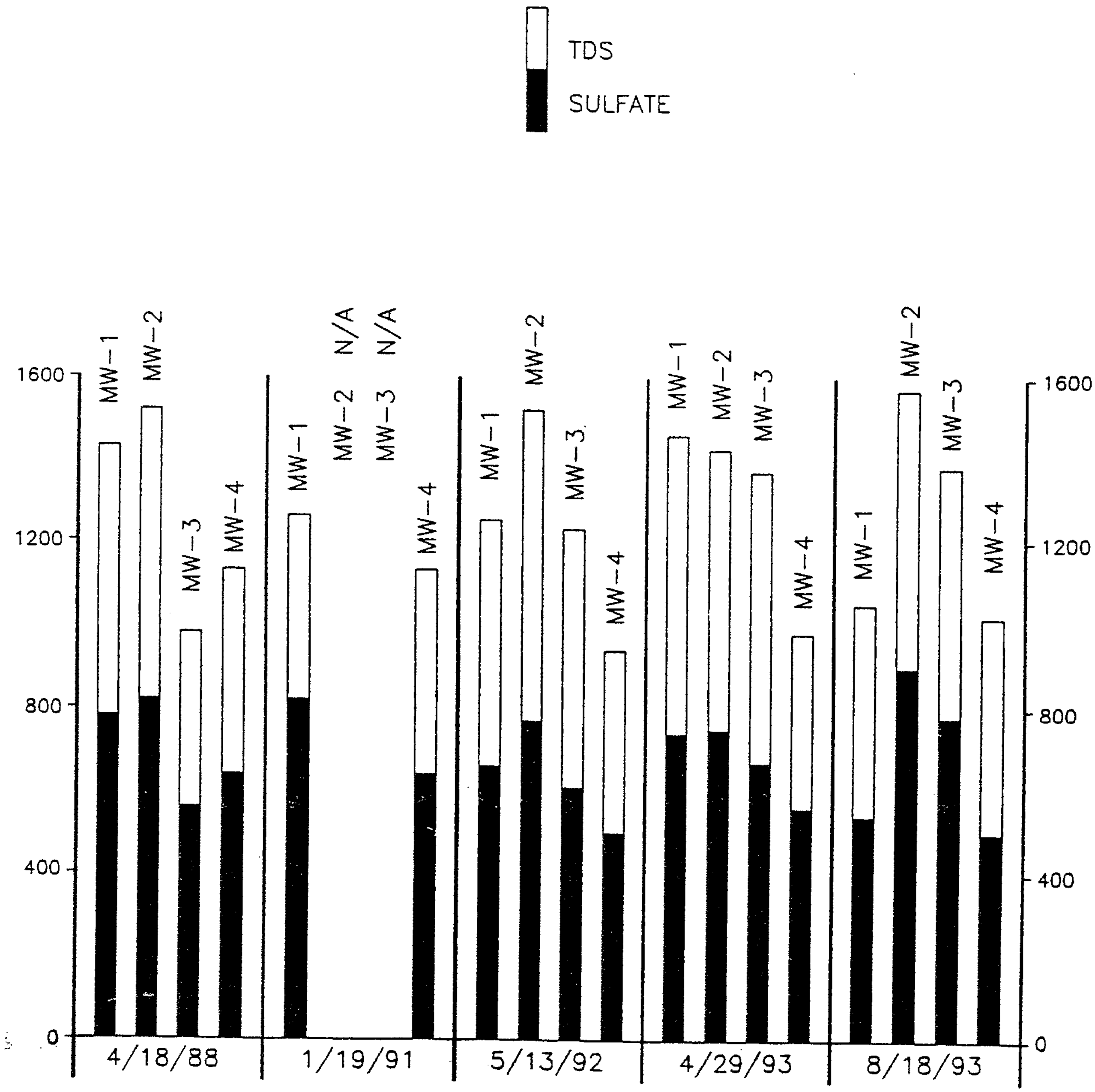


FIGURE: T9	SOUTH PASS RESOURCES, Inc.				WATER QUALITY SURVEY: MONITOR WELLS & RED RIVER Molycorp, Inc. Questa, New Nexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

HISTOGRAMS
OF MONITOR WELL CHEMISRTY
TAILINGS PONDS AREA



SOUTH PASS RESOURCES, Inc.				HISTOGRAMS-MONITOR WELL CHEMISTRY	FIGURE:
PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico	T10

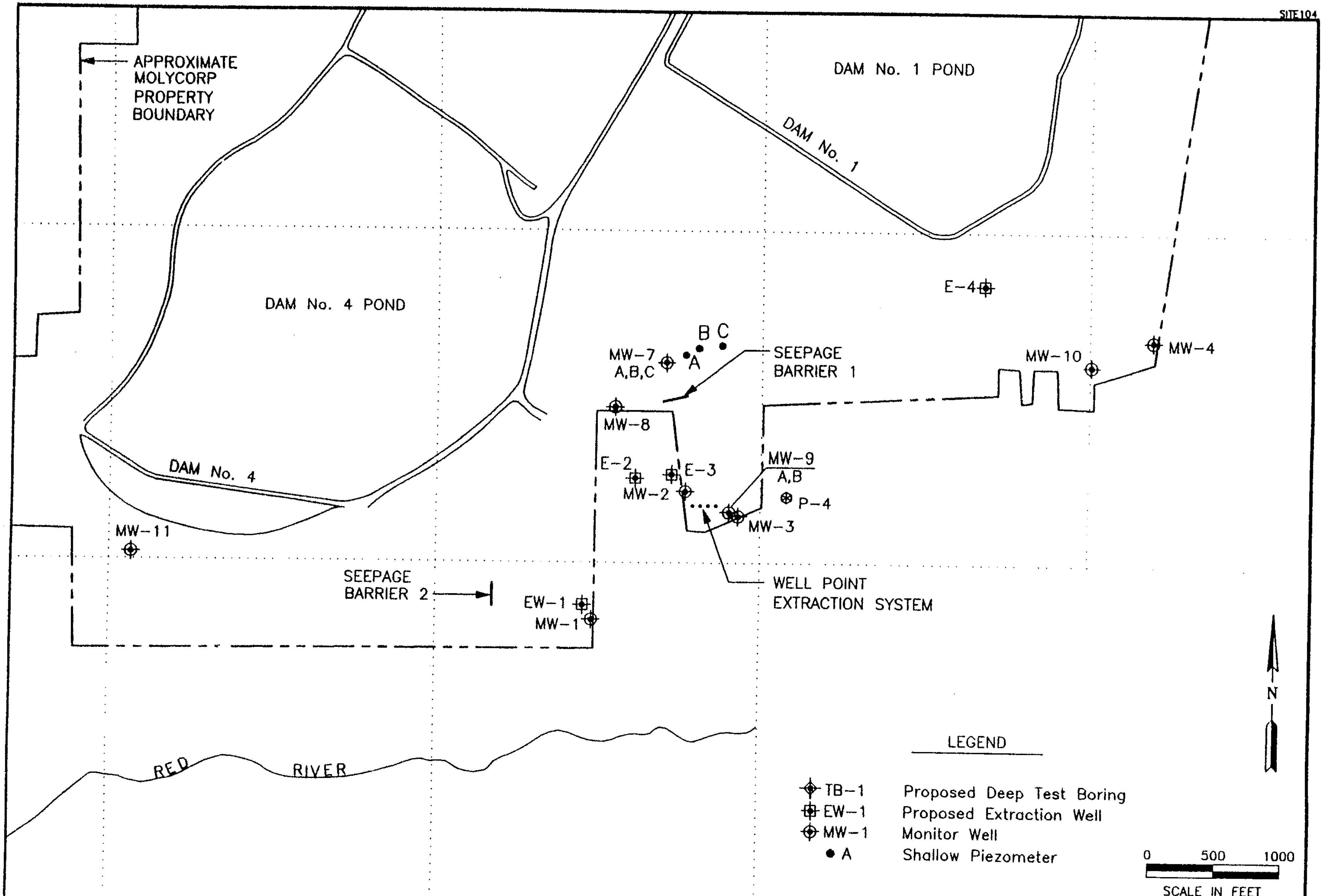


FIGURE:	SOUTH PASS RESOURCES, Inc.				EXTRACTION SYSTEM – TAILINGS PONDS AREA
T11	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico

TABLE M3
WATER CHEMISTRY: RED RIVER DRAINAGE STUDY
(Concentrations in mg/L)
(page 1 of 2)

NOTE: SEE FIGURE M8 FOR SAMPLE LOCATIONS

	#1	#6	#7	#8A	#10	#10A	#10B	#11A	#12	#13	#14	#16
pH	7.70	7.62	7.46	7.54	7.40	7.50	7.10	7.00	7.15	7.20	6.95	6.90
TDS	132	204	250	250	298	254	288	308	316	334	334	352
Sulfate	13	74	103	106	144	93	144	148	151	162	162	171
Fluoride	0.12	0.33	0.43	0.60	0.90	0.75	1.20	1.30	1.40	1.30	1.50	1.60
Alkalinity	91	61	54	54	49	56	46	47	46	44	40	25
Aluminum *	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Aluminum **	1.30	5.00	2.00	2.00	2.00	1.70	3.30	2.50	3.30	3.70	4.30	7.60
Iron	0.225	0.63	0.48	0.60	1.02	0.345	1.440	0.330	1.590	0.240	1.260	0.36
Copper	<0.01	0.105	0.057	0.065	0.016	<0.01	<0.01	<0.01	0.049	0.010	0.122	0.016
Zinc	0.011	0.046	0.107	0.101	0.128	0.101	0.218	0.191	0.181	0.191	0.239	0.355
Manganese	<0.01	0.29	0.36	0.32	0.43	0.32	0.99	0.85	0.85	0.88	1.11	1.68
Lead	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

* - Dissolved
** - Suspended

TABLE M3
WATER CHEMISTRY: RED RIVER DRAINAGE STUDY
(Concentrations in mg/L)
(page 2 of 2)

NOTE: SEE FIGURE M8 FOR SAMPLE LOCATIONS

	Old Adit (Prado)	Portal Springs #1	Portal Springs #2	Portal Springs #2A	Cabin Springs	Spring at Capulin	Portal Springs: Culvert Discharge	Spring above Sample Point #14	Sulpher Gulch Spring
pH	7.90	7.50	4.80	4.94	5.20	3.40	4.90	4.00	6.00
TDS	3,694	382	1,434	956	1950	2206	1254	1450	540
Sulfate	1255	181	788	634	978	1276	551	756	260
Fluoride	4	1	11.4	10	14	5	14	4.0	2.10
Alkalinity	250	41	0	0	0	0	0	0	22
Aluminum *	<0.50	<0.50	19.40	10.90	30.40	107	11.50	61.70	1.50
Aluminum **	2.30	1.80	0.60	7.00	6.60	43	22.40	1.00	8.80
Iron	0.032	0.420	0.315	2.40	0.063	35.90	2.80	0.210	2.00
Copper	0.075	0.015	0.270	0.135	0.405	1.170	0.450	0.825	0.075
Zinc	5.220	0.119	2.00	1.30	3.50	4.40	2.30	6.80	0.518
Manganese	7.00	0.15	10.60	4.70	18.10	15.20	4.70	25.50	0.54
Lead	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium	<0.005	<0.005	0.019	0.016	0.019	0.016	0.016	0.028	<0.005
Molybdenum	<0.10	0.153	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

* - Dissolved
** - Suspended

APPENDIX A

WATER TABLE CONFIGURATION

The accretion studies were made under base flow conditions which means, because accretion occurs along the entire stretch of the Red River included in the study, groundwater flows directly to the river. Therefore, the river can be classified as a gaining stream. Where water-level elevation contours cross a gaining stream, the contours point or "V" in an up stream direction. This is because the river as the lowest topographic element in the drainage basin intersects the water table resulting in any particular contour extending from that point on the river in a downstream direction, but flaring out at some angle beneath the floodplain or bedrock valley walls in this case.

There are limiting angular positions for these contours with respect to the river channel. These positions range from a contour normal to the river channel (i.e., "normal contour pattern") to an acute angle configuration in which the contours are nearly parallel to the channel and the acute angle points up stream (i.e.,"acute contour pattern") as illustrated in Plate 1. One elevation for any of these contours is fixed by elevations along the river channel.

The "normal" configuration was drawn by simply extending a series of parallel contours from their respective elevations along the river. The "acute"pattern was drawn by connecting the appropriate elevation of the Red River with a corresponding elevation on the deepest and farthest down gradient tributary gulch (Goat Hill Gulch) in the mine drainage area. This represents an extreme configuration because if it existed there would be natural springs along the bottom of the gulch wherever the water table was intersected.

The absence of such springs indicates the water table is deeper than the bottom of Goat Hill Gulch, but for the purpose of indicating a maximum condition this configuration will be used. To test these two extreme configurations water level contours can be evaluated based on existing information on water levels drawn in this case from dewatering information associated with the mining operations.

