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July 31, 2001

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U.S. Nuclear Regulatory Commission
Washington, DC 20555

Re: **License SUA-1473**
Docket Number 40-8905

Dear Mr. Layton,

As we discussed during your site orientation visit on July 24, 2001associated with the ACL review for Quivira's Ambrosia Lake facility, please find enclosed a copy of the New Mexico Environment Department's analysis of the groundwater remediation program approved by NMED in 1984 and subsequently incorporated into the NRC license as the CAP for the site. This document is informally known as "The Bostick Report."

If you have any questions regarding the enclosed material, please contact me at 505.287.8851x205, or via email at pluthiger@ramc.net.

Regards,

Peter Luthiger
Supervisor, Radiation Safety
And Environmental Affairs

Enclosure

xc: P. Goranson (w/o encl.)
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HEALTH & ENVIRONMENT

department

GROUND-WATER DISCHARGE PLAN ANALYSIS
FOR
KERR-MCGEE NUCLEAR CORPORATION
AMBROSIA LAKE URANIUM MILL
QUIVIRA MINING COMPANY

Prepared by Kent Bostick

GROUND WATER SECTION
GROUND WATER QUALITY AND HAZARDOUS WASTE BUREAU
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION

February 1985

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1.0 SUMMARY AND CONCLUSIONS

Quivira Mining Company (QMC, formerly Kerr-McGee Nuclear Corporation) has operated an acid-leach uranium mill and tailings facility in the Ambrosia Lake area, near Grants, McKinley County, New Mexico, since 1958. The site contains a make-up water reservoir and two above-grade, unlined tailings ponds, one of which is actively used. Discharges from these tailings ponds have impacted water quality in the alluvium and the bedrock aquifers below the site. Ground waters to be protected at the site are in the alluvium, the Tres Hermanos sandstones, the Dakota Sandstone and the Morrison Formation. Unlined evaporation ponds at the site have also impacted water quality in the alluvium and the bedrock aquifers, but the use of the unlined evaporation ponds has been discontinued and their surfaces have been stabilized to prevent continued seepage of tailings fluids. Lined evaporation ponds in Section 4 are permitted under a separate discharge plan, DP-71. Mine backfilling with tailing sands is also covered under a separate discharge plan, DP-264. Analyses of these activities are presented in Appendices A and B of this report. In March 1981, QMC submitted a discharge plan (DP-169) for activities at the mill and tailings facility that might impact ground water. In April 1983, QMC entered into an Assurance of Discontinuance (A of D) with the New Mexico Water Quality Control Commission (WQCC) to supply further information and commitments that the Environmental Improvement Division (EID) deemed necessary for discharge plan evaluation. This technical analysis of QMC's proposed ground-water discharge plan (DP-169), and materials submitted pursuant to the A of D for its acid-leach uranium mill and tailings facility, has been conducted by Kent Bostick, a ground-water hydrologist with the EID, Ground Water and Hazardous Waste Bureau. During the analysis, an attempt was made to determine whether the discharge plan for the mill and tailings facilities satisfies the requirements of the New Mexico Water Quality Act and the New Mexico Water Quality Control Commission (WQCC) Regulations. It was determined that these requirements were met, and discharge plan DP-169 was approved March 30, 1984.

Specifically, QMC's plan was analyzed from the perspective of whether QMC has sufficiently demonstrated that discharges (planned or accidental releases) will not result in ground-water contamination beyond WQCC standards at a place of withdrawal of water for present or reasonably foreseeable future use. The EID has sampled wells on and adjacent to QMC's property and analyzed the samples at the NM Scientific Laboratory Division. These analyses agree closely with analyses of samples collected and analyzed by QMC. As a result of the agreement in analyses, the EID believes that QMC has accurately defined the levels and areal extent of contamination resulting from the operation of their mill and

tailings facility.

The EID has determined that QMC's activities described in the discharge plan will not result in ground-water contamination beyond the WQCC standards at any place of present or foreseeable future use.

1.1 Hydrologic Impacts

The QMC Discharge Plan presents the existing and potential impacts to ground-water quality which may result from 1. the tailings facility; 2. the mill; 3. releases of radioactivity from the tailings-slurry pipeline and the tailing dam; and 4. flooding. The plan does not cover the effects of adding materials from the Kerr McGee uranium conversion facility. If such materials are added to the milling process, a plan amendment and subsequent analysis could be required.

1. According to a water balance prepared by QMC in 1980, approximately 203 gallons per minute (gpm) of tailings fluids seeped to ground water from unlined tailings Ponds 1 and 2, unlined decant Pond 3 and unlined evaporation Ponds 4, 5, 6, 7 and 8. However, seepage of tailings fluids to ground-water at the mill site will be substantially less now that QMC has discontinued the use of the decant pond and unlined evaporation ponds. Seepage that leaves the unlined tailings Ponds 1 and 2 will be collected in a seepage interception ditch and discharged to lined evaporation Pond 9. The liner in Pond 10 is being repaired and it may also be used for evaporation of tailing fluids.

   Acidic tailings fluids in the tailings ponds are characterized by high chlorides, sulfates and TDS, numerous metals and radionuclides, including Ra-226, Th-230 and U-238. Tailings fluids contain constituent concentrations that exceed most numerical WQCC ground water standards.

   Mine dewatering discharges from the Westwater, Dakota and Tres Hermanos Aquifers have created a condition of saturation in the alluvium in a one-half mile wide channel along the length of the Arroyo del Puerto. Seepage from the make-up water reservoir, the unlined decant Pond 3 and unlined evaporation Ponds 4 through 8 has also contributed to saturation. Ground water in the alluvium at the mill site flows southeastward along erosional subcrops of the bedrock aquifers until it becomes recharge to the bedrock aquifers. Southeast of the mill site, ground water in the alluvium moves to the southeast as underflow in the Arroyo del Puerto channel.

Water quality in the alluvium reflects the influence of mine water discharges to the Arroyo del Puerto, leakage from the make-up water reservoir and seepage from the unlined tailings and evaporation ponds. Analyses of ground water samples from alluvial wells indicate that the alluvium has a substantial capacity to buffer the low pH of tailings fluids and cause the precipitation of heavy metals. Although existing concentrations of arsenic, boron, cadmium, chromium, lead, selenium, nitrate, chloride, sulfate and TDS may exceed the WQCC numerical ground water standards, the existing concentrations are the allowable limit. Water quality in the alluvium should improve substantially because seepage of tailings fluids from unlined tailings ponds will be collected by a deepened seepage interception ditch.

In 1983, at the request of the EID, QMC performed downhole investigations in shafts and ventilation holes to determine the potentiometric surfaces and water quality in the bedrock aquifers at the site.

QMC's investigations determined that all of the bedrock formations were dewatered down to and including the Westwater Canyon Member of the Morrison Formation. Water quality of basal saturation in the Tres Hermanos b Sandstone (Trb) and Dakota Sandstone has been impacted by tailings seepage over substantial areas. The WQCC numerical ground-water standards are exceeded for silver, arsenic, cadmium, chromium, manganese, nickel, lead, selenium, chloride, nitrate, sulfate and TDS in the Trb and Dakota Sandstone. Unlined tailings ponds and evaporation ponds were located over the outcrops and subcrops of the Trb and Dakota. Tailings seepage has moved downdip to the northeast in these aquifers. The removal of unlined ponds 3 through 8 will further prevent tailings seepage from entering the Dakota Sandstone. However, as the tailings ponds 1 and 2 are situated over the subcrop of the Trb, seepage impacts to the Trb will continue. Only a small area of water quality in the Tres Hermanos a Sandstone (Tra) has been influenced by tailings seepage, where concentrations of silver, manganese, nickel, lead, selenium, chloride, sulfate and TDS exceed the WQCC numerical ground-water standards. Some additional water-quality impacts in the Tra may become evident since a portion of the newly expanded unlined tailings Pond 2 will cover the subcrop of the Tra.

QMC has satisfactorily demonstrated to the EID by the downhole investigations and the use of a numerical model that tailings seepage in the bedrock aquifers is captured by the large potentiometric depression created by the mine shafts and ventilation holes. Furthermore, the WQCC

standards should not be violated at a place of reasonably foreseeable future use, because QMC has demonstrated that when the bedrock aquifers are repressurized many years from now, residual tailings seepage will be diluted to below the WQCC numerical ground-water standards.

2. Operating accidents resulting in leaks and small spills within the mill are contained within the confines of the processing areas, which are drained by sumps. Large spills in the mill facility, would be contained by the Spill Prevention, Control and Countermeasure System. The EID's analysis of the site's geology and hydrology and the engineering designs incorporated into the mill supports QMC's conclusion that minimal impacts to ground water should result from a spill within the mill facility.

3. A rupture of the tailings slurry pipeline that carries tailings from the mill to the tailings impoundment is unlikely, because the pipeline is buried for most of its length. Ruptures at points of exposure of the pipeline at the surface would be controlled by containment structures. To detect a possible rupture and prevent possible water quality impacts, fluid pressure within the pipeline is monitored continuously with an alarm that shuts down the pumps in the mill, should an accident occur.

   A break in the tailings dam is not a probable event due to daily monitoring, the operating criteria that maintains a minimum beach length and the quarterly safety evaluation required by the State Engineer. The EID believes that potential releases of radioactivity from the tailings-slurry pipeline and tailings dam are unlikely. Should an accidental release occur, ground water quality impacts would be negligible because of design features and the contingency plans described in QMC's application for Radioactive Materials License Renewal.

4. The QMC mill and tailings facilities are adequately protected from floods resulting from the 100-year storm during operation. Floods in the Arroyo del Puerto resulting from the probable maximum precipitation (PMP) event will not reach the base of the tailings dam. Floods in the west arroyo will not cause tailings to be eroded because rip rap will stabilize the channel surfaces of the west arroyo adjacent to the reclaimed tailings ponds. Ground-water quality impacts from the PMP would be negligible.

1.2 Monitoring Commitments

QMC has proposed an extensive monitoring schedule to protect water quality in the alluvial and bedrock aquifers. The

schedule is designed to detect possible migration of contaminants or increases in existing concentrations.

EID believes that the monitoring schedule and monitor well locations proposed by QMC are sufficient to detect any additional migration of tailings seepage or possible increase in existing concentrations. This will assure that QMC's activities will not cause the WQCC ground-water standards (existing concentrations) to be exceeded in the alluvium and the WQCC numerical ground-water standards to be exceeded in the bedrock aquifers when they repressurize.

2.0 INTRODUCTION

2.1 Discharge Plan Submittal and Review

Quivira Mining Company (QMC, formerly Kerr-McGee Nuclear Corporation) voluntarily submitted a proposed discharge plan (DP-169) for its acid-leach uranium mill and tailings facility located at Ambrosia Lake near Grants, McKinley County, New Mexico, in March 1981. The Director of the Environmental Improvement Division (EID) notified QMC by letter on August 24, 1982, that a discharge plan was required. Pursuant to the Water Quality Control Commission (WQCC) Regulation 3-106A, a discharger cannot discharge without an approved discharge plan after 240 days following written notification that a discharge plan is required. The 240 day period for QMC's DP-169 expired on April 27, 1983. Discharge plan submittals to that date were incomplete and insufficient to support EID approval of the discharge plan. QMC entered into an Assurance of Discontinuance (A of D) with the WQCC on April 12, 1983, to avoid being in violation of the Water Quality Act and WQCC Regulation 3-106, requiring that certain discharges be according to an approved discharge plan. The A of D provided that information necessary for the EID review of the discharge plan would be submitted according to schedule. The discharge plan and A of D submittals describe the potential impacts to ground water which may result from the operation of the mill and tailings facility. The discharge plan was approved March 30, 1984.

This document presents an analysis of QMC's discharge plan conducted by Kent Bostick, a ground-water hydrologist with the EID Ground Water Quality and Hazardous Waste Bureau. The analysis presented herein is based on review of the discharge plan, A of D submittals, quarterly monitoring reports and additional information supplied by QMC to the EID upon request.

As part of the review, the EID technical staff performed ground-water sampling to provide an independent analysis of the site conditions. This discharge plan analysis assesses whether QMC's discharge plan satisfies the technical requirements of the WQCC Regulations. Major provisions of the WQCC Regulations require that ground water having an existing total dissolved solids concentration of less than 10,000 milligrams per liter (mg/l) is to be protected from contamination resulting from discharges onto or below the surface of the ground. WQCC numerical ground-water standards are established at the point of present or foreseeable future use for arsenic, barium, cadmium, chromium, cyanide, fluoride, lead, total mercury, nitrate, selenium, silver, uranium, combined radium-226 and radium-228 radioactivity, and eight other parameters, based on human health criteria. There are

14 additional standards based on criteria for secondary domestic and irrigation use and a provision that the discharge must not cause a toxic pollutant (as defined in Section 1-101.UU of the Regulations) to be present at a place of foreseeable future use.

A proposed discharge plan shall set forth, in detail, the methods or techniques the discharger proposes to use or processes expected to naturally occur which will ensure ground-water protection. The discharger must demonstrate that approval of the discharge plan will not result in concentrations in excess of the WQCC ground-water standards or the presence of a toxic pollutant at any place of withdrawal of water for present or reasonably foreseeable future use. The Regulations state: "If the existing concentration of any water contaminant in ground water is in conformance with the standard of Section 3-103 of these regulations, degradation of the ground water up to the limit of the standard will be allowed." In the case where the existing concentrations in the aquifer exceed the WQCC numerical ground-water standards: "When an existing pH or concentration of any water contaminant exceeds the standard specified in Subsection A, B, or C, the existing pH or concentration shall be the allowable limit."

Provided that the other requirements of these Regulations are met, the EID director shall approve a proposed discharge plan if the discharge will not result in WQCC ground-water standards being violated or a toxic pollutant being present at the place of use in the present or reasonably foreseeable future.

2.2 General Description of Mill and Tailings Facilities

QMC's mill and tailings facilities are located in Section 31, T14N, R9W, McKinley County, New Mexico (Figure 1). The mill uses an acid-leach circuit to process uranium ore. In 1983, the milling rate was approximately 3000 tons per day of operation, with an operating schedule of 8 days on, 6 days off. The mill has a nominal capacity to process 7000 tons of uranium ore per day.

Approximately 2200 gallons per minute (gpm) of mine water is now supplied from QMC's mines to the uranium mill. Before reaching the mill, the water is processed at ion exchange plants for the extraction of uranium. Most of the mine water (approximately 1970 gpm) is stored in a make-up reservoir located near the mill (Figure 2). Slightly less than 290 gpm is withdrawn from the reservoir, subjected to barium chloride treatment to precipitate radium and released to the Arroyo del Puerto, an ephemeral stream shown in Figure 2. About 1380 gpm of the make-up water for the mill is derived from the reservoir and another 240 gpm is derived directly from the ion

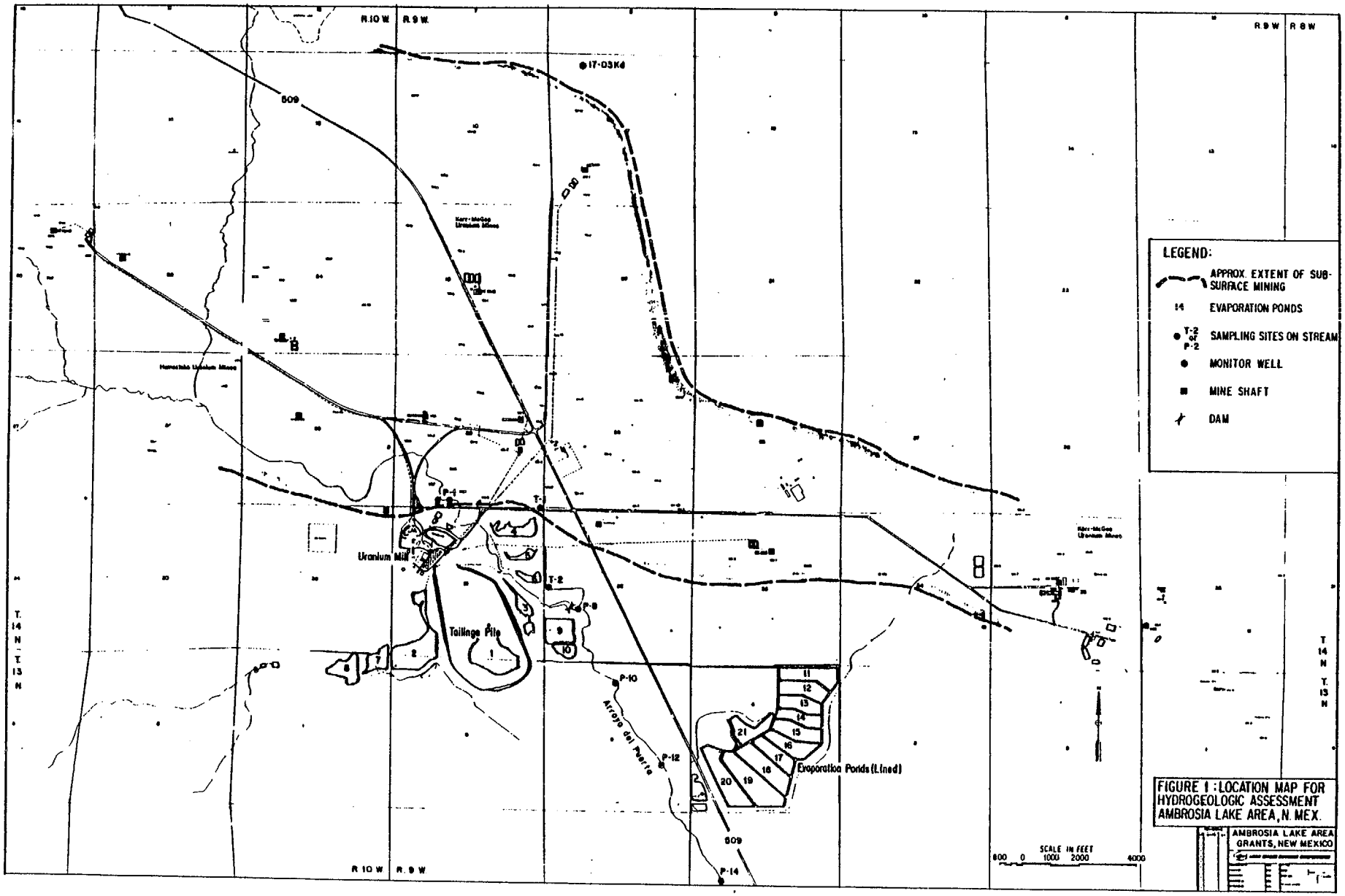


FIGURE 1 : LOCATION MAP FOR HYDROGEOLOGIC ASSESSMENT AMBROSIA LAKE AREA, N. MEX.

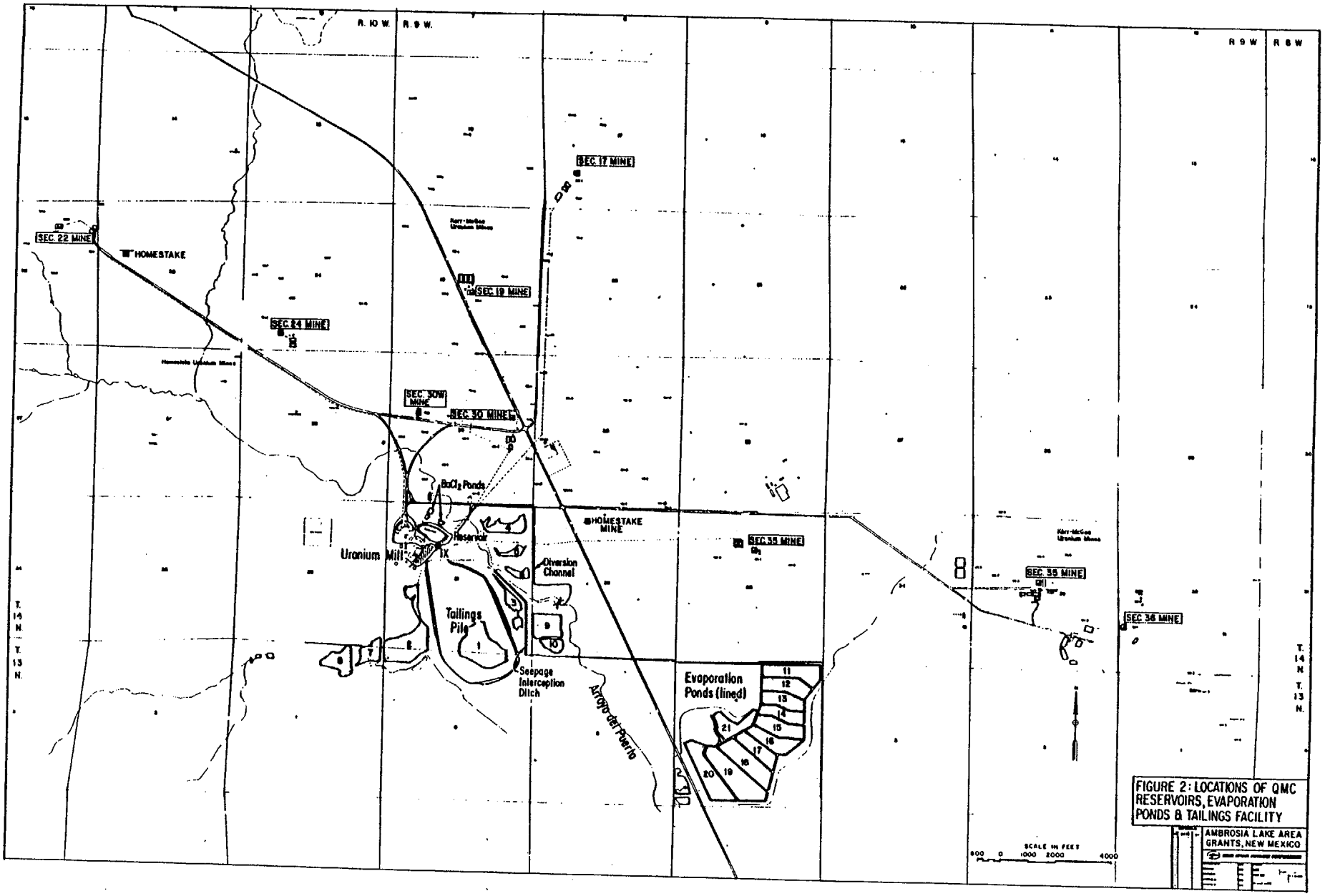


FIGURE 2: LOCATIONS OF QMC RESERVOIRS, EVAPORATION PONDS & TAILINGS FACILITY

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

exchange plants and is treated for use in the mill office and for private consumption.

Most of the uranium is removed from the ore in the acid-leach milling process. However, the weight of the uranium in the ore is less than .02 of one percent. The waste from the ore, called tailings, is transported from the mine to the tailings ponds in a slurry form by pipeline.

The slurry is approximately one-half liquid by weight. The slurry is deposited in tailings Ponds 1 and 2, shown on Figure 2. Separation of liquid and solids occurs in the tailings ponds. Decant towers collect part of the clarified liquid, which is piped to an ion-exchange facility. This facility removes additional uranium from the tailings liquid. The liquid is then recycled into the mill circuit.