TABLE T1
MONITOR WELL CHEMISTRY

Aug 18, 1993

Boring or Monitor Well No.	MW-A	MW-C	MW-1	MW-2	MW-3	MW-4	MW-6	MW-7A	MW-7B	MW-7C	MW-9A	MW-10	MW-11	CH
pH	7.4	7.2	7.9	7.7	7.4	7.3	NA	7.1	8.9	10.6	7.6	8.1	8.1	7.7
TDS	1115	1940	1051	1553	1393	1021	398	1046	1220	990	759	191	267	305
Sulfate	603	1113	540	900	793	543	58	571	651	613	355	54	78	57
Sodium	58	117	56	102	72	86	NA	41	80	81	47	36	32	98
Potassium	2.4	6.5	3.5	4.7	3.5	1.4	NA	1.9	<1.0	157	1.3	1.8	3.1	117
Calcium	189	339	169	231	219	155	NA	185	163	119	130	18	34	30
Magnesium	38	61	39	52	48	38	NA	36	3.1	<1	26	3.3	11	6.0
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Aluminum	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA	<0.001	<0.001	0.034	<0.001	0.002	0.001	0.003
Lead	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.1	<0.002	<0.002	0.006	<0.002	<0.002	<0.002	<0.002
Molybdenum	0.50	2.8	0.08	1.8	<0.005	0.21	<0.02	0.04	<0.005	<0.005	0.02	0.02	0.09	<0.005
Iron	0.20	0.05	0.06	0.06	0.03	0.05	<0.1	<0.02	<0.02	0.03	<0.02	0.03	<0.02	<0.02
Manganese	0.05	2.6	0.03	0.58	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	1.2	<0.01	0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.00	0.00	0.014	0.00	0.00	0.00	0.01	0.03	0.20	0.008	0.12	0.038	0.014	0.007
Carbonate Alkalinity	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	<1.0	10	24	<1.0	<1.0	<1.0	<1.0
Bicarbonate Alkalinity	156	18	148	116	17	18	NA	134	<1	<1	169	66	81	187
Hydroxide Alkalinity	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	<1.0	3.0	300	<1.0	<1.0	<1.0	<1.0
Fluoride	0.37	2.8	0.34	0.92	0.45	0.71	1.0	0.25	0.19	0.78	0.16	0.65	0.66	1.20

TABLE T2
PRIVATE WELL CHEMISTRY

Aug 18, 1993

Well #	P-1	P-2	P-3	P-4A	P-4B	P-5	P-6	P-7	P-8	P-9
DATE	1988	1979	1979	1987	1993	1993	1987	1975	1987	1993
Bicarbonate Alkalinity	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Carbonate Alkalinity	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hydroxide Alkalinity	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	<0.01	NA	NA	<0.01	<0.005	<0.005	<0.1	NA	<0.001	<0.005
Calcium	246	NA	NA	128	NA	NA	37	NA	212	NA
Chlorine	21	NA	NA	NA	NA	NA	<5.0	NA	18	NA
Chromium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	<0.01	NA	NA	0.005	0.01	<0.01	NA	NA	<0.1	0.01
Fluoride	0.40	0.50	0.50	NA	0.45	0.42	NA	NA	NA	0.7
Iron	<0.05	0.39	0.13	0.1	<0.05	0.08	<0.1	0.07	<0.1	0.12
Lead	<0.05	NA	NA	<0.05	<0.1	<0.10	<0.1	NA	<0.01	<0.1
Magnesium	39	NA	NA	17	NA	NA	3.0	NA	22	NA
Manganese	0.01	0.0	0.02	NA	<0.01	<0.01	<0.05	NA	<0.05	0.143
Molybdenum	0.07	0.0	NA	0.0	<0.005	<0.005	<0.1	2.27	<0.1	<0.005
Potassium	3.0	NA	NA	1.0	NA	NA	4.0	NA	2.0	NA
Redox Pot.	NA	NA	NA	27	NA	NA	NA	NA	NA	NA
Sodium	58	NA	NA	79	NA	NA	9.0	NA	41	NA
Sulfate	763	228	44	358	97	112	32	NA	504	94
TDS	1376	619	345	772	398	276	186	NA	982	270
Zinc	0.08	2.45	0.01	0.64	0.89	0.21	<0.1	NA	<0.1	0.08
pH	7.8	7.4	7.7	7.0	7.5	7.7	7.7	NA	7.1	7.3

KEY TO TABLE T3
LOCATIONS OF WATER SAMPLES

#1	Red River below Highway 38 bridge.
#2	Spring on north side of Red River
#3	Field Drainage to Red River, 500 feet east of Outfall 002
#4	Field Drainage to Red River, 450 feet east of Outfall 002
#5	Red River 300 feet east of Outfall 002
#6	Outfall No. 002
#7	Field Drainage 75 feet west of Outfall 002
#8	Red River above Questa Springs
#9	Near Questa Springs, southeast of concrete box
#10	Near Questa Springs, end of old pipe
#11	Red River 500 feet west of Questa Springs
#12	Spring, north side of Red River Station 47+20
#13	Red River Station 47+70, above Hatchery
#14	Spring south side of Red River Station 36+80
#15	Spring north side of Red River Station 36+40
#16	Red River
#17	Hatchery; cold water inlet
#18	Hatchery; warm water inlet

TABLE T3
WATER QUALITY SURVEY ALONG THE RED RIVER
(page 1 of 2)

Sample Location Number	#1	#2	#3	#4	#5	#6	#7	#8	#9
Total Alkalinity	38	90	99	94	43	152	165	50	158
Dissolved Aluminum	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Suspended Aluminum	7.8	0.50	<0.50	<0.50	8.0	<0.5	2.7	6.2	8.5
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Copper	0.036	0.007	<0.005	0.008	0.028	<0.005	0.009	0.029	0.016
Fluoride	0.84	0.55	0.60	0.46	0.90	1.90	0.80	0.88	0.38
Iron	0.594	0.543	0.405	0.115	0.569	0.102	1.09	0.573	2.94
Lead	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Manganese	0.92	0.02	0.05	0.05	0.88	1.40	0.03	0.88	0.07
Molybdenum	<0.03	<0.03	0.20	<0.03	<0.03	1.80	0.20	<0.03	<0.03
Total Dissolved Solids	255	247	246	648	240	1764	727	268	1094
Total Suspended Solids	31	20	7.0	6.0	22	2.0	39	21	88
Sulfate	119	92	92	172	118	840	228	141	504
Zinc	0.250	0.021	0.047	0.012	0.222	0.010	0.017	0.207	0.047
Temprature °C	8.3	10.5	11.2	17.8	9.1	9.7	10.1	9.8	7.8
pH	7.23	6.76	7.44	8.22	7.60	7.26	7.20	7.14	7.02

NA - NOT AVALIABLE

TABLE T3
WATER QUALITY SURVEY ALONG THE RED RIVER
(page 2 of 2)

Sample Location Number	#10	#11	#12	#13	#14	#15	#16	#17	#18
Total Alkalinity	177	54	82	51	82	80	49	43	77
Dissolved Aluminum	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Suspended Aluminum	<0.5	3.1	1.7	3.0	<0.50	<0.50	3.1	<0.50	<0.50
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Copper	0.005	0.033	0.011	0.026	<0.005	<0.005	0.024	<0.005	<0.005
Fluoride	0.60	0.90	0.80	0.90	0.80	1.10	0.90	0.64	0.54
Iron	<0.05	0.618	2.36	0.590	<0.05	<0.05	0.527	0.138	0.181
Lead	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Manganese	0.01	0.88	0.13	0.83	0.01	NA	0.781	NA	NA
Molybdenum	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Total Dissolved Solids	576	269	271	259	304	145	247	176	284
Total Suspended Solids	7.0	22	47	22	<1.0	<1.0	24	NA	NA
Sulfate	210	138	115	128	126	20	129	80	63
Zinc	0.010	0.215	0.046	0.206	0.005	<0.005	0.191	<0.005	0.010
Temprature °C	7.1	10.3	15.3	10.5	16.9	16.4	11	8.3	15.8
pH	7.50	7.45	6.94	7.45	8.14	7.26	7.8	7.14	7.87

NA - NOT AVALIABLE

Q	=	355,449.6 gallons/day = 0.55 cfs
A	=	300,000 $feet^2$
i	=	0.036 foot/foot

The calculation gives an estimated hydraulic conductivity (K) of 33 gallons/day/ft^2. If the estimated value for K is substituted in the seepage velocity formula, the resulting velocity is 1.58 feet/day. The higher K value results in a travel time of 6.06 years from the caved area to the river. In summary, the two different approaches to travel time indicate that mine water in the caved area, after the water table stabilizes, could reach the river in a time period ranging from 6.06 to 19.97 years. Adding the time (approximately 1 year from May 1994) that it would take for the water table to stabilize, mine water could reach the Red River from the caved area between 7.06 to 20.57 years.

where:	V	=	seepage velocity, in feet/day;
	K	=	hydraulic conductivity, in gallons/day/square foot;
	i	=	hydraulic gradient, in feet/feet;
	n_e	=	porosity, as a percent; and
	7.48	=	gallons per cubic foot.

The hydraulic gradient (0.036 ft/ft) and the down-gradient distance to the river from the caved area (3,500 feet) are based on the "normal" water-table configuration map (Figure M6). Seepage velocity was estimated by using a hydraulic conductivity equal to 10 gallons/day/ft^2 and a porosity of 10 percent. These values are in the mid- to upper-range of values for fractured igneous and metamorphic rocks and in the lower range for permeable basalt. The resulting seepage velocity is 0.48 foot/day and the travel time from the caved area to the river is 19.97 years. High-angle faults that cut across the structure of the mineralized zone and the low-angle north- and west-dipping faults may represent preferential pathways for flow to the river at rates less than the calculation indicates. However, without field data based on tracer tests applied to the local fracture system, estimates of seepage velocity and travel time calculated from formulas *derived from granular or matrix flow* may not be completely accurate.

Another approach to estimating hydraulic conductivity and travel time is to use the dewatering rate for the mine, 0.55 cfs, as the quantity of water that could be available for recharge to the river from the underground mine area. Using the following equation for discharge, it is possible to estimate the hydraulic conductivity:

$$Q=KiA$$

where	Q	=	discharge (recharge to river), in gallons/day;
	K	=	hydraulic conductivity, in gallons/day/square foot;
	A	=	cross-sectional area, in square feet; and
	i	=	hydraulic gradient, in feet/feet.

To calculate a cross-sectional area, it is assumed that the springs just above river level and any water that moves up along low-angle faults beneath the river bed would be within a zone of about 50 feet in thickness and that the length of the recharge zone down gradient of the mined area is about 6,000 feet. Therefore,

M-3 SEEPAGE CONTROL AND MONITORING

Acidic seepage from the waste rock dumps above Capulin Canyon are partially contained by a collection and pump-back system in upper Capulin Canyon. Seepage water from the collection pond is pumped to a horizontal borehole that connects Capulin Canyon to Goathill Gulch to the east. Seepage from the Capulin and Goathill dumps flows in Goathill Gulch where it is discharged into the caved area that extends entirely across the canyon.

Monitoring of water quality is currently conducted through a sampling program involving the Columbine and Mill wells and tributary drainage and springs down-gradient from the mine facility. During the summer of 1994, 16 monitor wells will be constructed (at the locations shown on Figure M9) to evaluate current water quality and to monitor any changes as the mine rewatering continues and the collection system in upper Capulin Canyon is expanded. Most of the monitor wells are designed to be converted to extraction wells if necessary. In addition to this geologic mapping along the Red River Valley (spring 1994), an attempt will be made to correlate geologic structures with the geochemistry of springs, seeps, and the Red River.