The tailings embankment is made of coarse tailings, and "marginal" weeping is intended to occur. Liquids weeping from the tailings are collected in a seepage interception ditch around the tailings facility, formerly Pond 3 (as shown on Figure 2). However, QMC has committed to eliminate the use of Pond 3 and deepen the seepage interception ditch to the East of Pond 3 (Figure 2) to capture seepage weeping from the tailings ponds. Seepage collected in the interception ditch will be discharged into lined Pond 9 which will subsequently replace Pond 3 as a decant pond. From Pond 9, collected seepage will be discharged to lined ponds in Section 4, covered under a separate discharge plan (DP-71), or returned to the mill for recycling. Pond 10, a lined evaporation pond, will be repaired and used for the same purpose as Pond 9. QMC has permanently discontinued the discharge of any fluids to unlined evaporation Ponds 4, 5, 6, 7 and 8 and is transferring residual tailings in Ponds 7 and 8 to the unlined tailings Ponds 1 and 2. Before reclamation of unlined ponds 4, 5, 6, 7 and 8, QMC estimated by water balance that as much as 585 gpm of tailings fluid was lost by evaporation and 203 gpm was lost by seepage from the unlined evaporation and tailings ponds. Evaporation and seepage is substantially reduced by the fact that QMC presently discharges to only unlined tailings ponds 1 and 2, and the decant is transported to lined ponds for evaporation.

2.3 Potential Points of Discharge and Impacts on Ground Water

The operation of the mill and tailings facilities produces several possible points of effluent discharge. This analysis addresses each of the following possible points of discharge and their potential impact on ground-water quality:

1. Ground-water quality impacts from tailings facility;

2. Ground-water quality impacts from the mill facility;

3. Ground-water quality impacts from potential releases of radioactivity and other contaminants from the tailings-slurry pipeline and tailings dam; and

4. Ground-water quality impacts from flooding.

2.4 Summary of Hydrogeologic Setting

QMC's mill and tailings facility is located north of the Zuni Uplift portion within the San Juan Basin. The basin is characterized by broad areas of relatively flat-lying sedimentary rocks, dipping to the northeast, with portions of the basin covered with alluvium and basalt flows. The site is within the Ambrosia Lake valley that extends from the western side of Mount Taylor. The stratigraphic sequence of hydrologic significance at the site consists, in descending order of the alluvium, the Mancos shale and the Tres Hermanos sandstones, the Dakota Sandstone and the Brushy Basin and Westwater Canyon members of the Morrison Formation. A cross-section showing the structural relationships of the geological formations is given in Figure 3. The alluvium rests on the erosional surfaces of the bedrock and is saturated in the vicinity of Arroyo Del Puerto, due to the discharge of mine waters into the ephemeral streambed and seepage from unlined evaporation ponds and unlined tailings ponds. Depth to water in the alluvium is from 0 to 60 feet. The bedrock formations above the Westwater Canyon Member of the Morrison Formation (hereafter designated the WCM) have been dewatered by ventholes and mine shafts located to the north of QMC's mill and tailings facility. Recharge to the bedrock aquifer occurs along the outcrop areas and flows northeast toward potentiometric depressions caused by mine dewatering (Figure 4). Aquifers below the WCM will not be discussed because dewatering of the WCM in the Ambrosia Lake mining area has created an upward hydraulic gradient, thereby precluding water quality impacts in aquifers lower than the Westwater (Figure 5).

Figures 4

2.5 Ground Waters to be Protected

QMC's minewater discharges to the Arroyo del Puerto and seepage from unlined evaporation ponds and tailings ponds have created a condition of saturation in the alluvium along the Arroyo del Puerto Channel. Alluvial ground water along the Arroyo del Puerto Channel to the east and south of the QMC mill and tailings facility, must not be degraded above the WQCC numerical standards or existing concentrations, whichever are higher.

Three sandstone members of the Tres Hermanos Formation (Trc,

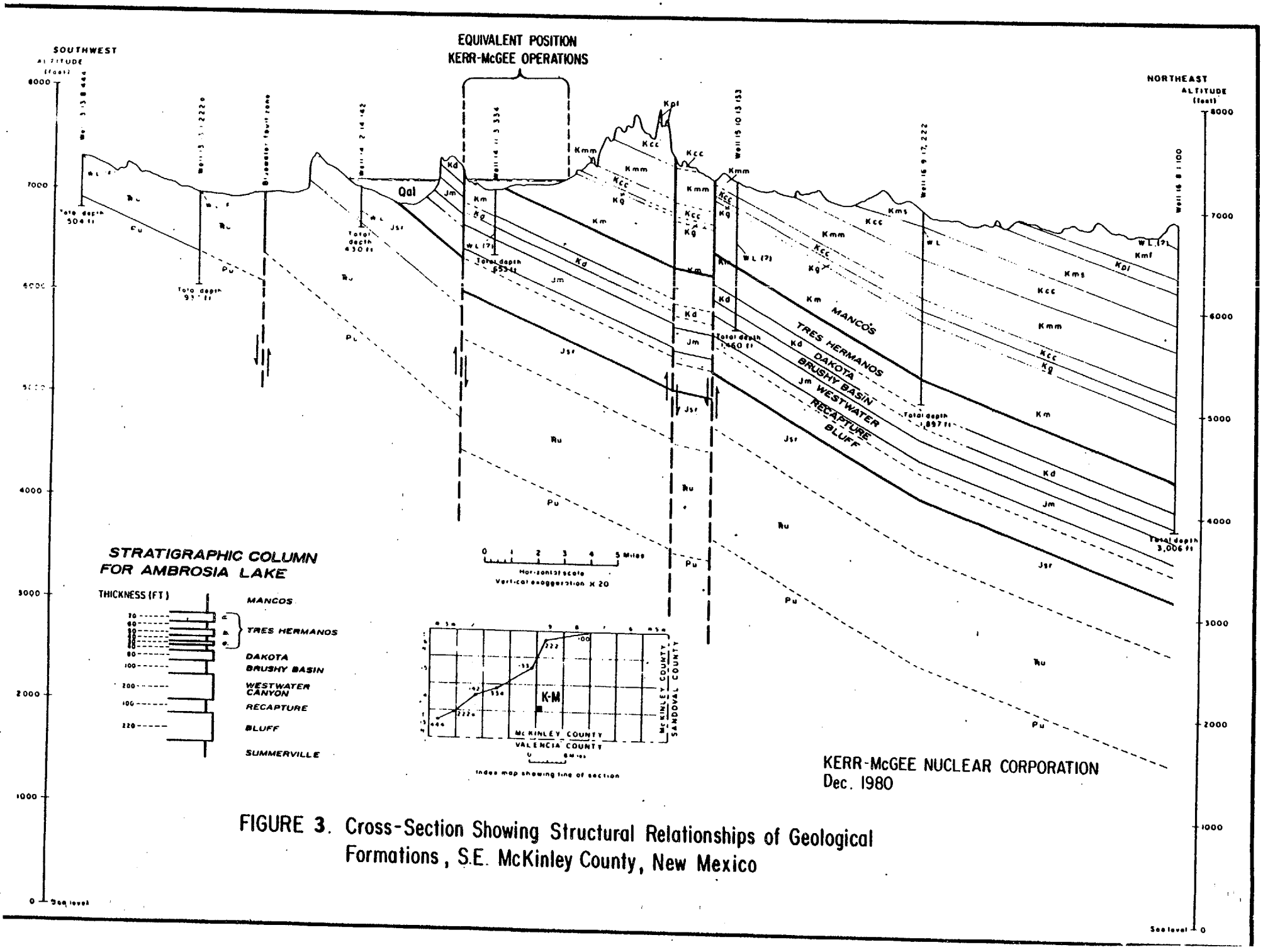


FIGURE 3. Cross-Section Showing Structural Relationships of Geological Formations, S.E. McKinley County, New Mexico

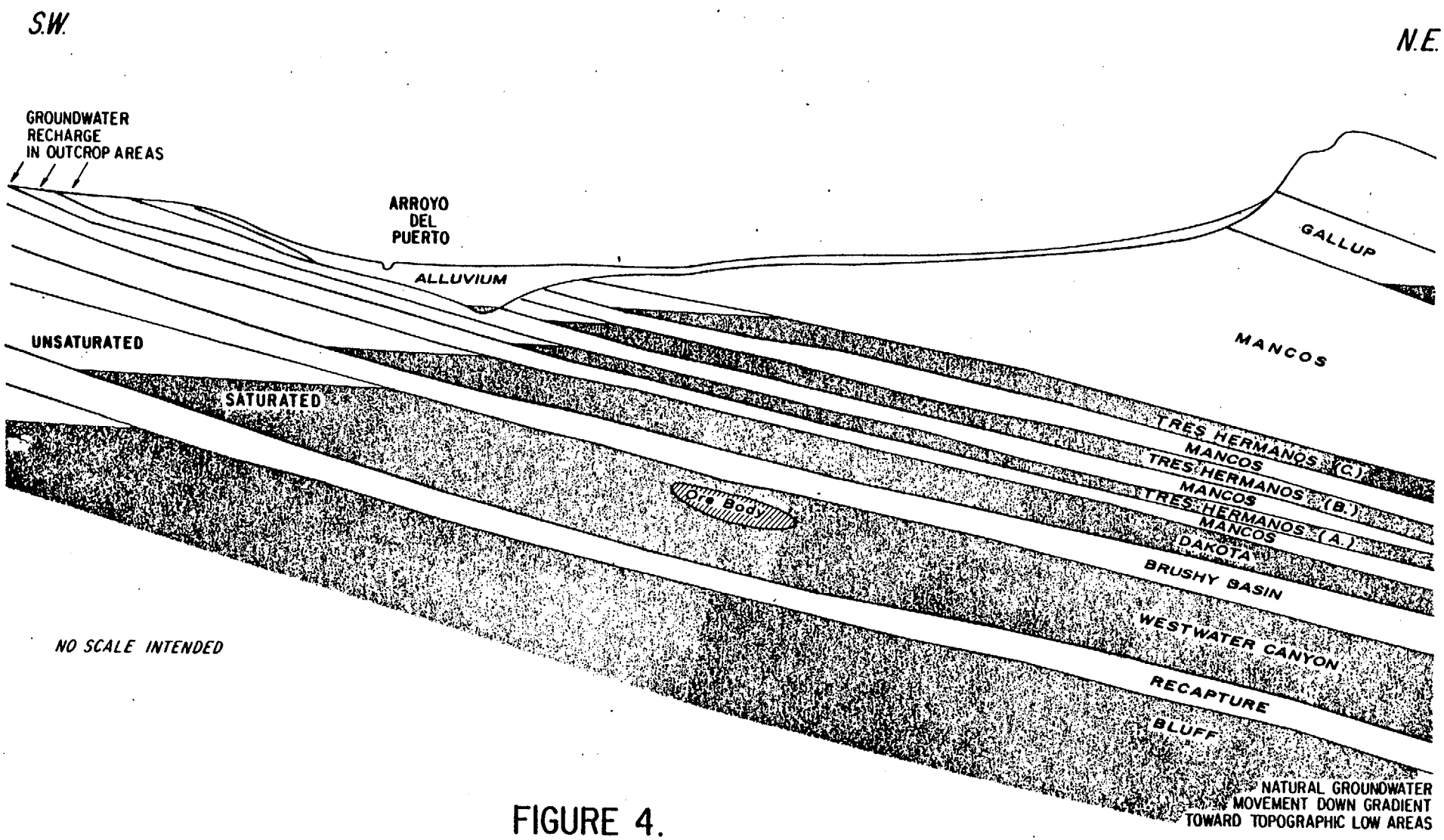


FIGURE 4.

NE-SW CROSS-SECTION THROUGH AMBROSIA LAKE AREA-GENERALIZED PRE-MINING CONDITIONS

KERR-McGEE NUCLEAR CORPORATION Dec. 1980

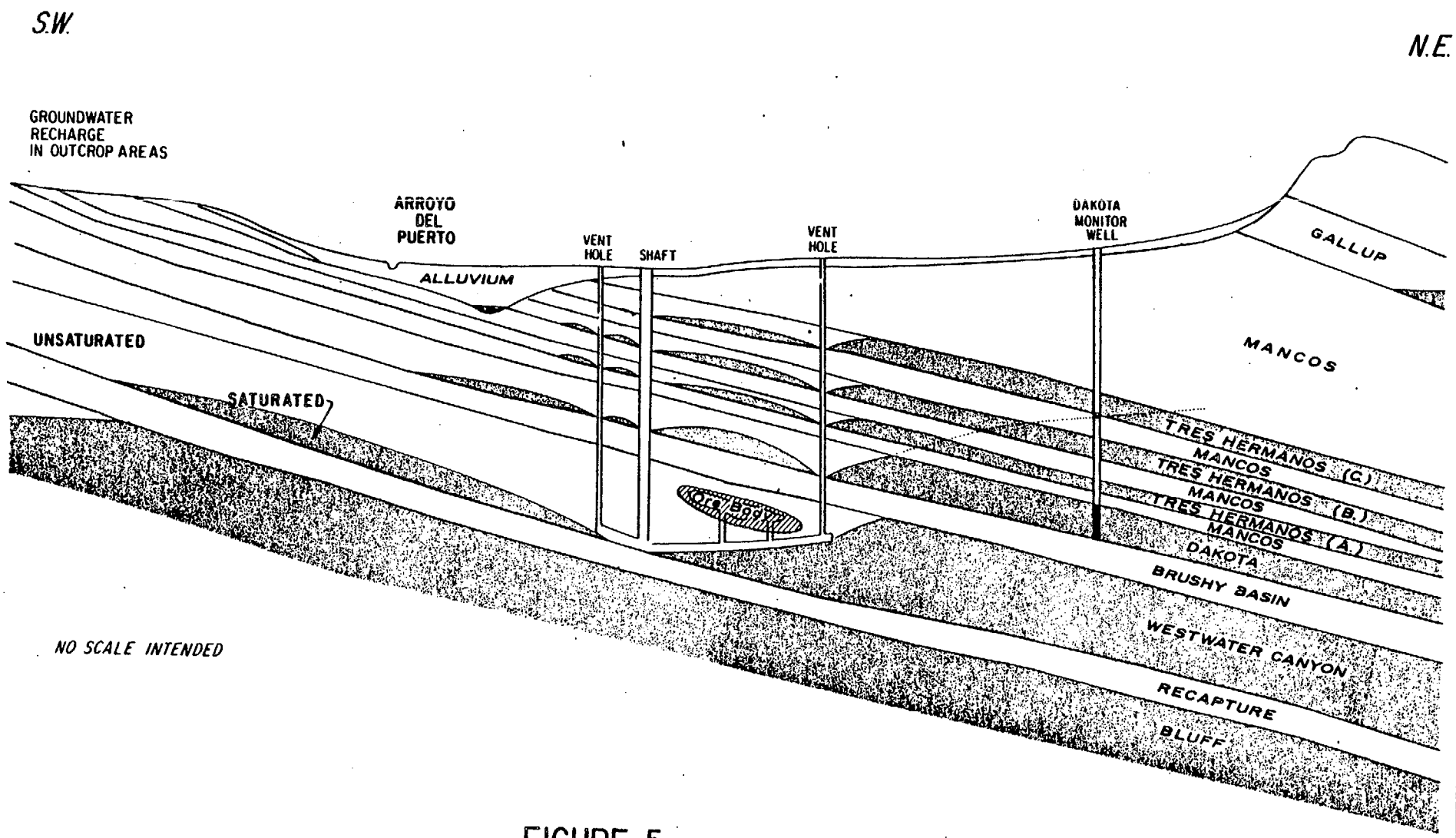


FIGURE 5.

NE-SW CROSS-SECTION THROUGH AMBROSIA LAKE AREA - GENERALIZED MINING CONDITIONS

KERR-McGEE NUCLEAR CORPORATION Dec. 1980

Trb and Tra) and the Dakota Sandstone are water bearing at the site. Water quality in the Trb and the Dakota Sandstone has been extensively influenced by tailings seepage at the site, whereas the water quality in the Tra has been influenced in only a small area by tailings seepage. However, these formations have been almost completely dewatered at the site. They therefore cannot be considered to be aquifers of foreseeable future use until they are allowed to repressurize, which would probably occur several hundred years from the present.

The WCM at the site is a point of ground-water discharge because of mine dewatering, and tailings seepage should not affect water quality in this aquifer.

3.0 GROUND-WATER QUALITY

IMPACTS FROM TAILINGS FACILITY SEEPAGE

According to a water balance prepared by QMC in 1980, approximately 203 gpm of tailings fluids seeped to ground water from tailings Ponds 1 and 2 and evaporation Ponds 4, 5, 6, 7 and 8. However, seepage water at the mill site will be substantially less now that QMC has discontinued the use of unlined evaporation ponds. Seepage that leaves the unlined tailings Ponds 1 and 2 will be collected in a seepage interception ditch and discharged to lined evaporation Pond 9.

Tailings fluids in the tailings ponds are characterized by high chlorides, sulfates, TDS and low pH. Concentrations of heavy metals and radionuclides are also high including Ra-226, Th-230, and U-238. Tailings fluid constituent concentrations exceed most numerical WQCC ground water standards.

3.1 Tailings Facility Description

Tailings have been discharged at the site since 1958. The original tailings Pond 1, shown on Figure 2, covers 263 acres, stands from 25 to 90 feet high and contains 28 million tons of tailings. Tailings effluents were also previously discharged to unlined evaporation Ponds 4, 5, 6, 7 and 8. However, discharges to these unlined ponds were discontinued pursuant to the A of D in 1983. The ponds were allowed to drain, tailings salts were removed and placed in Ponds 1 and 2 and suitable reclamation cover was emplaced in the ponds to prevent continued leaching of any residual tailings salts. Some tailings have also been previously discharged to Pond 2. However, in 1984, Pond 2 was expanded to include the tailings starter dam. For the next few years tailings will be discharged to Pond 2. Pond 3 previously served as a decant for Pond 1. However, pursuant to the A of D, discharges of Pond 3 ceased in 1984 and effluents collected in the seepage interception ditch will be pumped directly to the lined evaporation Pond 9. The physical characteristics of QMC tailings ponds and evaporation ponds are summarized in Table 1.

Pond 1 rests on part of the subcrop of the Tres Hermanos b (Trb) Sandstone. Pond 2 is situated on part of the Trb and Tres Hermanos a (Tra) subcrops. The locations of the subcrops are shown on Figures 6 and 7. The tailings ponds were constructed using permeable native materials and seepage enters the subcrops and flows downdip to the northeast in each of these formations. Seepage impacts from the tailings facilities have impacted water quality in the alluvium the Trb and Dakota Sandstone (discussed in Sections 3.2.1.3 and 3.2.2.3 of this report). Because tailings Ponds 1 and 2 have