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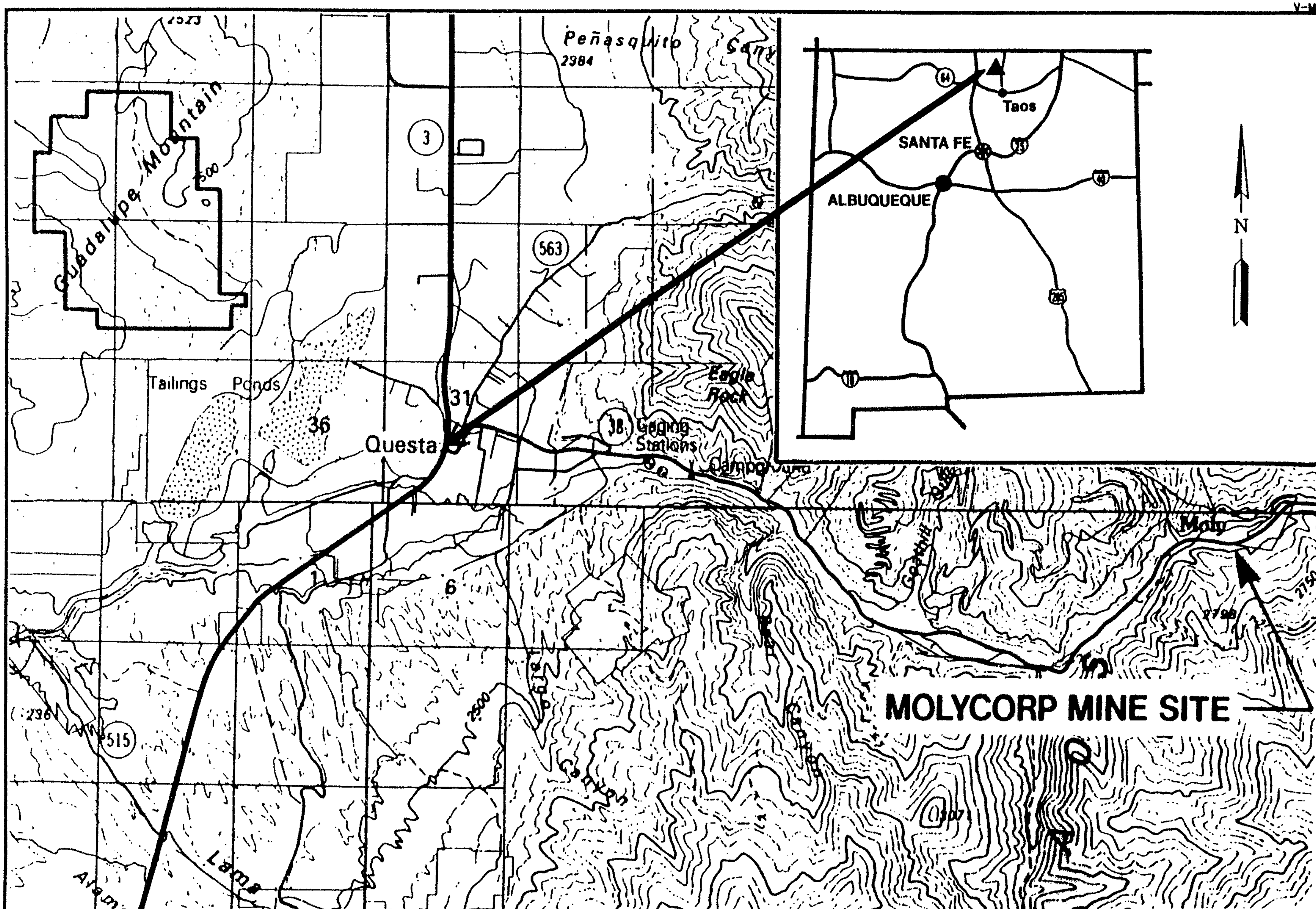
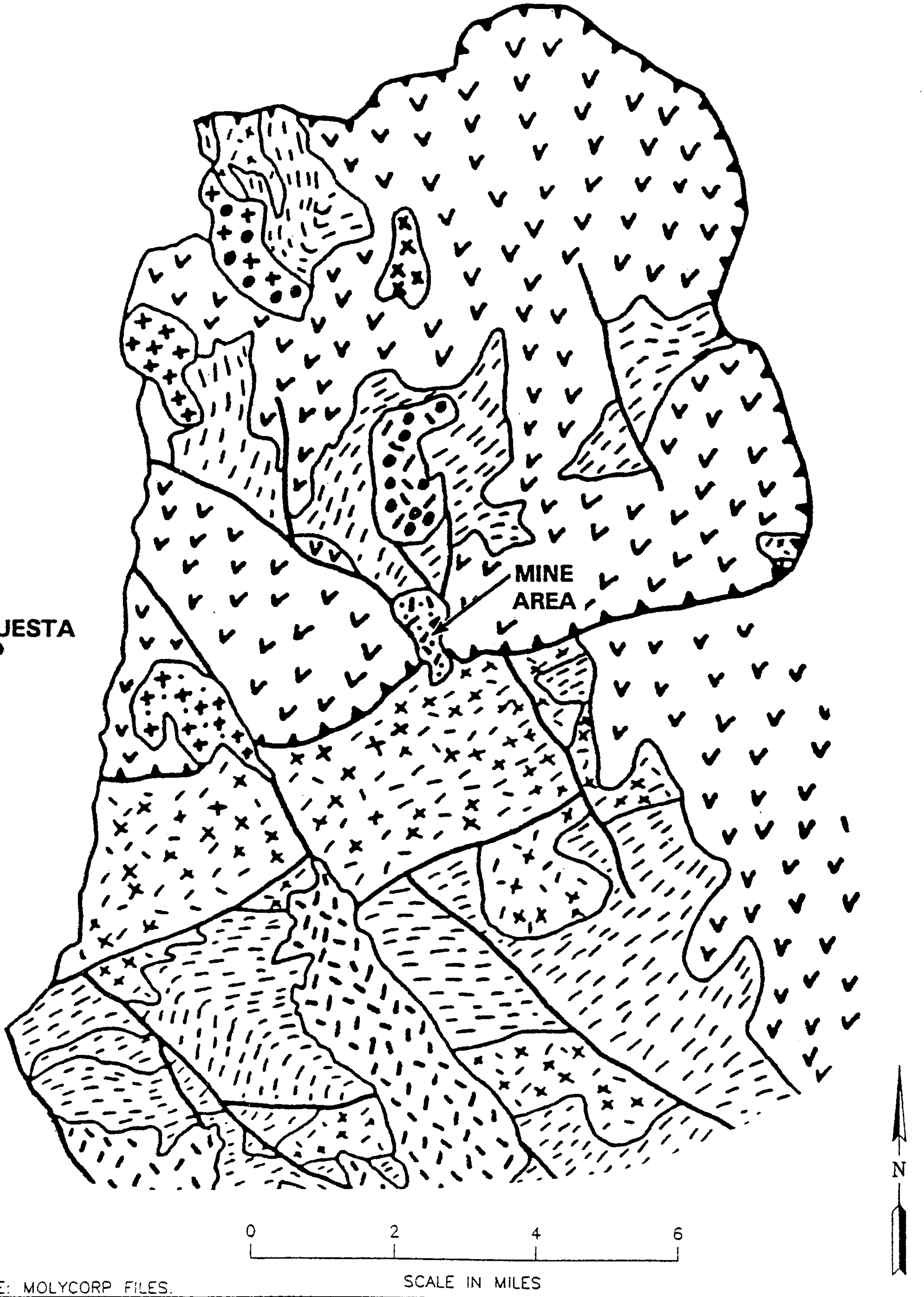


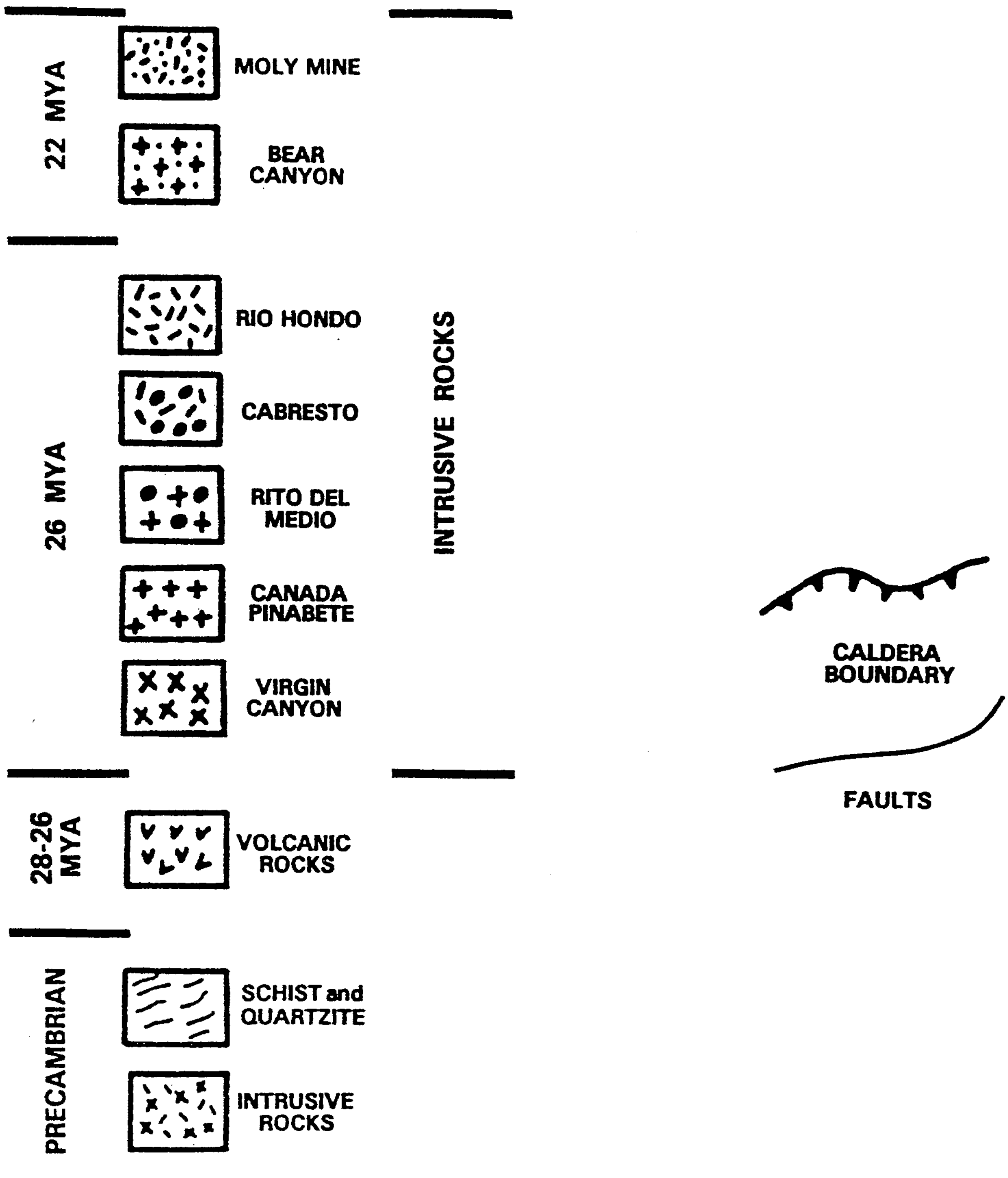
FIGURE: M1	SOUTH PASS RESOURCES, Inc.				LOCATION MAP Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	



REFERENCE: MOLYCORP FILES.

SOUTH PASS RESOURCES, Inc.				GENERALIZED GEOLOGIC MAP Molycorp, Inc. Questa, New Mexico	FIGURE: **M2**
PROJECT No: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY:		

GEOLOGY



REFERENCE: MOLYCORP FILES.

SOUTH PASS RESOURCES, Inc.				GENERALIZED GEOLOGIC MAP KEY	FIGURE:
PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY:	Molycorp, Inc. Questa, New Mexico	M2a

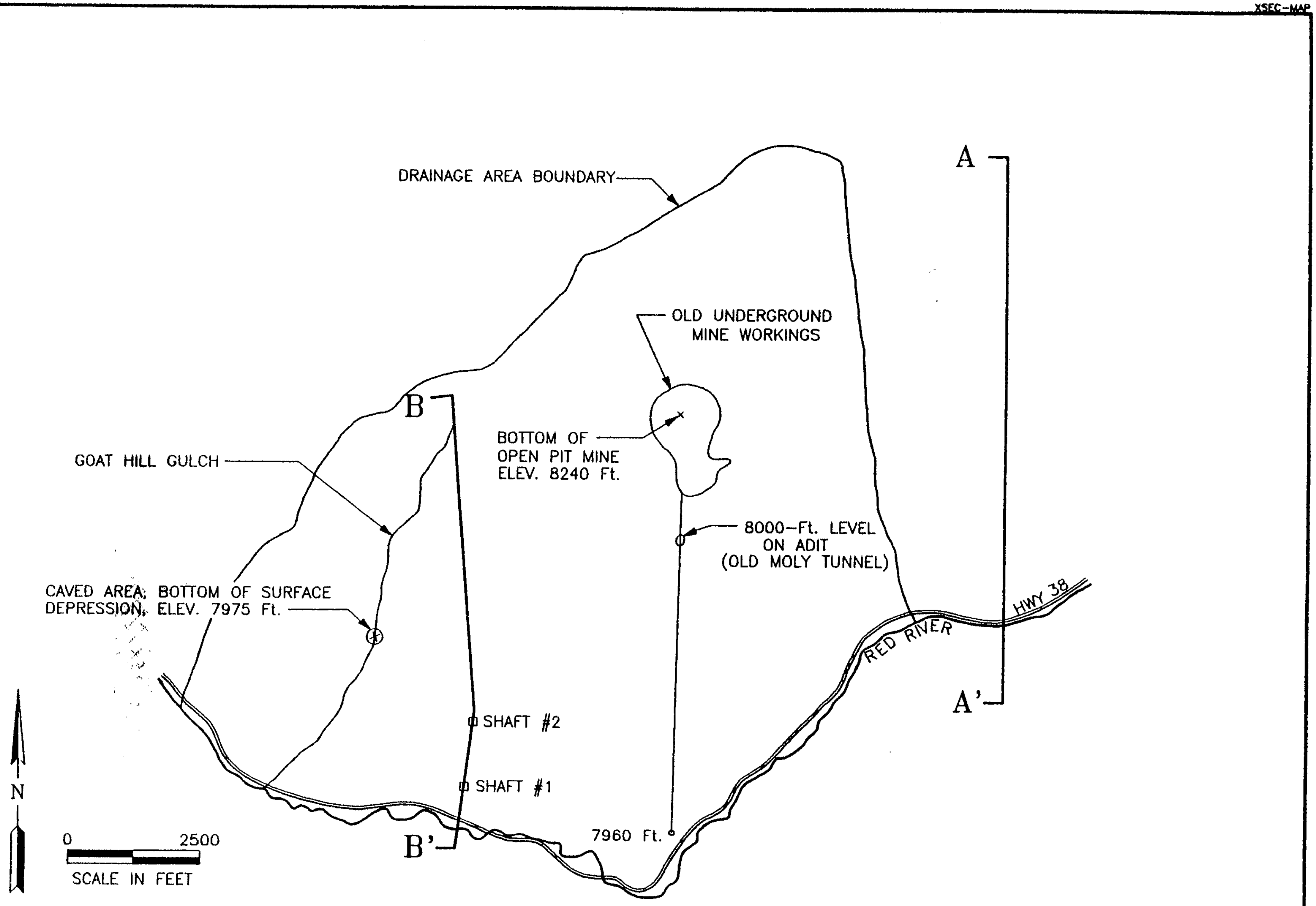


FIGURE: **M3**

SOUTH PASS RESOURCES, Inc.