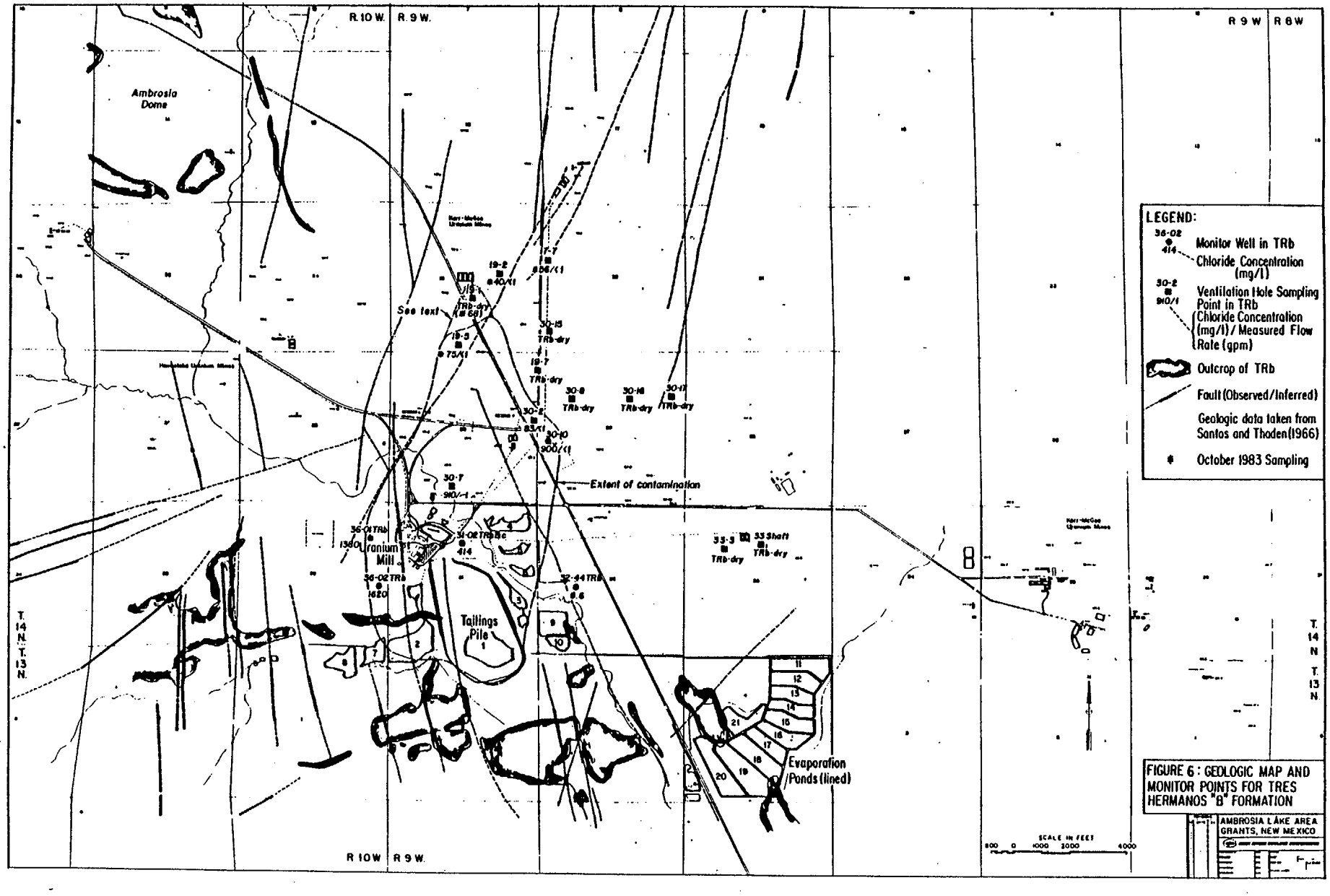


FIGURE 6: GEOLOGIC MAP AND MONITOR POINTS FOR TRES HERMANOS "B" FORMATION

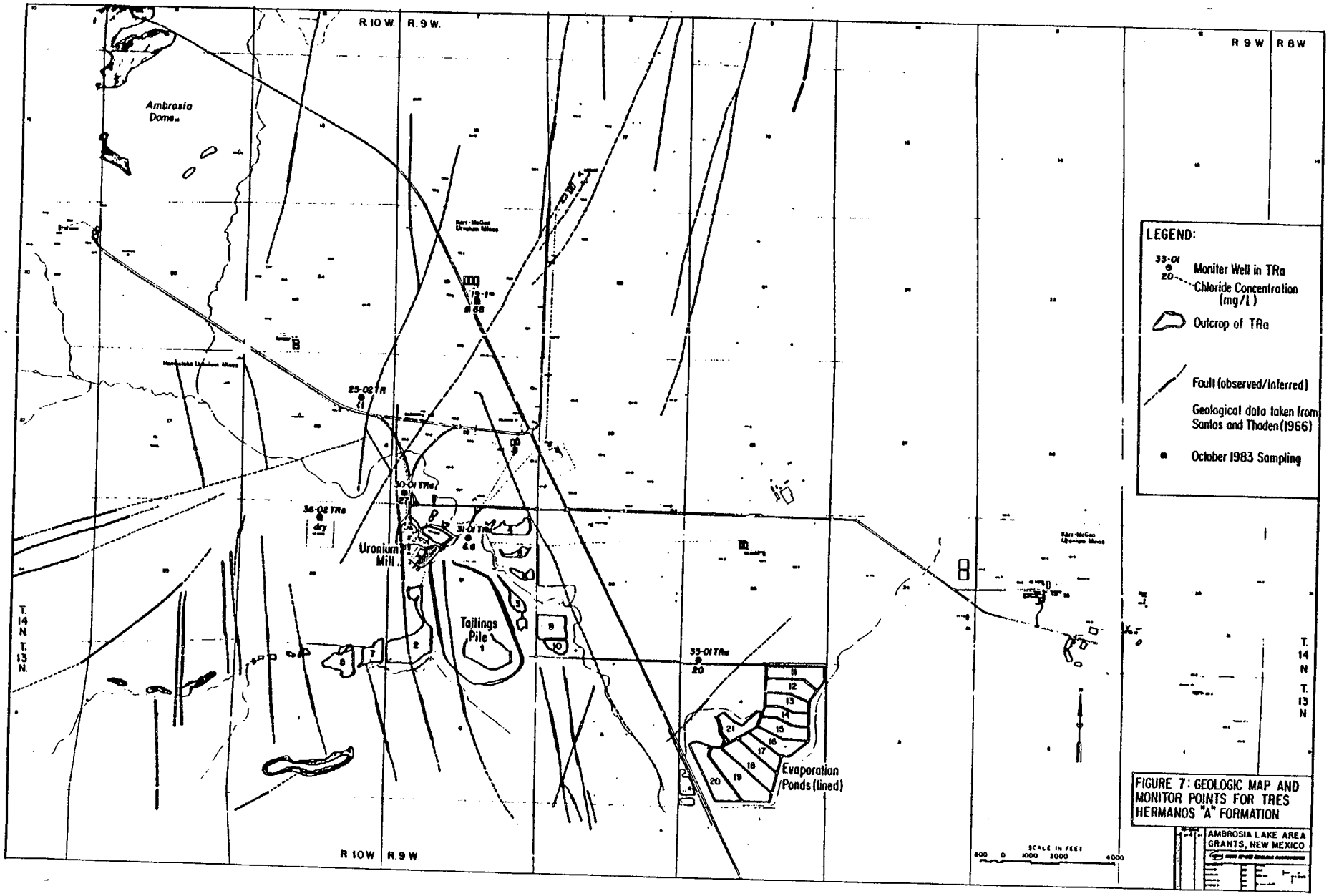


FIGURE 7: GEOLOGIC MAP AND MONITOR POINTS FOR TRES HERMANOS "A" FORMATION

been expanded to cover part of the Tra subcrop, seepage impacts on ground-water quality are anticipated in this water-bearing sandstone.

The seepage interception ditch shown on Figure 2 is used to collect seepage from the embankments of tailings Ponds 1 and 2 after the seepage enters the alluvium and moves downdip in the Trb sandstone and alluvium. The seepage interception ditch will be excavated into the Trb sufficiently to create a potentiometric sink in the alluvium and Trb, thereby preventing tailings seepage from migrating beyond this hydraulic barrier. Tailings seepage collected in the seepage interception ditch will be discharged to Pond 9, a lined evaporation pond, which should have no water quality impacts. Pond 10 will also be used as a lined evaporation pond once its liner is repaired.

For the purpose of this report, the tailings facility to be considered in the following discussion will include Ponds 1 and 2, the seepage interception ditch and the evaporation Ponds 9 and 10.

3.1.1 Chemical Analyses of Tailings Liquid and Make-up Reservoir

Tailings liquid has a high chloride, sulfate, total dissolved solids content and low pH. High concentrations of heavy metals and radionuclides, including Ra-226, Th-230 and U-238. A comparison of tailings liquid contained in Ponds 1, 2 and 9 with the WQCC numerical ground-water standards is given in Table 2. Tailings liquid constituent concentrations exceed the standards for many human health parameters.

The mill circuit uses kerosene, isodecanol and alamine in the milling process. QMC believes that most of the organics are contained in the milling process and are not found in the tailings fluids. To ascertain whether or not these organics were present in the effluent, both the EID and QMC sampled for purgeable organics. While none of the analyses confirmed the presence of kerosene, isodecanol or alamine, the tailings fluids were characterized by a moderately high total organic carbon (50 mgC/l). Analyses also confirmed the presence of dimethyl selenium, an extremely toxic compound. However, present analytical methods available to the EID did not allow for quantification of dimethyl selenium.

Water quality in the make-up reservoir exceeds the WQCC numerical ground-water standards for selenium, sulfate and TDS. Analyses of make-up reservoir water quality are presented in Table 2.

Table 1. Evaporation Pond Characteristics, 1979
(Maximum Area and Volume Reported in 1979)

Pond	Area (Acres)	Volume (Acre-feet)	Date of Construction	Remarks
1	62	372	1958	Unlined
2	46	299	1958	Unlined; in contact with Tres Hermanos (outcrop)
3	27	53	1958	Unlined
4	13	26	1958	Unlined
5	11	16	1958	Unlined
6	8	16	1958	Unlined
7	12	13	1961	Unlined; in contact with Tres Hermanos (outcrop)
8	24	24	1961	Unlined; in contact with Dakota (outcrop)
9	24	73	1976	Plastic lined
10	7	17	1976	Plastic lined; needs remedial work
TOTALS (Approximately)				
	234 Acres	909 Acre-Feet		

At maximum capacity, the ponds total about 234 acres in area.

Table 2. Chemical Analyses of Tailings Liquid and Make-Up Reservoir[1]

Sample Collection Points

Parameter (mg/l)	11/9/81 Make-Up Reservoir	11/9/81 Pond 1	11/9/81 Pond 3	5/17/83 Pond 9	WQCC Numerical Standard
Mg	70	1,995	509		
HCO_3	195	<1	<1	0	
Ca	227	756	411		
Cl	58	2,774	990	38,927	250
K	98	109	25	185	
Na	292	1,327	800	36,685	
SO_4	1,188	37,483	6,454	63,005	600
TDS	2,056	44,484	10,844	206,135	1,000
NO_3 as n		11	1.8		10
NH_3 as n		289	99		
As	.017	3.9	.25		0.1
Ba	.1	<.1	<.1		1.0
Cd	<.001	0.05	.014		0.01
Pb	<.005	0.41	.038		0.05
Mo	.9	18.9	1.6		1.0
Se	.082	0.315	.054		.05
U_3O_8	1.74	4.9	5.0		5.0
V	.015	81.9	11.1		
Zn	.05	38.1	5.2		10
Mn	.067	176	29		0.2
Al	<.25	2,000	275		5.0
Fe	<.1	3,870	260	1.65	0.2
pH		1		between 6 and 9 ph units	

[1] EID samples analysed at the NMSLD.

Ground water quality in the alluvium, discussed in Section 3.2.1.3 of this report, is much higher in these parameters and seepage from the reservoir should not cause existing concentrations to be exceeded. Therefore, ground water quality impacts of seepage from the reservoir will not be discussed further.

3.1.2 Seepage Rate by Water Balance

In 1980, QMC prepared a water balance for the QMC discharge plan (DP-169). A summary of the water balance is presented below and a schematic diagram of the water balance is presented in Figure 8. While quantities of discharge are less now than in 1980, because of the reduction of milling rate and the discontinuance of the use of unlined evaporation Ponds 3, 4, 5, 6, 7 and 8, the discharge quantities presented represent a worst case analyses of possible seepage rates from the tailings ponds.

In 1980, approximately 2200 gallons per minute (gpm) of mine water was supplied by QMC mines to the company's uranium mill. Most of the mine water (1970 gpm) was stored in the make-up reservoir shown on Figure 2. However, 290 gpm of water was withdrawn from the reservoir and discharged to Arroyo del Puerto. This discharge is covered under a National Pollutant Discharge Elimination System permit. Approximately 30 gpm was lost from the reservoir in evaporation and 270 gpm in seepage. The remaining 1380 gpm, along with 240 gpm derived directly from the ion exchange plants, was employed for mill use and office or other use.

In 1980, approximately 1638 gpm of waste water from the mill was released to tailings Pond 1 and decanted to Pond 3. Tailings fluid in Pond 3 was previously pumped to ponds 4, 5, 6, 7, 8, 9 and 10 and Section 4 Ponds for evaporation. Ponds 1 through 10 collectively lost 585 gpm to evaporation and 203 gpm to seepage. Approximately 35 gpm of seepage from the make-up reservoir and evaporation ponds was collected at a dam across old Arroyo del Puerto creek bed and returned to the ponds. The remaining fluid is thought by QMC to go into storage in the tailings and evaporation ponds.

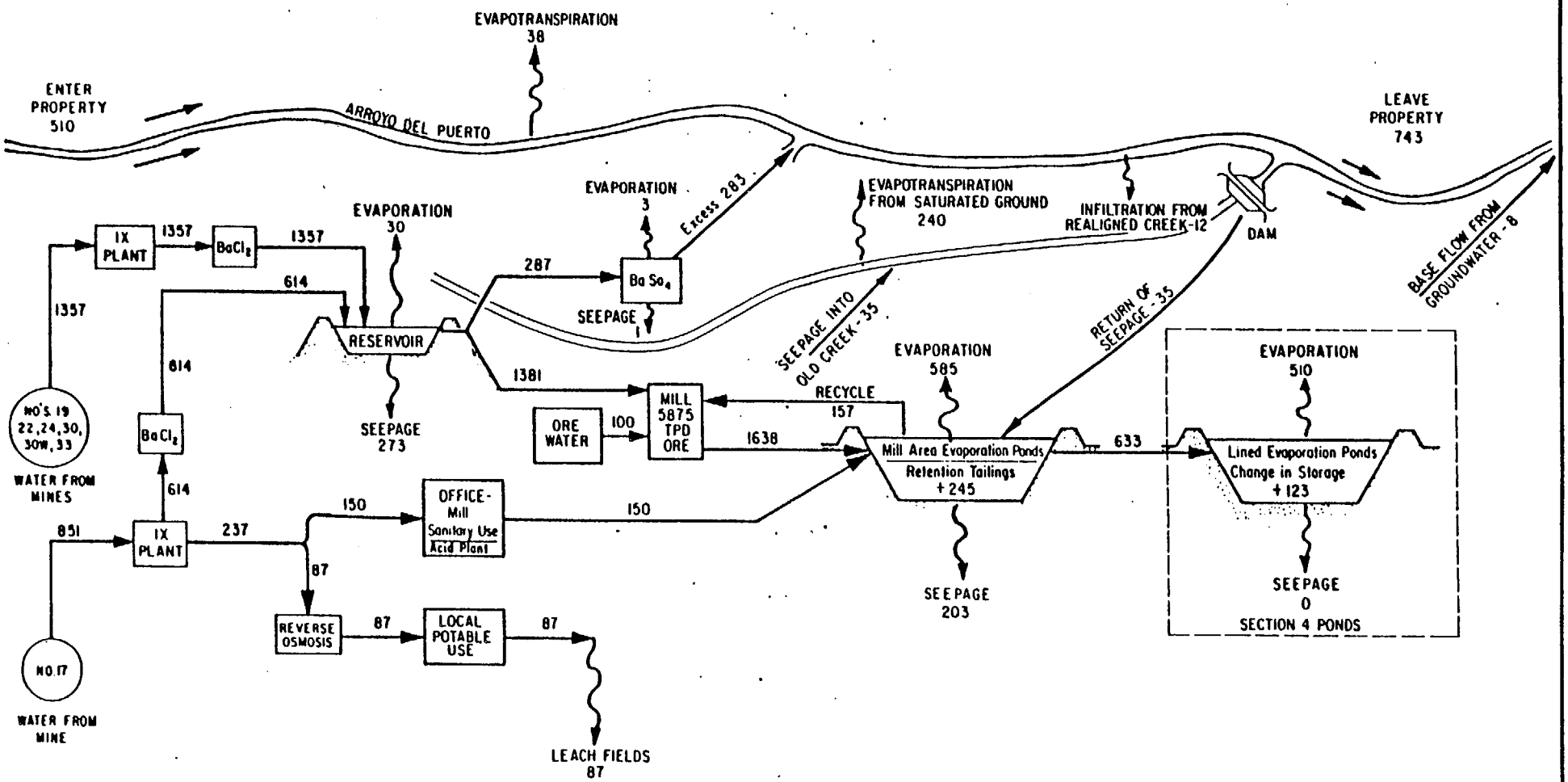
Seepage that leaves Ponds 1 and 2 in the alluvium will be collected by the seepage interception ditch and discharged to lined evaporation Pond 9.

3.2. Hydrogeologic Investigations

3.2.1 Alluvium

Mine dewatering discharges from the Westwater, Dakota and Tres

WATER BALANCE
KERR-McGEE OPERATIONS-AMBROSIA LAKE
Average Values* for 1979



* VALUES ROUNDED IN GALLONS PER MINUTE (GPM)

KERR-McGEE NUCLEAR CORPORATION
Dec. 1980

FIGURE- 8 Schematic Diagram of the Water Balance

Hermanos aquifers have created a condition of saturation in the alluvium in a one-half mile wide channel along the length of the Arroyo del Puerto. Seepage from the make-up water reservoir and unlined tailings Ponds 1 and 2, decant Pond 3 and unlined evaporation Ponds 4, 5, 6, 7 and 8 have also contributed to saturation. Ground water in the alluvium at the mill site flows northeastward along erosional subcrops of the bedrock until it becomes recharge to the bedrock aquifers. Ground water in the alluvium to the southeast of mill site moves to the southeast as underflow in the Arroyo del Puerto channel.

Water quality in the alluvium reflects the influence of mine water discharges to the Arroyo del Puerto, leakage from the make-up water reservoir and seepage from the unlined tailings and evaporation ponds. Analyses of ground-water samples from wells indicates that the alluvium has a substantial capacity to buffer the low pH of tailings fluids and cause the precipitation of heavy metals. However, although existing concentrations of arsenic, boron, cadmium, chromium, lead, selenium, nitrate, chloride, sulfate and TDS exceed the WQCC numerical ground water standards, the existing standards are the allowable limit. Water quality in the alluvium should improve substantially as seepage of tailings fluids from unlined tailings ponds is collected by the deepened seepage interception ditch.

3.2.1.1 Hydrogeologic description

Alluvium, consisting of wind and water-transported material, has been deposited in canyons incised into the erosional surface of the Mancos shale and Tres Hermanos sandstones. These canyons contain as much as 100 feet of sediment. An isopach map for the alluvium is presented in Figure 9. Alluvial channels lie below the Arroyo del Puerto and the arroyo that contains Ponds 7 and 8. Alluvial material has been frequently logged as very fine-grained sand and clay with occasional basal gravel layers. Layering and stratification of these materials is common in the alluvium and is generally related to wind deposition and soil horizon development.

3.2.1.2 Water levels

According to QMC, no records of water in the alluvium were made prior to mining activity. One well in the alluvium began to indicate basal saturation of the alluvium three years after mining and milling began. By 1957, several companies were pumping substantial quantities of good quality ground water from the WCM, Dakota sandstone and Tres Hermanos sandstones into the Arroyo del Puerto or its tributaries creating a line source of recharge to the alluvium that extended to San Mateo Creek in the southeast.

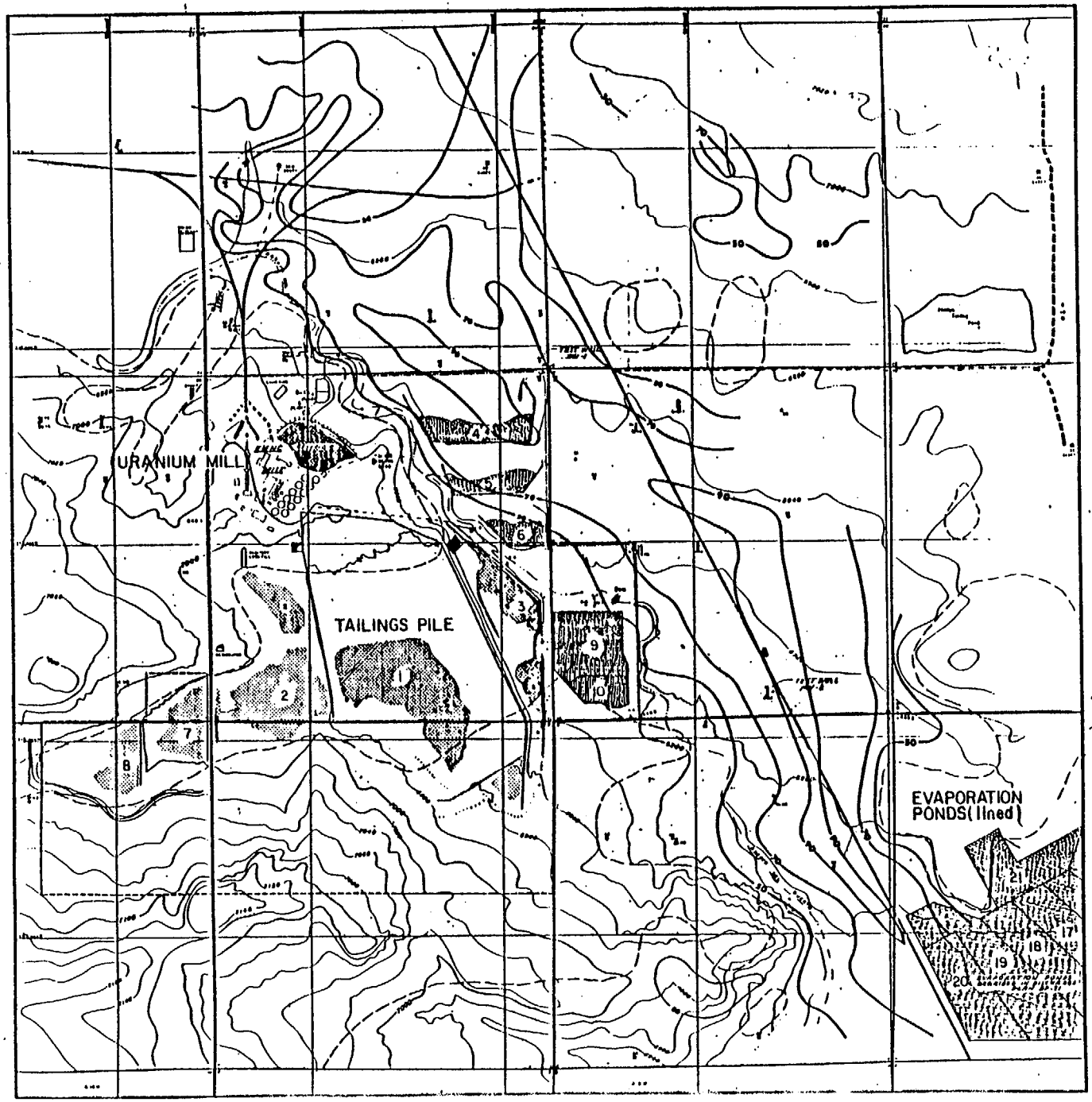


FIGURE 9: ISOPACH MAP OF ALLUVIUM

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Dec. 1980

Presently, the alluvium is saturated in a one-half mile channel along the length of the Arroyo del Puerto. A water table map for the alluvium in 1980 is presented in Figure 10. Examination of water elevation contours indicates that the mill site and tailings facility is also a source of recharge to the alluvium. In 1980, the make-up water reservoir and Ponds 1 through 8 probably contributed to the saturation of the alluvium in addition to the minewater discharged to the Arroyo del Puerto. Alluvial ground water flows northeastward along the erosional subcrops of the bedrock aquifers until it becomes recharge to the bedrock aquifers. Ground water in the alluvium to the southeast of the mill site moves to the southeast as underflow in the Arroyo del Puerto channel. QMC has committed to several activities which will modify the existing (1980) water table. By 1984 the only remaining sources of recharge to the alluvium at the mill site will be seepage from unlined tailings Ponds 1 and 2 and the make-up reservoir. The Arroyo del Puerto will still be a line source of recharge to the alluvium; however, water levels to the west of the Arroyo del Puerto will be kept at elevation 6890 feet by the seepage interception ditch, shown on Figure 11. A complete discussion of this follows in Sections 3.2.1.6 and 3.2.1.7.

3.2.1.3 Water Quality

Water quality in the alluvium reflects the influence of three sources: mine water discharges to the Arroyo del Puerto, leakage from the make-up water reservoir and seepage from the unlined tailings and evaporation ponds. An isospecific conductivity map for the alluvium in 1980 is presented in Figure 12. The general configuration of total dissolved solids can be estimated by multiplying the specific conductivity by 0.7. Alluvial ground water with a conductivity between 2000 and 4000 UMHOS are indicative of mine-water recharge to the alluvial aquifer in the vicinity of Arroyo del Puerto. The influence of seepage from unlined Ponds 1, 2, 3, 4, 5 and 6 on water quality in the alluvium is portrayed in Figure 12 by the extension of the 8,000 UMHOS conductivity line. Water-quality analyses for 9 wells representative of the alluvium are presented in Table 3. Locations of these wells are shown on Figure 13. Inspection of these analyses suggests that the alluvial materials have substantial capability to buffer the low pH of the tailings fluids and cause precipitation or adsorption of some heavy metals. However, arsenic, boron, cadmium, chromium, lead and selenium still exceed the WQCC numerical ground-water standards. Nitrate, chloride, sulfate and TDS also exceed the standards.