PROJECT No.:	DATE:	AUTHOR:	DRAWN BY:
001-03	6/13/94		M.O'M.

APPROXIMATE CROSS-SECTION LOCATIONS

Molycorp, Inc.
Questa, New Mexico

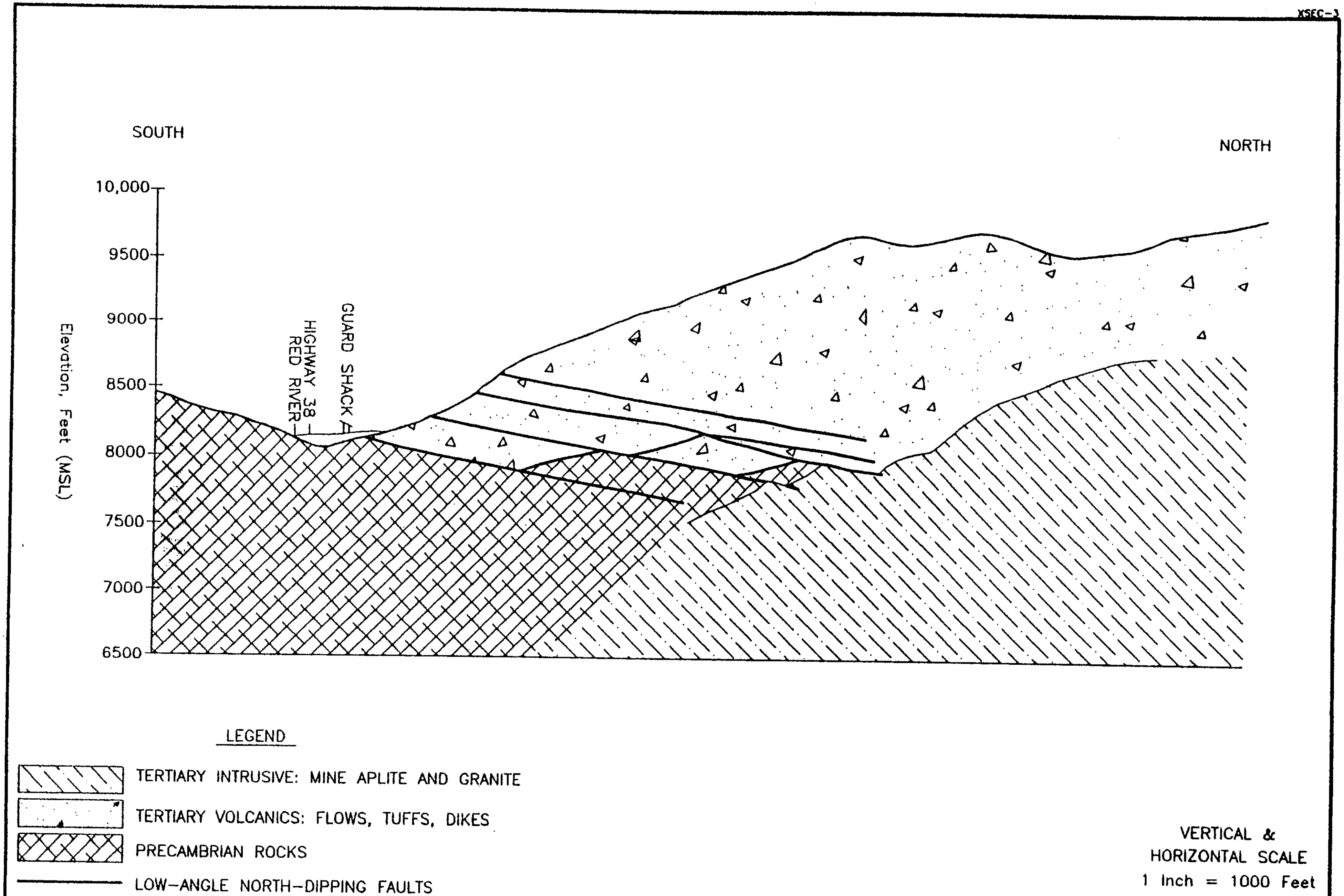


FIGURE: M4	SOUTH PASS RESOURCES, Inc.				CROSS-SECTION A – A'
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico

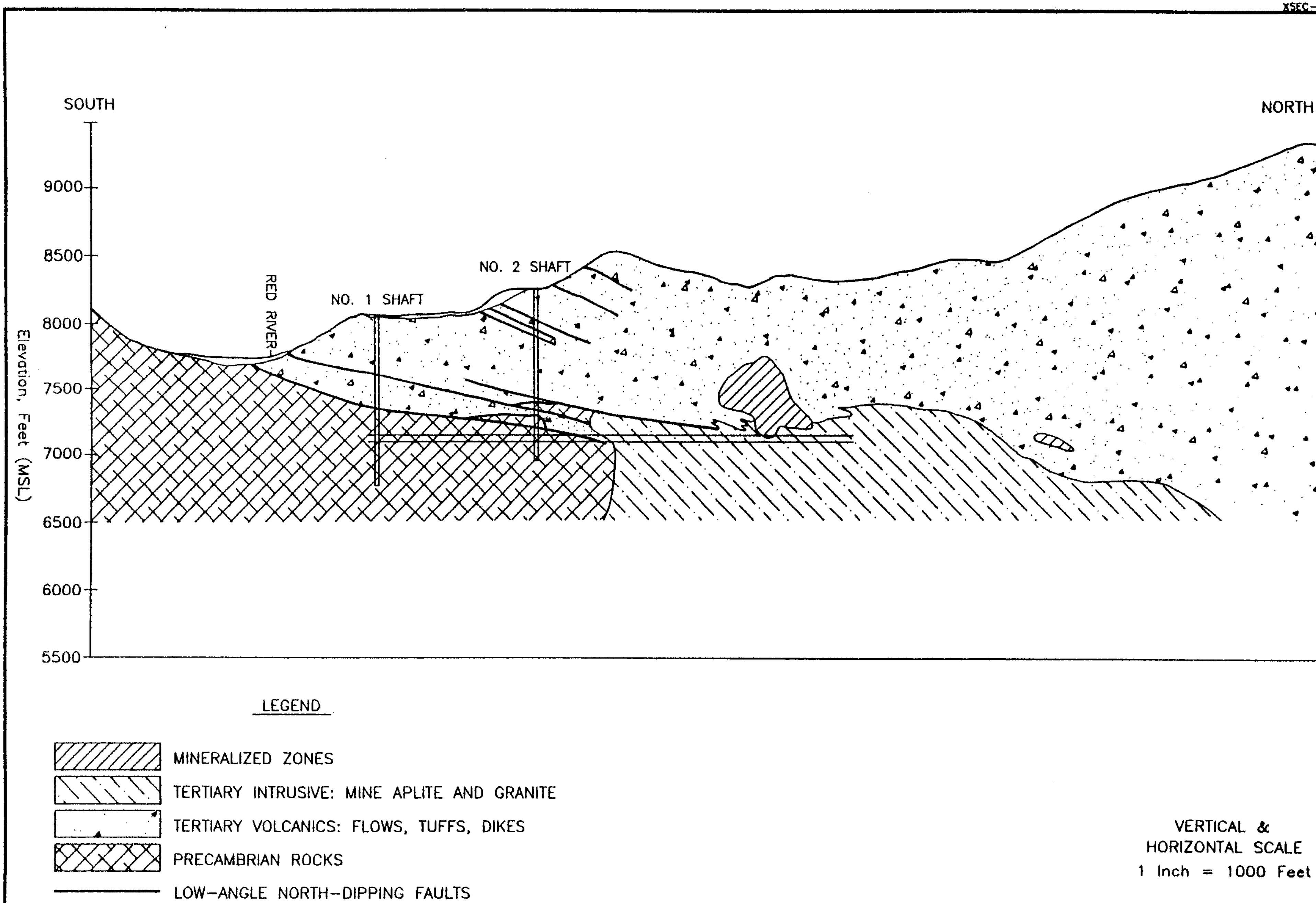


FIGURE: M5	SOUTH PASS RESOURCES, Inc.				CROSS-SECTION B – B' Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

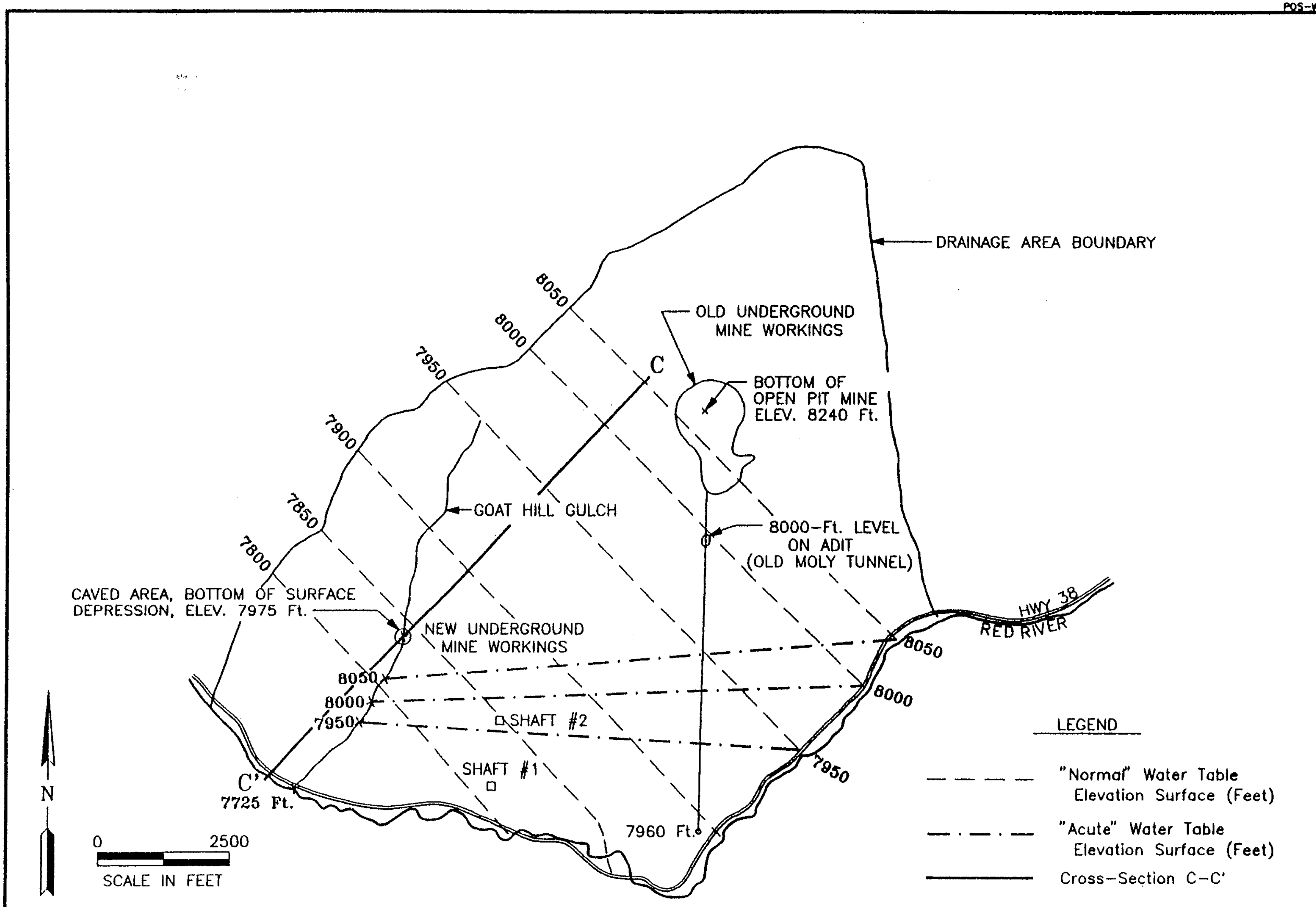


FIGURE: M6

SOUTH PASS RESOURCES, Inc.