Because existing concentrations in the alluvium exceed the

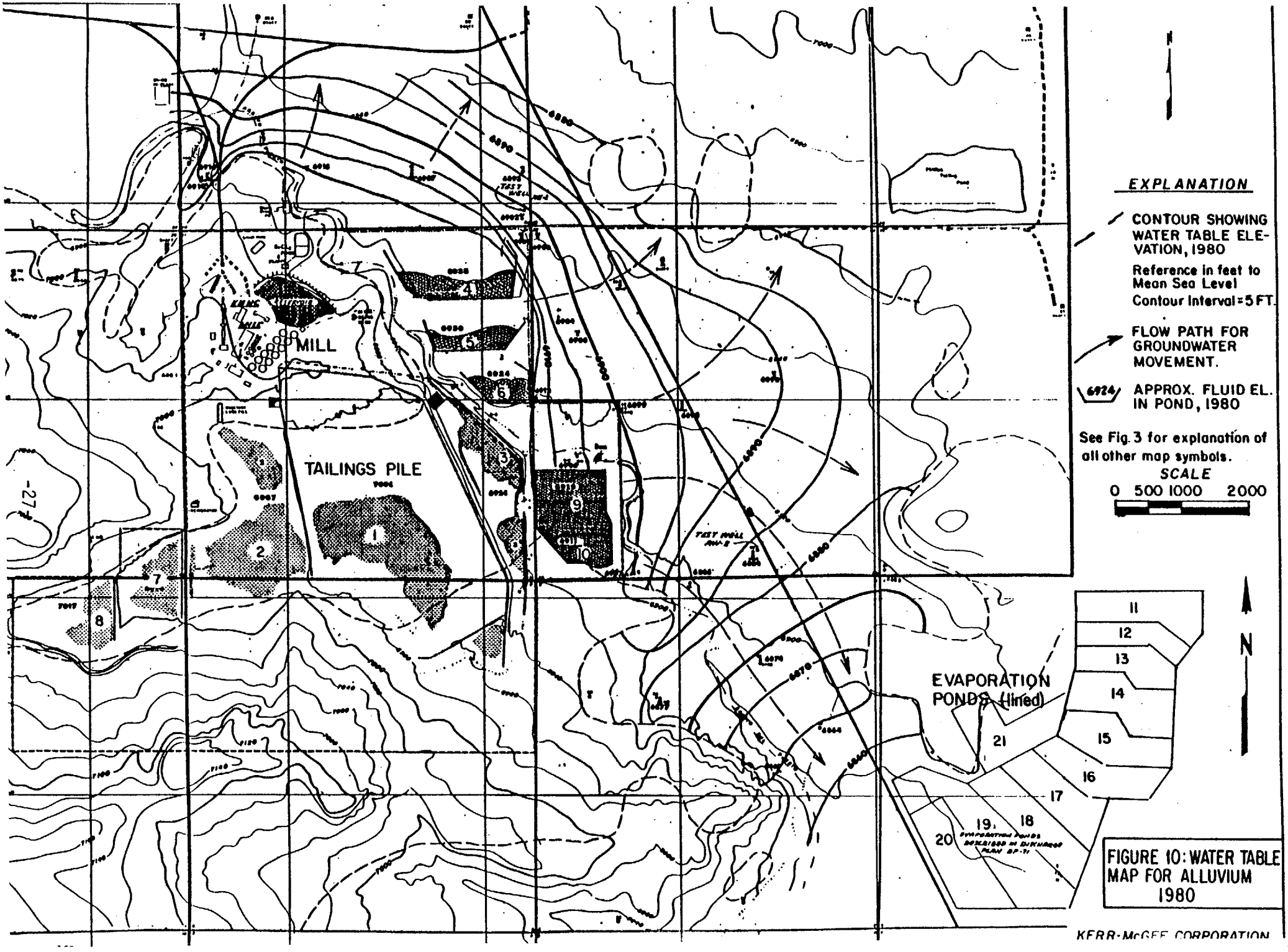
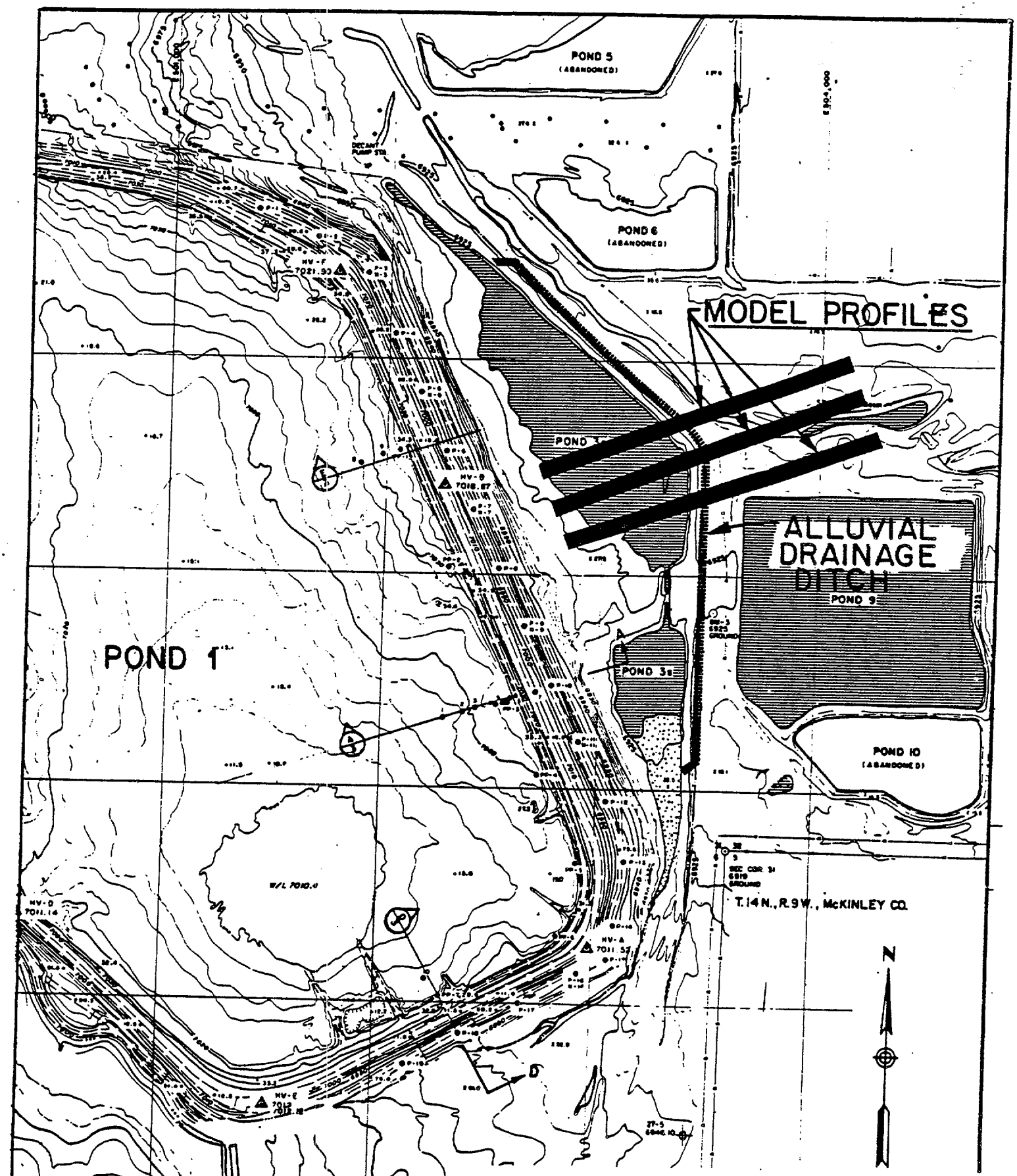


FIGURE 10: WATER TABLE MAP FOR ALLUVIUM 1980

KERR-McGEE CORPORATION

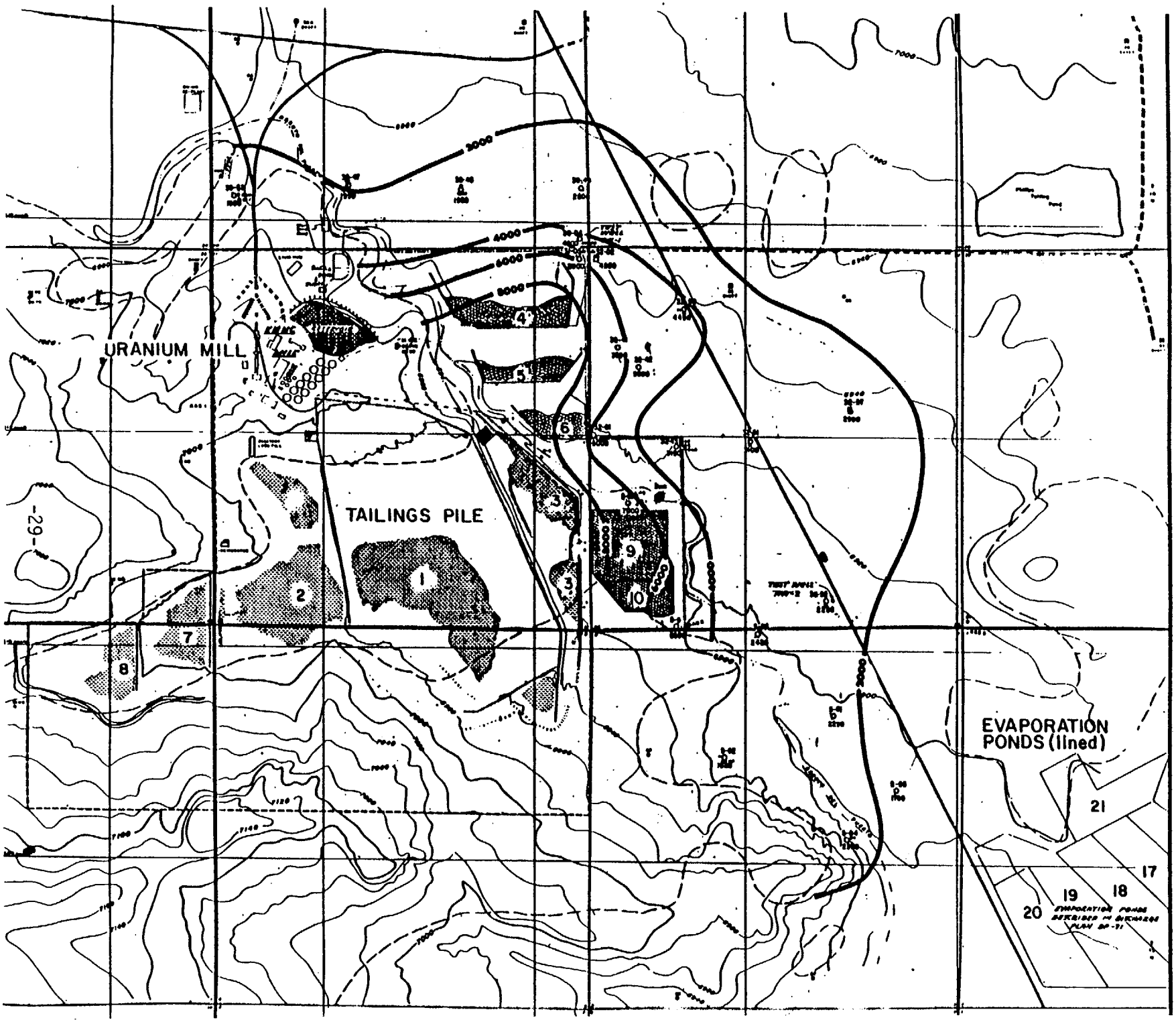


REVISIONS		
NO	DATE	BY

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

KERR-McGEE NUCLEAR CORPORATION

FIGURE 11 : LOCATION OF SEEPAGE INTERCEPTION DITCH & VERTICAL CROSS SECTION



EXPLANATION

CONTOUR SHOWING SPECIFIC CONDUCTIVITY (UMHOS) OF GROUNDWATER IN THE ALLUVIUM, 1980
CONTOUR INTERVAL = 2000 UMHOS

SEE FIG. 5 FOR AN EXPLANATION OF ALL OTHER MAP SYMBOLS.