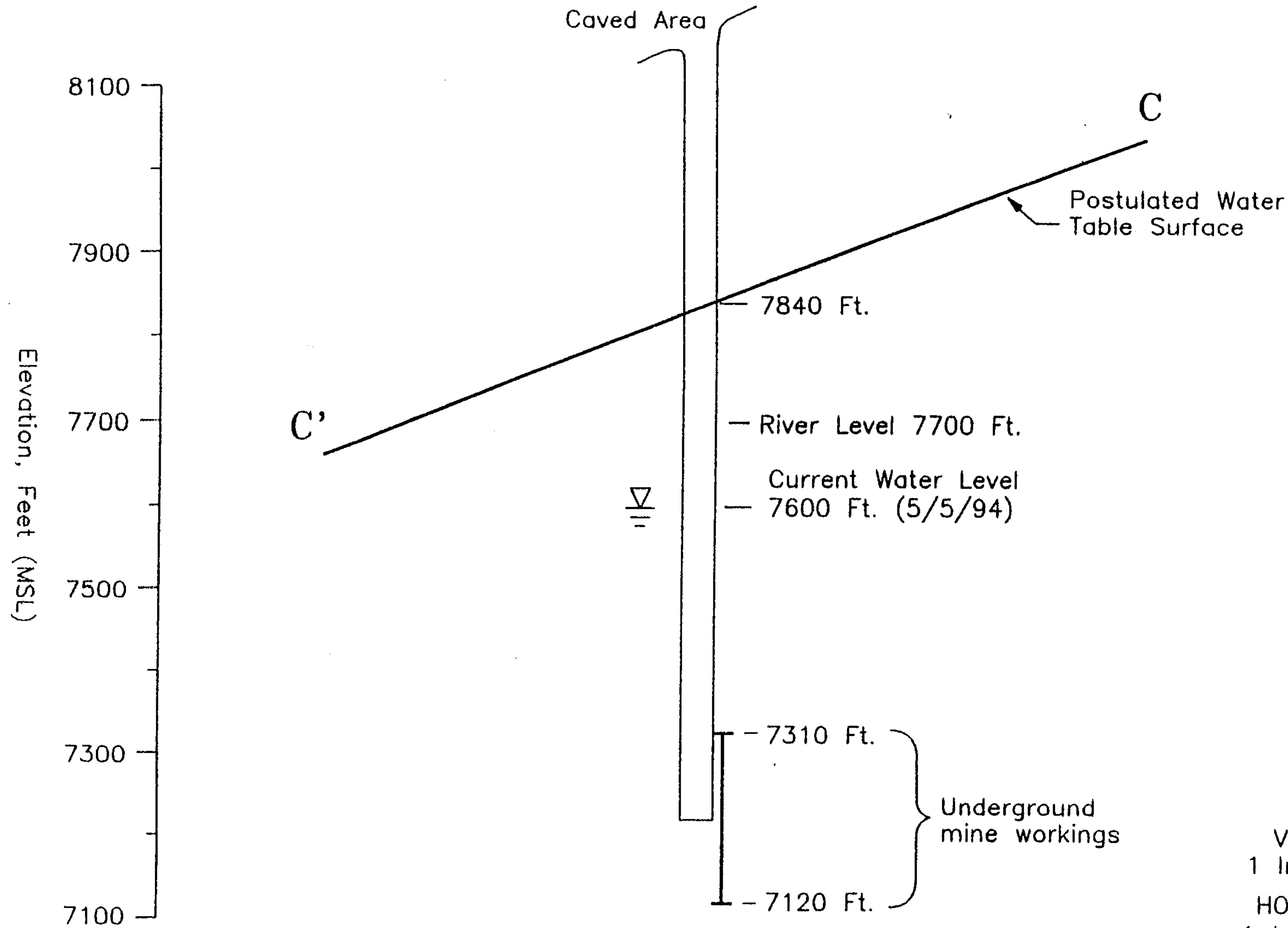
PROJECT No.:	DATE:	AUTHOR:	DRAWN BY:
001-03	6/13/94		M.O'M.

POSTULATED WATER-LEVEL ELEVATION SURFACES

Molycorp, Inc.
Questa, New Mexico

XSEC-5

RELATIONSHIP BETWEEN UNDERGROUND MINED AREA, POSTULATED WATER TABLE AND RED RIVER



VERTICAL SCALE
1 Inch = 200 Feet

HORIZONTAL SCALE
1 Inch = 2500 Feet

FIGURE:	SOUTH PASS RESOURCES, Inc.				CROSS–SECTION OF CAVED AREA
M7	PROJECT No.: 001–03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico

RED RIVER CANYON

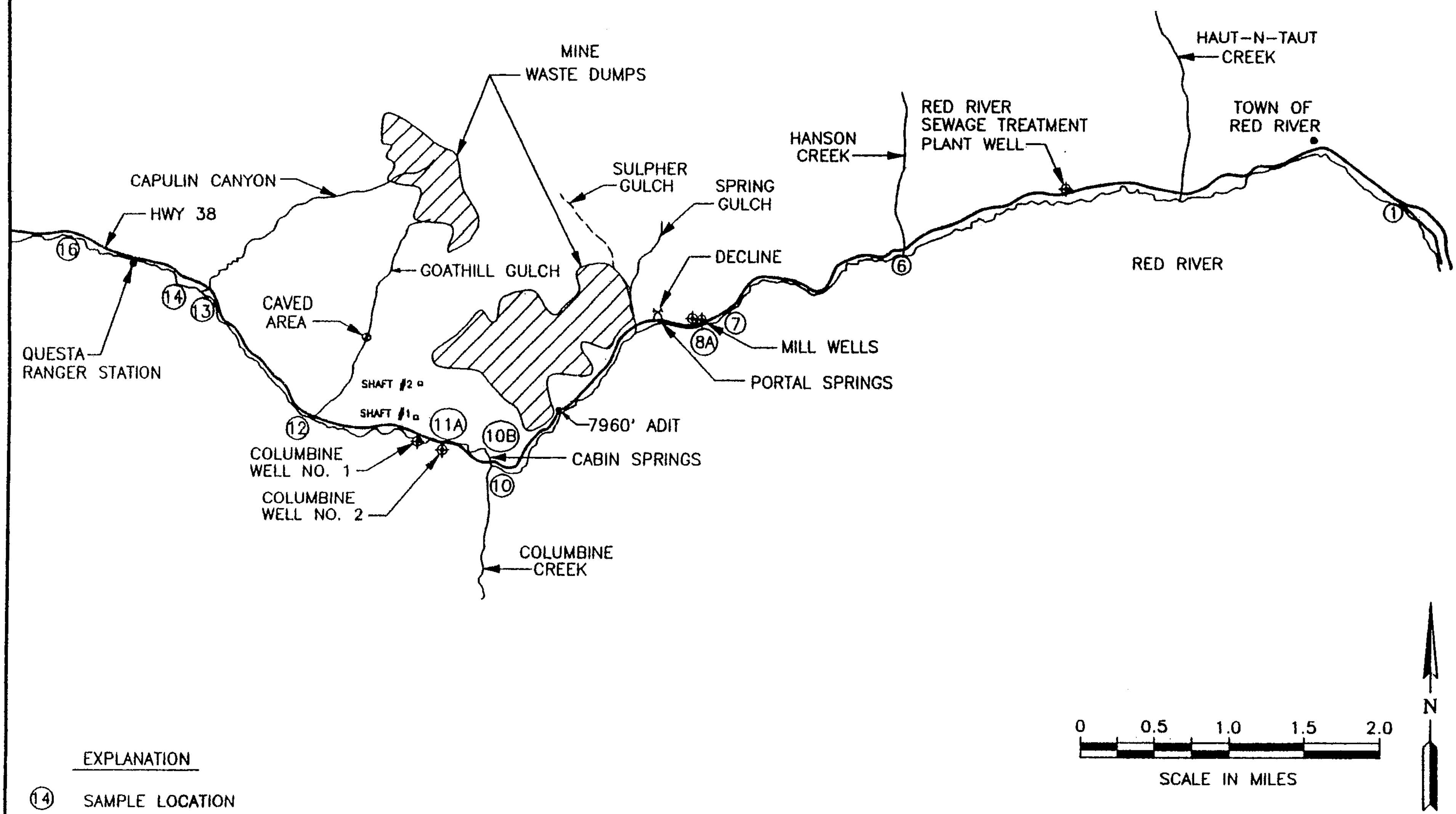


FIGURE: M8	SOUTH PASS RESOURCES, Inc.				RED RIVER CANYON SAMPLE LOCATIONS Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001A-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

SITE100

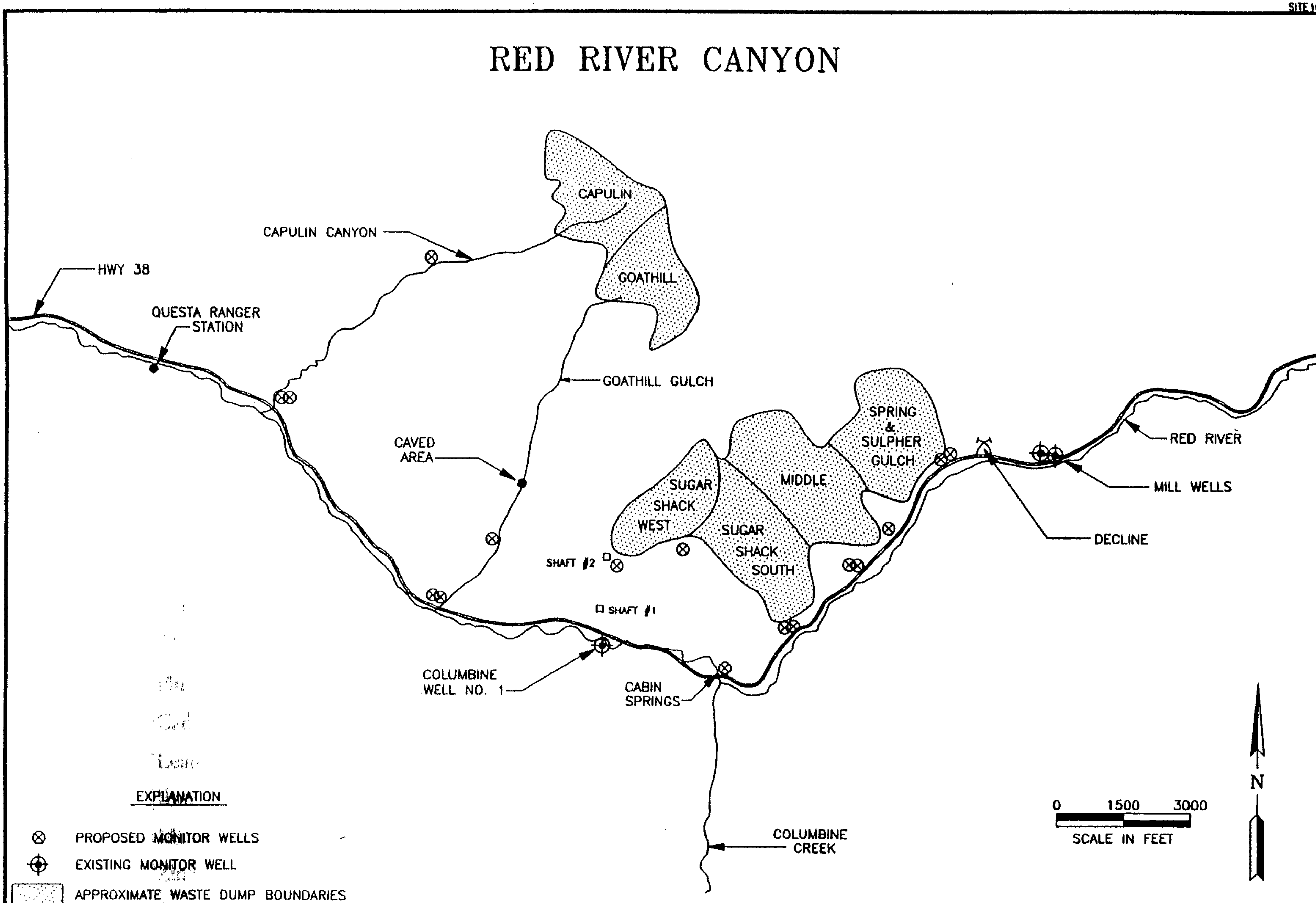


FIGURE: M9	SOUTH PASS RESOURCES, Inc.				PROPOSED MONITOR WELL LOCATIONS Molycorp, Questa New Mexico
	PROJECT No.: 001-03	DATE: 6/13/94	AUTHOR:	DRAWN BY: M.O'M.	

TABLE M1
CHEMISTRY OF MINE WATER
(Concentrations in mg/L)

	SEEPAGE BARRIER [1]			SHAFT No.1		Shaft No.2	Decline
	Water Out of Pumpback Point [2]	Water Into Pumpback Point	Horizontal Borehole Discharge [3]	Shallow	Deep		
pH	3.3	3.3	3.0	6.9	7.7	7.2	7.5
Aluminum	138	335	1195	NA	NA	<0.5	1.20
Sulfate	1530	3222	9805	1455	1480	1345	1004
TDS	3680	6940	23660	3072	3386	3164	2468
Fluoride	19.7	27.7	27	NA	13.1	5.0	7.10
Cadmium	0.06	0.12	0.52	<0.005	0.01	<0.005	<0.005
Lead	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.1
Iron	15.3	21.5	601	0.30	<0.05	<0.05	<0.05
Manganese	68.1	243.1	608	8.6	15.5	5.10	1.20
Zinc	16.9	38.6	119	1.3	0.30	2.70	2.80
Copper	0.9	1.0	5.0	<0.01	0.02	<0.01	<0.01
Molybdenum	NA	NA	NA	2.70	2.20	1.80	1.20
Arsenic	NA	NA	NA	<0.01	<0.01	<0.01	<0.01
Mercury	NA	NA	NA	<0.20	<0.20	<0.20	<0.20

(1) Seepage barrier in Capulin Canyon
(2) Water seepage 2000 feet down canyon from pond.
(3) Horizontal borehole drains into Goathill Gulch and Caved Area.

TABLE M2
WATER CHEMISTRY OF
WELLS, TRIBUTARIES AND RED RIVER WATER (1993-1994)
(Concentrations in mg/L)

	Red River Sewage Plant Well	Columbine Well No. 2	Haut-N-Taut Creek	Hanson Creek	Red River
pH	3.96	5.9	3.1	3.3	7.6
Aluminum	25.2	--	114	136.00	0.5
Sulfate	776	536	1884	1320	86
TDS	1,034	848	3940	3200	200
Fluoride	2.13	2.0	13.0	4.2	0.32
Cadmium	<0.005	<0.01	0.06	0.02	<0.005
Lead	<0.1	<0.05	<0.1	<0.1	<0.1
Iron	27	<0.05	44	25.6	0.467
Manganese	5.0	0.01	18.1	175	0.179
Zinc	1.9	0.69	9.20	5.40	0.041
Copper	0.051	<0.01	1.80	0.4	0.012

M-2 MINE AREA HYDROGEOLOGY

M-2.1 HYDROGEOLOGIC UNITS

At the Questa Mine area, the identified hydrogeologic units are:

- Precambrian/Tertiary Aquitard,
- Tertiary Aquifer,
- Hydrothermal Alteration ("Scar") Aquitard, {note: Not a true aquitard because it is not in the saturated zone}
- Valley-Fill/Mudflow Aquifer, and
- Valley-Fill/River Alluvium Aquifer.

Precambrian/Tertiary Aquitard: The Precambrian metamorphic and intrusive rocks and the stock-like Tertiary intrusives (Mine Aplite) form a hydrogeological basement or a regional aquitard analogous to the regional lower clastic (Precambrian/Cambrian quartzites) aquitard identified by Winograd and Thordarson (1975) in central and eastern Nevada. While shallow fracture systems (and in some cases, major through-going faults) allow for some movement of ground water, these rocks are characterized by low hydraulic conductivity and serve as barriers to deep circulation of ground water. Schilling (1956), in characterizing the vertical fracture system in the Mine Aplite, noted that these fractures pinch out downward into the main intrusive mass. These fractures (along with numerous small faults) are also mineralized in the ring fracture fault zone.

Tertiary Aquifer: The Tertiary volcanics and sedimentary rock units are highly fractured and faulted throughout the caldera block north of the river. (Note: sedimentary units are very thin and do not show on Figure M2.) The major structural features are high-angle northwest-, north- and northeast-trending faults and low-angle faults, either parallel to the intrusive/volcanic contact (contact conformable fractures) or along unit contacts. Joints related to some combination of tectonic and volcanic processes are also present in the volcanic units. Although mineralization and/or clay gouge along faults has sealed some of the fractures, not all are sealed and fracture flow does occur throughout the area. The Tertiary volcanic rock then represents the aquifer in the area and has highly variable hydraulic conductivity depending on the fracture orientation, fracture spacing, and the openness of the fracture system below the water table.

Hydrothermal Alteration ("Scar") Aquitard: The hydrothermal scars scattered across the ridges above the mined area are composed of pyrite, clay, quartz, and carbonates altered to iron oxide, gypsum, jarosite, plus residual quartz and clay resulting from near-surface oxidation processes. These masses of altered material are principally located above the natural water table, but they likely have very low hydraulic conductivity and serve to retard infiltration to the fractured Tertiary aquifer system. Several 90-foot deep boreholes drilled by Molycorp into the "scar" material were either dry or produced very small flows (on the order of less than 1 gpm) over time. Because masses of fractured rock are located within the hydrothermal "scars," some of this flow may have been from local perched water zones associated with isolated masses of rock. If the "scar" material extends below the water table, the altered rock might locally create semi-confined conditions.

Valley-Fill/Mudflow Aquifer: Schilling (1956) described and mapped mudflow deposits in the Sulpher Gulch area and related these flows to intense storms that periodically flushed valley debris to the Red River Valley. He noted that the mudflows tended to develop in tributary canyons that extend across the hydrothermal scar areas transporting the hydrothermally altered rock toward the main valley. At times, flows blocked the Red River Valley and spread laterally—covering parts of the valley floor. SPRI field observations were that mudflow deposits extend beyond the area mapped by Schilling and are present at Goathill Gulch and Capulin Canyon.

The mudflow material consists of angular, poorly sorted rock ranging from pebble to boulder sizes in a sandy matrix. A few samples examined in the field by SPRI staff indicate there is not much clay-size sediment in the matrix. Mudflow sediments from the tributary canyons should interfinger with the river alluvium, but drillers' lithologic logs for the Columbine and Mill wells on or close to the Red River Valley floor are not of sufficient detail to recognize this. Ephemeral flows and seepage from tributary canyons should infiltrate the mudflow sediment and these deposits can serve as a conduit between the tributary canyons and the main valley. In the main valley, mudflow deposits may be part of the saturated valley-fill.

<u>Valley-Fill/River Alluvium Aquifer</u>: Drillers' logs characterize the river alluvium as rounded gravels ranging from pebbles to boulder size and fine to coarse sand. Pumpage at Columbine wells No. 1 and No. 2 was in the 1,000 gpm range (Molycorp files). In the mill area, which was built on a broad flat surface north of the Red River, Mill well No. 1 pumped at 1,200 gpm. Mill well No. 1A initially pumped up to 1,500 gpm, but the well could not sustain this level and was pumped dry shortly after completion. Other wells attempted in the mill area were not productive. Well logs to-date indicate that bedrock lies at depths of 80 to 150 feet below the valley floor.

M-2.2 GROUND-WATER RECHARGE

Factors to be evaluated in preparing estimates of ground-water recharge include: topography (elevation, degree of slope); surface material (outcrop, soil sediment); permeability and run-off characteristics of surface material; bedrock conditions in terms of infiltration characteristics, porosity, and hydraulic conductivity; and climate (temperature, precipitation, evaporation);. Many of these parameters are not well defined in the Red River drainage area, but there are sufficient data to make some estimates of a ground water and Red River hydraulic connection.

The mine operations are located north of the Red River Valley where elevations range from 7,581 feet on the Red River opposite Capulin Canyon to 10,812 feet at the ridge north of the open pit, resulting in a relief of 3,221 feet. Excluding the relatively narrow flat to gently rolling valley floor, most of the topography is composed of steep to very steep slopes that are conductive to high rates of runoff. Major tributary canyons in the mine area have gradients in the order of 600 to 800 feet per mile.

The U.S. Soil Conservation Service (1982) defined four soil map units (as part of their soil survey of Taos County) in the mine area north of the Red River. Two of the soil units (Rock Outcrop/Ustorthentis Complex and Marosa Soil/Rock Outcrop Complex) are described as gravelly and/or sandy loams. These soils are characterized by rapid to moderate run-off with high erosion potential. Their infiltration ranges from 0.6 to 6 inches (number of inches per hour that water percolates downward in the soil). The soil units are described as complex because a significant percentage of the map area consists of outcrops of igneous and metamorphic rocks. Vegetative cover consists of Douglas fir, Engelmann spruce, and ponderosa pine with an understory of Gambel oak, mountain brome, kinnikinnick, Kentucky bluegrass, Arizona fescue, and whortleberry.

The third soil unit (Rock Outcrop/Badland Type) is associated with the hydrothermal scars. This soil is described as extremely acidic (pH <4.5). It occurs along portions of all of the major drainages (Capulin, Goathill, Spring & Sulpher Gulch). Typically, slopes are steep and are nearly barren of vegetation. The Soil Conservation Service (SCS) characterizes this unit as a soil that generates increasing sediment loads to tributary drainage as precipitation increases (very high run-off and erosion potential). As noted in the Section M-2.1, drainages that intersect the hydrothermal scar areas typically have mudflow deposits near their confluence with the Red River.

The fourth soil unit (Cumulii Hoplobenolls) covers parts of the main valley floor. It generally consists of stratified gravelly sandy loams and gravelly clays. Infiltration of the soil is slow to moderate (0.2 to 2 inches per hour). Periodic flooding is the chief hazard here.

Rainfall estimates related to elevation and soil units in the mine area were prepared by the SCS (1982). For the lower elevation, below 9,000 feet, the annual precipitation is 18 inches; between 9,000 to 11,000 feet, precipitation is 35 inches. In its report, the SCS indicates that annual snowfall can exceed 100 inches in the mountains. Schilling (1956) had estimated 21 inches of annual precipitation for the same area. The bulk of the precipitation is winter snowfall with some thunderstorm contribution during the summer months. The average annual temperature is 40° to 42° Fahrenheit.

Several authors have attempted to estimate the distribution of precipitation among run-off, evapotranspiration, and ground-water recharge. Wilson and Associates (1978) estimated that in the mountainous areas of northern New Mexico, 3 inches to 10 inches of the precipitation contributed to run-off and the balance was distributed between evapotranspiration and recharge to ground water. Vail (1989) measured the areas of drainage basins for the major tributary to the Rio Grande, including the Red River, and calculated basin discharges from an equation based on drainage basin area and average annual winter precipitation. For the lower Red River basin (Zwergle Dam east of the Town of Red River to the Questa Ranger Station stream gauge), Vail calculated a discharge of 38.2 cfs. A review of flow discharges measured over a 12-year period [U.S. Geological Survey (USGS) data in Molycorp files for 1943 to 1955] shows that discharge ranges from 7.74 cfs to 262.5 cfs. In general, the higher flow rates occur in the April through July period and the lower rates over the balance of the year. Overall, this section of the Red River between the dam and the Ranger Station appears to be a gaining stream with substantially higher flow discharge at the downstream station.

River accretion studies by the USGS (base flow measurements in late fall of 1965 and 1988) were referenced by Smolka and Tague (1988) in their water quality survey of the Red River between Zwergle Dam and the Fish Hatchery. After correcting for tributary and diversion flows, they estimate that the net gains from ground water were 9.0 cfs (1965) and 9.1 cfs (1988) between Zwergle Dam and the Ranger Station gauge east of Questa. The Molycorp mill was not in operation in 1965 or 1988 and was not a factor in the diversion calculations. A review of the 1943-1955 flow data for these two gauges indicate that base flow (ground-water recharge) conditions ranged from 7.74 cfs to 13.9 cfs (an average of 11.04 cfs). Vail (1989) used USGS stream flow data to estimate accretion to the Red River at nine locations from the Zwergel Dam site to the Bear Canyon area (near the Questa Ranger Station gauge). The segment from the Molycorp mill downstream to Bear Canyon shows an accretion of 6.6 cfs. Of this, 5.0 cfs comes from Columbine Creek, which leaves 1.6 cfs related to recharge from seeps and springs along both sides of the rivers.

Another approach to estimating drainage basin recharge to ground water utilizes the Maxey and Eakien (1949) approach. Their method estimates that 25 percent of the annual precipitation over the mine-area drainage basin could contribute to recharge. Vail (1989) calculated areas for the Red River drainage basin and for the lower Red River basin (from Zwergle Dam to the Ranger Station). Using an area of 83.24 square miles at 25 percent of 21 inches annual precipitation (Schilling, 1959), the entire basin would contribute 32.25 cfs to ground water. That part of the entire drainage basin in the mine area represents about 6 percent of the total drainage basin. On the assumption of a uniform distribution of ground-water recharge (as an approximation), 1.94 cfs would be recharged to the ground water. Using Vail's (1989) estimate of the square miles for discrete elevation zones and 25 percent of the annual precipitation for each zone as recharge results in a higher estimate of 2.56 cfs ground-water recharge for the mine drainage area. SPRI (1993), using a similar approach for the mine area drainage basin (Capulin Canyon to Spring & Sulpher Gulch), calculated a ground-water recharge of 1.45 cfs. If a water balance is assumed, this recharge equals accretion to the Red River.

A final approach to estimating recharge from ground water is to use the average of the baseflow from the 1943 to 1955 flow data (11.04 cfs) as an estimate of the total ground-water recharge for the basin. Again, with the assumption of an uniform distribution of recharge throughout the basin, the mine area portion of the drainage basin (6 percent of total area) would have contributed 0.66 cfs. This value is considerably lower than the precipitation-based estimates. The lower recharge values will be used here because there may be less error for a recharge estimate based on actual flow data than for estimates based on a precipitation approximation.

Molycorp records indicate when the deep underground mine was being developed, dewatering required about 250 gpm (0.55 cfs). The Smolka and Tague (1988) accretion study, during the time of mine development, shows a net accretion to the river from ground water of 9.0 cfs, similar to the pre-mine accretion of 9.1 cfs in 1965. This suggests that the mine was dewatered from the deeper part of the ground-water flow system and did not appreciably, if at all, reduce accretion to the river from ground water. It appears that most of the ground-water recharge to the river may come from the upper part of the ground-water system. In other words, the deep mine was not directly in the recharge zone. Schilling (1959), in his description of fracturing in the Sulpher Gulch area, indicated that many of the fractures (particularly sheeting type of fracturing related to contacts) tend to die out with depth. More water was probably in storage in the shallow fracture system close to the water table, and mineralization combined with lithostatic pressure effectively sealed much of the deeper level fractures. With lower hydraulic conductivity conditions at depth, a cone of depression (probably steep-sided) was developed over the deep mine. The cone probably did not extend to the river.

Vail's (1989) accretion study results in an estimate of 1.6 cfs of ground water recharging in the river in the segment opposite the mine. If the recharge was equally distributed on both sides of the river, this would mean that 0.8 cfs was derived from the north (mine) side. This value is fairly close to the 0.66 cfs estimated from the base flow data. It is evident that if all of the 0.55 cfs taken from storage during dewatering was withdrawn from the shallow portion of the ground-water system , some measurable loss of accretion to the river might be expected. Rather, it appears that much of the deep mine discharge came from the deeper levels of the ground-water system and had little affect on the shallower part. If there was any loss in accretion to the river in the segment opposite the mine, the amount may have been too small to show up in the accretion estimates.

M-2.3 WATER-TABLE CONFIGURATION

Based on Molycorp data, dewatering inflow for the older underground workings and for the open pit ranged from 15 to 30 gpm, which are very low flow rates. If these areas were below the water table, such rates could only be explained by very tight rock conditions in which virtually all the fractures were sealed. Schilling's (1956) and Rehrig's (1969) descriptions of the fracture systems and field examination of rock exposures in the same area indicate that open fractures exist (some fracturing can be related to mine activities). It is also likely that these low flow rates can be attributed to perched fracture water above a regional water table. The deeper underground workings dewatered at 250 gpm. [For comparison, Newmont's Gold Quarry Mine in Nevada is in fractured sedimentary rock and dewaters at 50,000 gpm (Carrillo, 1993).] However, if the fractures in a mineralized zone were largely sealed by mineralization/clay gouge, then 250 gpm, even below the water table, would not be unreasonable. It is possible that the open pit and most of the older underground workings near Sulpher Gulch (down to 7,800 to 7,900 feet) were above the regional water table and that the inflows were from perched fracture water. Currently, this inflow from the open pit and the older underground mine drains though a borehole into the deeper mine workings.

If the gaining stream model is used with the "normal" (versus the "acute") contour configurations (see Appendix A) and with the dewatering data, it appears that a "normal" contour surface (Figure M6) would allow for most of the old workings and the pit to be relatively dry and above the regional water table. The Moly Tunnel (7,960 adit) would be at the water table at an elevation of 8,000 feet. Construction of the 7,960 adit did not produce much water and, therefore, the 8,000-foot water-level contour might have curved more to the north. The "normal" water-table surface would have a southwesterly gradient of 0.036 foot/foot in this very simplified configuration. In contrast, the "acute" water table configuration would place most of the old workings and part of the open pit below the pre-mine water table.

We can use the simplified "normal" water-table surface to estimate the elevation of the water table in various areas of the underground workings. For example, the water level would continue to rise in the caved area above the underground workings in the Goathill Gulch area to an elevation of approximately 7,840 feet. At Shaft No. 1, the elevation would be about 7,820 feet and at Shaft No. 2, it would be closer to 7,850 feet. With respect to the old Moly Tunnel (7,960 adit), a conservative position would place it just below the water table at about 8,000 feet.

Another element in the water-table surface configuration is the additional recharge from seepage barriers to the mine through the caved area. This recharge currently amounts to about 70 gpm captured by the seepage barriers constructed on Capulin and Goathill Gulches. An additional 30 gpm drains from the open pit through a borehole in the old underground mine to the deeper workings. These seepage water amounts are occasionally augmented by surface water related to storm discharge. How much of this water actually reaches the caved area is unknown since it is a surface discharge and a certain amount must be lost to evaporation or infiltration to the vadose zone. (In the vadose zone, the water would be bound by surface tension in intergranular voids or micro-fractures.) It is possible that the additional recharge might cause some mounding of the water table surface, particularly in the caved area, and locally a slightly steeper gradient.

Rate of Rise for the Water Table

On May 19, 1994, the water level in the mine workings was at 7,600 feet (Figure M7). According to Molycorp records, the caved area began to fill by October 20, 1992. Using the elevation of the bottom of the caved area (7,226 feet) and the time since filling began (549 days), the rate of rewatering is 0.68 foot/day. The actual daily rate values range from less than 0.68 to as much as 2.0 feet/day, depending on seasonal recharge conditions. However, if the 0.68 foot/day is used as the rate, it would take 147 days (from May 1994) for the water level to rise to the down-gradient elevation (7,700 feet) of the Red River. (This assumes a southwestern gradient based on the normal contour configuration in the caved area at Goathill Gulch: Figure M7). In other words, after 147 days (0.4 year) from May 1994, there would be a slight gradient from the cave area toward the river. Using the same rate of 0.68 foot/day, it would take 0.97 year to reach the postulated water-table elevation of 7,840 feet in the caved area. In the case of the Moly tunnel (7,960 feet), it would require 1.61 years for the water level to reach 8,000 feet and begin to flow down to the adit.

M-2.4 MINE AREA WATER CHEMISTRY

Data on the chemistry of mine-related water (Table M1), well, tributary, and Red River water (Table M2), and spring and river water (Table M3) are provided for comparison purposes. Chemistry for these tables is derived from 1993-1994 (unless otherwise indicated) Molycorp files. All concentrations are expressed in milligrams per liter (mg/L).

Water collected at the seepage barrier in upper Capulin Canyon reflects the chemistry of the leachate generated by oxidizing waters infiltrating the mine waste dump at the head of the Canyon, mixed with natural seeps issuing from the hydrothermally altered rock in the same area. These are acidic waters (Tables M1 and M2) resulting from the reaction between vadose waters and the pyritic material in the waste dumps and the hydrothermal scars. Concentrations of TDS, sulfate, aluminum, fluoride, iron, manganese, and zinc are all fairly high in both natural and mine-related seepages. The seepage water collected below the pump-back pond (down-gradient of the barrier) shows a significant reduction in all constituents (except pH) compared to the inflow to the pond. The reduction probably reflects losses due to chemical precipitation along the canyon bottom and from dilution caused by surface springs tributary to the Canyon. The chemistry of the natural drainage samples (Table M2) is fairly close to the chemistry of the Capulin Canyon sample (water from below the pump-back pond) suggesting that this Capulin water may largely consist of natural seepage from hydrothermally altered rocks along the canyon with little or no barrier water. The sample was taken in October 1993, which is a time of low discharge for natural seeps as well as both natural and mine-induced tributary flows.

The mine waters are significantly more alkaline (higher pH) but lower in metals, sulfate, and TDS compared to seepage waters. Vadose water above the rising water table in the mine is oxidizing and reacting with the fractured, pyritic rock to produce the TDS and sulfate concentrations. Water levels are probably rising faster than downward infiltration is occurring; therefore, high TDS/sulfate water is incorporated and diluted in the ground water. Once the pyrite-bearing rock is submerged beneath the water table, little oxidation occurs (Frost, 1979), and the ground-water chemistry should be a combination of ambient water quality plus leachate from the vadose zone. The deep water sample (taken at a depth of 400 feet below the water table) collected at Shaft No. 1 has a chemistry very similar to the shallow sample. This similar chemistry is probably not related to vertical dispersion, but rather to the incorporation of vadose water at an earlier time when the water table was lower than present -- indicating that ground water may be nearly stagnant, enclosed by low hydraulic conductivity rocks.

Table M2 illustrates the water chemistry for ground water from wells screened in valley-fill (sewage plant well and Columbine Well No. 2), from tributary drainage carrying water impacted by natural hydrothermal scar areas (Haut-N-Taut, Hanson Creek) and the Red River. It is clear that surface water draining from the hydrothermal areas along tributary drainages upstream from the mine area is of significantly poorer quality in terms of pH, TDS, sulfate, and metal content than are the mine water samples.

The sewage plant well is screened in valley-fill near an area of hydrothermal scar material, which is a source of mudflow sediment and which may be interbedded in the valley-fill. This would account for the low pH, high TDS/sulfate, and high iron, manganese, and aluminum content. The Columbine well is screened in river alluvium and is of much higher quality than the tributary waters. The reason for its low pH relative to the river water is not clear. The driller's log indicates clay and gravel at a depth of 92 to 122 feet, which could be mudflow material from hydrothermal scars just north of the river. Another possibility is that since the river is gaining, there should be upward directed flow and some seepage from hydrothermally altered rock may be entering the ground-water system near the river. There is, in fact, a long pre-mine history of seepage of acidic, metal-bearing surface and near-surface recharge water throughout the area. The limonite-cemented alluvial materials, some close to river level, are the result of this seepage. Ground water, even in the river alluvium, may show the impact of seepage following similar flow paths.

Geochemical surveys along the Red River were conducted in November 1988 and October 1992 (Vail, 1989) and in February 1994 by Molycorp (Table M3). Water samples were collected from tributary drainages, seeps and springs and the Red River. All of these studies show that where natural acidic springs and natural acidic tributary drainages reach the river, the pH of the river samples decreases 0.2 to 0.4 of a pH unit (see Table M3: Stations 1 and 6 and Figure M8). Significant lowering of pH and increases in sulfate, total dissolved solids, and some metals occur at and downstream of Capulin Canyon (Table M3: Stations 13, 14, and 16).

These geochemical surveys of the Red River along with seeps, springs, and tributary inflows within and outside of the mine area are continuing. Statistical analyses (cluster analyses, multivariate analyses of variance, canonical analyses, and discriminanat analyses) of the chemical data combined with stable isotope studies (lead and strontium) will be used to characterize the different sources and to estimate their contribution to tributary inflows and to the Red River. Tritium studies of selected water samples will be used to evaluate the age of various tributary waters (such as springs and seeps).

Sampling will continue at different times of the year to evaluate any changes in river chemistry related to seasonal increases or decreases in tributary inflows. Early spring melting of snow at the higher elevation increases the flow in tributary canyons and transports acidic seepage to the river. There is a narrow window of time during which tributary flow is increasing the input of seepage to the river, but the river itself is still near base flow conditions. When this occurs, the seepage water should have its maximum effect on the river.

Figure M7 illustrates the relationship between the deep underground mine, the caved area, the postulated water-table surface, and the Red River. The underground mine would be on the order of 530 feet below the water table and 390 feet below river level. For the deep mine water to impact the Red River, there would have to be sufficient head to move the ground water upward principally along preferred pathways. These pathways could consist of the low-angle northward- and westward-dipping faults and north-south high-angle faults that intersect the mine workings. Based on the lack of impact on the Red River by the mine dewatering, these structures do not appear to be efficient conduits between the mine and the river.

Water-quality data from the shafts shows that vadose-generated high TDS and high sulfate water is distributed to at least a depth of 400 feet below the present water table. As the water rises during the rewatering of the mine, it moves across the acidic vadose zone—which accounts for the chemical similarity of the shallow and deep waters. It also appears that, because of the low hydraulic conductivity of the rocks enclosing the deep mine, the rate of ground-water flow is very low, no dilution (typical of the high flow rate) is occurring, and the ground water may be nearly stagnant in the submerged mine. The chief chemical difference between the shallow and deep samples is the rise in pH, the decrease in iron, and the increase in manganese concentrations.

The most likely source of mine-affected ground water is from the upper part of the caved area. There are two reasons for this area being a source of higher sulfate/TDS water:

- The caved area developed as the result of the block-caving mining method conducted at Molycorp's deeper mine. The upper part of the caved area consists, in part, of hydrothermally altered rock (pyrite, kaolinite, sericite, and quartz), which is typical of hydrothermal scar material and of unmineralized andestic volcanics (unpublished map, Molycorp). The elevation of the postulated water-table surface across the caved area is expected to be at least 7,840 feet (SPRI, 1993). The elevation of the rim of the caved area is 8,100 feet, leaving 255 feet of fragmented unmineralized volcanic rock and hydrothermal scar material above the water table. It is this material, in the vadose (unsaturated) zone above the water table, that would be subject to more intense oxidation processes.

- Seepage barrier water from Capulin and Goathill Gulch mine waste dumps is discharged to the caved area.

M-2.5 GROUND-WATER TRANSPORT

The mine workings are in a mineralized zone where fractures and faults are completely, or at least partially, sealed by mineral deposits, clay gouge, and intrusive material in the form of dikes. The structural trend of the mineralized zone is east to northeast, roughly normal to the postulated water-table elevation contours, or parallel to the southwesterly flow direction. If these fractures were open to any great extent, then they would be a significant pathway for recharge to the Red River. The lack of any known impact of the mine dewatering on accretion to the Red River suggests that there is a poor hydraulic connection between the east-trending structures and the river. Based on Molycorp maps, some north-trending, high-angle faults intersect the mineralized zone and extend to the river. Where such faults were cut by the mine workings, in some cases, inflows of ground water occurred (no measured discharge data are available). If ground water that is influenced by the mine water reaches the river, it would more likely be along a few preferential pathways related to the north-trending high-angle faults and/or the low-angle north-dipping faults that intersect the surface near the river. Mapping of springs and seeps along the river, combined with rock units and structure as well as water chemistry, would help to identify potential pathways.

With the currently available information, it is not possible to make meaningful quantitative estimates for the velocity of ground water through the fractured bedrock. Tracer tests in sets of nearby boreholes would probably allow the best estimate of fracture-related, ground-water velocity. These tests would need to be well planned in terms of distances between boreholes and their relationship to mapped fractured systems.

Seepage velocity formulas are based on advection in granular material, not fractured rock. Using the caved area (located on Goathill Gulch) above the deep underground workings as a source and published values for hydraulic conductivity and porosity for fractured rock (Freeze and Cherry, 1979), rough estimates of travel time from the mine to the river can be made. According to Freeze and Cherry (1979), the range of hydraulic conductivity for fractured igneous and metamorphic rocks is 10^{-1} to 10^{3} gallons/day/ft^{2} and for permeable basalt 1 to 10^{5} gallons/day/ft^{2}. The porosity range for fractured crystalline rock is 0 to 10 percent, and for fractured basalt 5 to 50 percent.

The seepage velocity formula is:

$$V = \frac{Ki}{7.48 n_e}$$

MINE AREA

TABLE OF CONTENTS

MINE AREA

APPENDIX

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Mine Area

The Molycorp, Inc. molybdenum mining operation lies north of the Red River between the towns of Questa and Red River, New Mexico. The area is characterized geologically by metasedimentary, metavolcanic, and metamorphic rocks overlain by some sedimentary rocks. The area was also intruded by granitic solutions. Thus, east-trending dikes, elongated intrusions, and mineralized veins characterize the ore zone.

HYDROGEOLOGY

Hydrogeologic units include a basement (Pre-Cambrian) aquitard, tertiary-, volcanic-, and sedimentary-rock aquifers, hydrothermal scar materials of low hydraulic conductivity, and valley-fill mudflow and valley-fill alluvial aquifers.

The Red River is a gaining stream over the entire reach from Red River to Questa. During mining operations, there was no apparent dewatering of the Red River because of mine dewatering. Thus, the cone of depression from mine dewatering did not affect accretion of ground water to the Red River.

A post-rewatering water table was constructed for the mine area based on a limited amount of dewatering information on the older higher level underground mine and open pit and on the Red River being a gaining stream. When the water table stabilizes (Spring 1995, based on the rate of rewatering), it will slope to the southwest with a gradient of approximately 0.04 foot per foot.

WATER QUALITY

Low pH (acidic), high total dissolved solids (TDS), and high sulfate water are characteristic of the natural seeps and springs, as well as surface water, in tributary drainages across hydrothermal scar areas outside of the mine property. Seepage water from the waste rock dumps in Capulin Canyon has low pH, high TDS, high sulfate water with elevated concentrations of fluoride, cadmium, iron, manganese, zinc, copper, and aluminum. The natural acidic waters also have elevated concentrations of fluoride, iron, manganese, zinc, copper, and aluminum, but not as high as the waste dump drainage. It is emphasized that natural discharges to the Red River and its tributaries have a measurable and adverse impact on surface-water quality.

The deep underground mine water, as it rises across a vadose zone of fractured pyritic rock, also shows elevated levels of TDS and sulfate (but far below that of the seepage from the rock dumps). The water is slightly alkaline (pH 7.2).

Geochemical studies of the Red River in relationship to seeps, springs, and tributary drainage show that pH slightly decreases and TDS/sulfate increases downstream from acidic water sources. Geochemical surveys utilizing statistical analyses of the water chemistry and stable isotope data (lead and strontium) are continuing and will be used to characterize the different sources of acidic water and to estimate the contribution of each tributary inflow on the Red River.

The degree of change in river chemistry is seasonal and is related to a combination of near baseflow conditions for the river and a heavy inflow from the tributary drainages.

SEEPAGE CONTROL

A seepage barrier system has been constructed in upper Capulin Canyon below Capulin waste dump. Seepage water captured by the system is pumped to Goathill Gulch where it drains into a caved area. The vadose caved area (which extends to the surface in Goathill Gulch) is a potential source of alkaline, high TDS, and high sulfate water after the water table stabilizes.

A system of 16 monitor wells will be constructed in 1994 to evaluate ground water from all of the mine waste dumps and from the caved area. The wells are designed to function as extraction wells if necessary.

M-1 SITE DESCRIPTION

M-1.1 LOCATION AND GEOGRAPHIC SETTING

The Molycorp/Questa molybdenum mine is located on the western slope of the Taos Range of the Sangre de Cristo Mountains, Taos County in north-central New Mexico (Figure M1). State Highway 38 runs along the north side of the Red River and connects the mine area with the Town of Red River (6 miles to the east) and the Town of Questa (6 miles to the west).

M-1.2 MINING HISTORY

The Questa Molybdenum mine was initially developed by Molycorp in the 1920's (Schilling, 1956). This underground mining operation consisted of the development of numerous adits and drifts between the elevation of 8,864 feet (Old Glory hole) and 7,764 feet at the deepest level. The mine portals were along Sulpher Gulch, an intermittent tributary to the Red River. The Moly tunnel extended south from about the 8,000-foot level to an elevation of 7,960 feet near the Red River. The elevation of the Red River segment opposite the mined area ranges from about 7,500 feet to 7,950 feet.

In the late 1950's, the underground mining was replaced by an open-pit operation which removed much of the upper part of the old underground workings. A deeper-level mineralized zone was identified in 1975, and underground mining by the block-caving method began. The deepest level in the new workings is the Haulage level (elevation 7,120 feet), above which is the Grizzly level (elevation 7,180 feet) and the Undercut level (elevation 7,200 feet). The service shaft (Shaft No. 1) is located about 800 feet north of the Red River and extends from a surface elevation of 8,090 feet to the Grizzly level (elevation 7,180 feet). Shaft No. 2 lies north of No. 1 and extends from a surface elevation of 8,270 feet to the Grizzly level. A caved area developed above the new workings along Goathill Gulch (see Figure M3). The caved zone extends from the surface (approximate elevation of 7,975 feet) to a depth of approximately 795 feet (elevation of 7,180 feet).

Water from natural seeps, seasonal precipitation, and water from the waste dumps is collected in several sumps near the head of Capulin Canyon. This water flows down-gradient to a pump-back pond from which it is pumped to a horizontal borehole connecting Capulin Canyon to Goathill Gulch. The Goathill Gulch surface drainage consists of natural seep water, seasonal flows related to precipitation, and waste dump water from a dump above the Gulch, and the borehole flow from Capulin Canyon. These combined waters flow into the caved area in lower Goathill Gulch.

The mine is currently on standby status until economic conditions improve for the molybdenum market. With an increased demand/price for molybdenum, the mine will be dewatered and operations resumed.

M-1.3 GEOLOGY

General Geologic Setting

The major sources of geological data for the Questa Mine area are Schilling (1956), Rehrig (1969), Lipman (1981), Bookstrom (1981), and numerous unpublished maps, cross-sections, and reports by Molycorp geologists. A common thread to all of these geological studies is that the mineralization at Questa was related to Tertiary magnetism and hydrothermal solutions focused along an east- to northeast-trending structural zone. This structural zone is variously interpreted as part of a graben (Schilling, 1956); as a zone of intense faulting (called the Red River Structural Zone by Rehrig, 1969); and the southern part of the outer ring fracture zone that formed the outer wall of the Questa caldera (Lipmann, 1981; Bookstrom, 1981).

The development of the caldera and the associated volcanic and intrusive rocks was a late Oligocene to Middle Miocene event (27.2 million years to 22 million years before present) that overlapped in time and space with the regional rifting associated with the Rio Grande Rift System. The range-bounding high-angle fault along the west side of the Sangre de Cristo Mountains (about 5 miles west of the mine) is related to regional extension across the Rio Grande Rift and the uplift of the range in Mid-Tertiary time. At least the later movements along this range-front fault are younger than the caldera structure because the outer ring fracture zone is truncated by the range-front fault.

Rock Units

The oldest rock units exposed in the vicinity of the mine are Precambrian amphibolites, quartz-biotite schists, metaquartzites, granite gneisses, and intrusive quartz monzonites. These units are overlain by an Early Tertiary conglomerate and sandstone unit followed by a complex sequence of Oligocene and Miocene rhyolitic to quartz latitic ashflow tuffs, breccias, and lava flows and a sequence of basalt/andesite lava flows. These volcanics are intruded by a number of dikes and small stocks or plutons that range widely in composition (quartz latite, rhyodacite, rhyolite, granite porphyry, and aplite). At the

Questa mine, most of the molybdenum mineralization is found in the outer parts of the Mine Aplite (22 million years before present) and adjacent volcanic units.

Structure

Geological maps of the Questa mine area (Figure M2) show a northeast- to east-trending structural zone (see Caldera boundary on Figure M2) along which intrusions of granitic rock and mineralization have occurred. This zone more or less parallels the Red River in the vicinity of the mine but farther to the west, swings to the southwest, away from the river. The structural zone is believed to be the southern part of the outer ring fracture zone (outer wall or rim) for the Questa Caldera. The zone is characterized by a swarm of east-trending dikes, elongated intrusions, and mineral veins that were emplaced in fractures developed parallel to the caldera rim.

South of the structural zone, northeast- and northwest-trending high-angle faults extend throughout the Precambrian block (Precambrian rocks and some pre-caldera volcanic rocks). Some of these faults are truncated by the caldera wall. North of the structural zone, the geology is more complex. Fault-bound blocks of Precambrian rocks, pre-caldera volcanics, and younger caldera-related volcanics occur throughout the area. These structural blocks and the outer fracture zone along the caldera wall became the plumbing system through which granites intruded (such as Mine Aplite) and the later mineralizing hydrothermal waters migrated.

A variety of fractures developed throughout the caldera block. These include:

- high-angle joints (called sheeting in the aplite) and fracture cleavage;
- contact conformable fractures between the intrusions and the volcanic units;
- high-angle northeast-, north-, and northwest-trending faults; and
- low-angle faults both within the Mine Aplite (west-dipping) and as structural contacts between various Tertiary units.

The low-angle faults are presented in cross-sections on Figures M3, M4, and M5. These are probably related to listric (concave-up fault planes), normal faults developed along the caldera boundary, and/or large slide blocks derived from the walls of the caldera. Within the structural zone mine, geologists have mapped volcanic megabreccias that may be representative of slide blocks. Some of the northerly-trending high-angle faults extend to the caldera boundary near the Red River truncating the easterly structures.

Mineralization

The mineral deposit consists of quartz/molybdenite (molybdenum sulfide) vein fillings in east- to northeast-striking, nearly vertical fractures in the Mine Aplite and in the immediately adjacent andesitic flow rocks intruded by the Aplite. Pyrite (iron sulfide) is fairly abundant in the quartz veins (with or without molybdenite) and in the clay gouges that fill some of the fault zones. Calcite, fluorite, and biotite are commonly associated with the vein minerals. The major alteration mineral in the volcanics outside of the veins is chlorite. Field photographs by Rehrig (1969) indicate that many fractures and small faults are barren of mineralization.

Schilling (1956) described intense zones of alteration associated with hydrothermal pipes (i.e., steeply inclined breccia structures) that probably formed at fault/fracture intersections in the volcanic rocks overlying the intrusion. The alteration minerals in these pipes consist of pyrite, chalcopyrite, quartz, kaolinite, sericite, and carbonates. Subsequent descending oxidizing ground waters reacted with the pyrite and carbonate minerals to form limonite (iron oxide), jarosite (hydrous iron/potassium sulfate), and gypsum (hydrated calcium sulfate) -- creating the yellow- and red-colored hydrothermal scars common throughout the area. Schilling (1956) reported that iron-enriched mine drainage waters precipitated limonite near the portal to Z Tunnel (old underground workings) and that pre-mine alluvial deposits cemented by limonite occur in the upper Sulpher Gulch drainage above the older workings. During field reconnaissance, SPRI geologists observed that limonite-cemented alluvial material occurs in the lower part of Goathill Gulch near State Route 38 and on an outcropping of cemented gravels on the north side of State Route 38, west of the cabins. This indicates that the natural oxidation processes of the past continue today in the mine area.