SCALE

0 500 1000 2000

FIGURE 12

ISOSPECIFIC CONDUCTIVITY MAP FOR THE ALLUVIUM, 1980

KERR-McGEE NUCLEAR CORPORATION
Dec 1980

Table 3 Water Quality Analyses From Selected Alluvial Wells

PARAMETER	WELL NUMBER									WQCC NUMERICAL STANDARDS	UNITS
	A-1	S-12	5-03	32-01	32-02	32-41	32-43	32-51	32-52		
Ag	0.027	0.037	<0.020	<0.020	<0.020	<0.020	0.037	0.027	<0.020	0.05	mg/1
Al	0.079	<0.008	0.016	<0.008	<0.008	<0.008	0.085	0.028	0.022	5.0	mg/1
As	0.17	0.33	<0.11	0.25	0.20	<0.11	0.18	<0.11	<0.11	0.1	mg/1
B	0.92	0.48	0.20	0.37	0.60	0.21	0.90	0.21	0.47	0.75	mg/1
Ba	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	1.0	mg/1
Ca	320	620	350	300	15	95	670	430	500	---	mg/1
Cd	0.12	0.010	<0.007	0.010	0.007	0.008	0.014	0.014	0.009	0.01	mg/1
Co	0.13	0.082	0.027	0.027	0.027	0.027	0.062	0.055	0.023	---	mg/1
Cr	0.12	0.059	0.027	0.058	0.059	0.040	0.060	0.043	0.036	0.05	mg/1
Cu	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	1.0	mg/1
Fe	700	0.17	0.059	0.068	0.16	0.19	0.075	0.087	0.26	1.0	mg/1
Hg	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0004	<0.0003	0.0004	0.0005	0.002	mg/1
K	17	13	3.0	22	10	11	13	3.7	3.2	---	mg/1
Mg	1600	1500	280	1300	1100	830	600	160	350	---	mg/1
Mn	9.6	3.9	0.005	0.30	0.15	1.4	0.29	0.47	.24	0.2	mg/1
Mo	0.036	0.041	<0.018	0.020	<0.018	<0.018	<0.018	<0.018	<0.018	1.0	mg/1
Na	2300	2100	240	1800	1800	690	560	320	620	---	mg/1
Ni	0.077	<0.038	<0.038	<0.038	<0.038	<0.038	<0.038	<0.038	<0.038	0.2	mg/1
Pb	0.20	0.13	0.16	0.12	0.083	0.11	0.18	0.13	0.10	0.05	mg/1
Se	0.13	0.33	<0.10	0.24	0.19	<0.10	0.34	0.12	0.25	0.05	mg/1
V	0.049	<0.005	0.012	<0.005	<0.005	<0.005	0.031	0.018	0.017	10.0	mg/1
Zn	1.6	1.3	0.30	1.2	1.0	0.83	0.66	0.18	0.38	---	mg/1
F	2	<1	<1	1.2	<1	0.83	<1	<1	<1	1.6	mg/1
Cl	3560	2870	230	2300	2210	1410	110	73	180	250	mg/1
CN	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.2	mg/1
HCO3	280	2640	280	2040	1610	120	890	90	290	---	mg/1
CO3	<10	<10	<10	<10	<10	<10	<10	<10	<10	---	mg/1
NH3(N)	320	80	<0.1	60	2	15	14	2	<0.1	10.	mg/1
NO3(N)	36	<1	<1	5.5	<1	<1	540	4.4	22	10.	mg/1
SO4	7730	5540	1700	5540	3680	3050	2530	2090	3150	600	mg/1
TDS	15700	13900	2910	12100	9630	6220	6900	3120	4940	1000	mg/1
TOC	39	16	56	13	33	16	27	13	15	---	mg/1
pH	6.0	6.5	7.5	7.0	8.5	8.0	6.9	7.2	7.6	bet. 6 & 9	units
Ra-226s	1.78±0.11	0.37±0.02	0.11±0.02	0.16±0.08	0.14±0.08	1.23±0.60	0.24±0.09	0.20±0.03	0.20±0.04	30	pCi/1
Ra-228s	<3.2 at 2σ	<3.3 at 2σ	<4.5 at 2σ	<5.3 at 2σ	<4.7 at 2σ	<2.2 at 2σ	<3.0 at 2σ	<4.5 at 2σ	<2.9 at 2σ	30	pCi/1
U238	0.016	0.019	0.078	0.021	0.021	0.012	0.023	0.0008	0.37	5.	mg/1
Benzene	<0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.01	mg/1
SPEC. COND	12000	11000	2500	9000	8000	5500	5000	3800	2600		UMHOS

Note: Samples Collected January 1984 by QMC

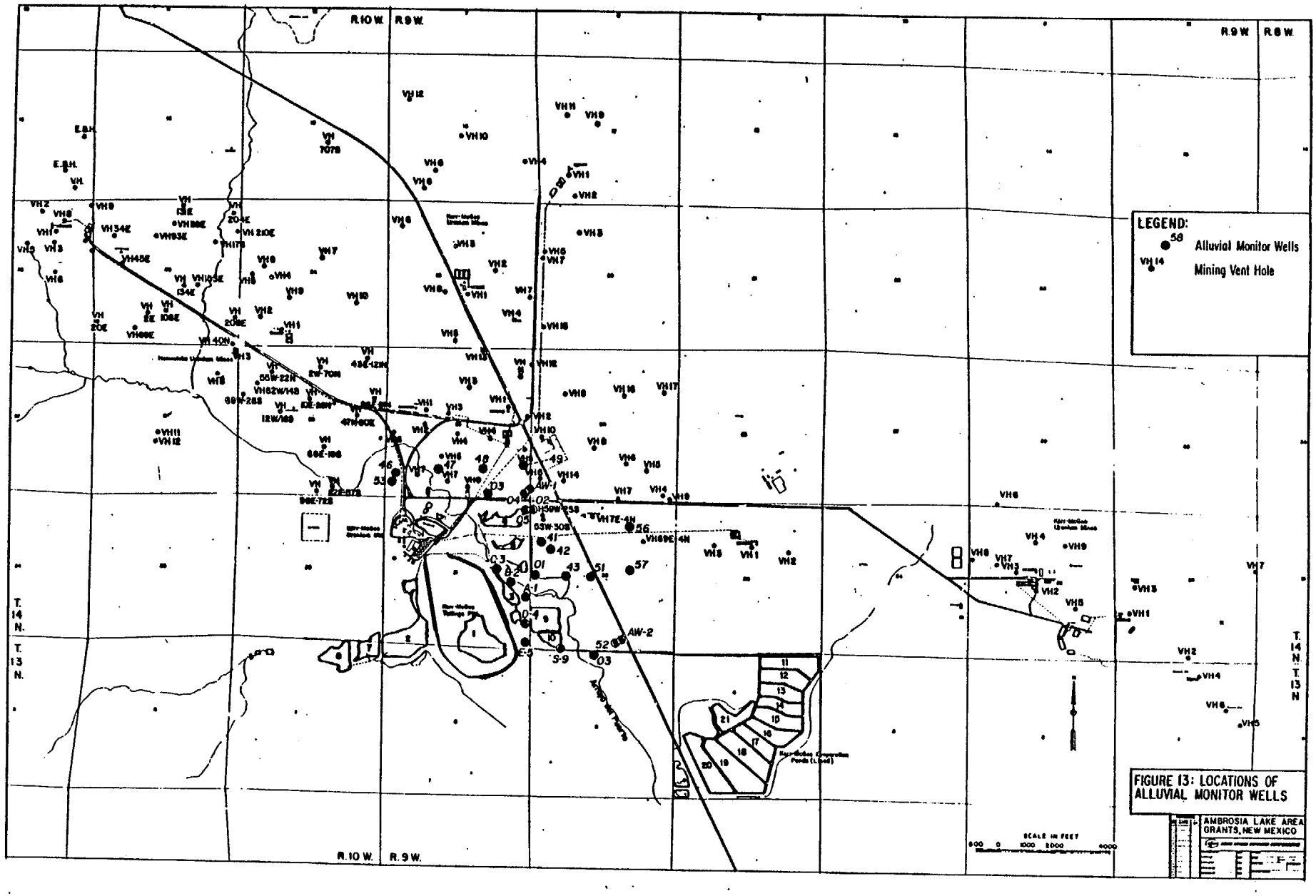


FIGURE 13: LOCATIONS OF ALLUVIAL MONITOR WELLS

WQCC numerical ground-water standards, they become the allowable limit. QMC's activities will not be permitted to cause concentrations to exceed the existing concentrations presently found in the alluvial aquifer. However, water quality in the alluvium should improve, due to the construction of the seepage interception ditch. An extensive alluvial monitoring program described in Section 7.0 will assure that the allowable limit will not be exceeded.

3.2.1.4 Aquifer Parameters

Two pumping tests conducted in the alluvium yielded transmissivities ranging from 205 gallons per day per ft. (gpd/ft) to 250 gpd/ft. QMC obtained a hydraulic conductivity of approximately 10 gpd/ft^2 by dividing by the saturated thickness. A semiconfined storage coefficient of 2×10^{-1} was determined from one of the pumping tests.

3.2.1.5 Ground-Water Velocity and Underflow

Using a hydraulic conductivity of 10 gpd/ft^2, an effective porosity of 20% and hydraulic gradients obtained from Figure 10, QMC estimated ground-water velocities. North of the mill site, steep hydraulic gradients yield ground-water velocities of about 38 feet per year (ft/yr), whereas gentler gradients to the east and southeast of the mill site yield ground-water velocities of 14 and 18 ft/yr, respectively.

QMC calculated volumetric flow rates using subsurface cross-sectional areas and the ground-water velocities obtained from above. QMC estimated 30 gpm of flow to the north of the mill site, toward the mines, 20 gpm of flow to the east of the mill site, and 10 gpm of flow toward the alluvial subsurface narrows to the southeast. Based on changes in water quality in the Arroyo del Puerto, QMC estimated 8 gpm of ground water is entering the arroyo as base flow.

Alluvial sediments in the Arroyo del Puerto Channel, are the principal pathway of ground-water migration as it leaves the Ambrosia Lake area.

The rate of ground-water movement from the mill area through alluvial sediments can be calculated in a manner similar to that described previously. Because the alluvial aquifer is completely saturated, the water-table gradient from the mill area to the confluence of the Arroyo del Puerto and the San Mateo Creek is assumed to be the same as the stream gradient. Using an average permeability of 10 gpd/ft^2, an effective porosity of 20% and a hydraulic gradient of 140 ft head drop in a 20,000 ft distance, the rate of ground-water movement is found to be 18 feet per year (ft/yr). Travel time for this 20,000 ft distance at this rate would take approximately 1,100

years. The rate is likely to slow considerably when mining and milling activities cease in approximately 20 to 30 years, because no further mine wastewater will be produced to sustain the ground-water mound and steeper hydraulic gradients.

3.2.1.6 2-dimensional, Vertical Plane Seepage Model

QMC performed electric analog modeling at the request of the EID to determine the relative effectiveness of remedial action alternatives that would prevent seepage from the unlined tailings Ponds 1 and 2 from moving down-hydraulic gradient in the alluvium. Deepening the present seepage interception ditch to the contact between the alluvium and the Trb was the most effective remedial action alternative, as electric analog modeling indicated that the seepage would not move past the hydraulic sink created by the deepened seepage interception ditch.

Vertical cross section models were constructed of teledeltos paper for three cross-sections shown on Figure 11. Because the hydraulic conductivity of the alluvium and the Trb is approximately the same, the formations were treated as one hydraulic unit.

The models were cut to scale (no vertical exaggeration) to represent the field flow regime in the Trb Sandstone and alluvium. The top boundary represents the water table and the bottom boundary is an impermeable barrier, in this case the top of the Mancos Shale. The paper's electrical conductivity is analogous to hydraulic conductivity while electrical voltage is analogous to hydraulic head. Ground-water flow is controlled by known constant head lines such as pond and ditch water levels. In the analog model, electric flow is controlled by voltage sources and grounds (Todd, 1959).

As the teledeltos paper is isotropic and homogeneous with respect to electric flow, the ground-water model also assumes isotropic and homogeneous conditions. Voltage is measured at various points on the paper with a probe and is displayed on a digital voltmeter. Contouring the voltage readings results in an equipotential profile.

Six models were generated for various combinations of conditions and locations. Three cross-sections were considered with geometry and boundary conditions representative of the north, center and south sections of the present-day seepage interception ditch. The three cross-section locations vary only in the presence and position of the old creek bed. The results show comparable seepage rates in the three sections under present-day conditions.

Electric analog modeling of the use of a slurry wall to prevent seepage from Ponds 1 and 2 from migrating eastward in the alluvium indicates that more seepage occurs with the wall present than without. The slurry wall prevents some of the underflow from being pulled back by the seepage interception ditch from the east side of the seepage interception ditch. Consequently, the underflow that continues to move eastward is increased. Perhaps relocation of the slurry wall would allow some cut-off of seepage, but the slurry wall is only marginally effective.

By contrast, the selected option of deepening the present seepage interception ditch is quite effective. Calculations show that deepening the ditch 20 feet from its present depth should reduce underflow seepage to zero.

In summary, electric analog modeling indicates that a slurry wall is ineffective in cutting off seepage while deepening the present ditch is very effective. The actual degree of effectiveness is expected to differ from the modeled results, primarily due to anisotropic conditions. The complex geometry and geologic structure is also a source of uncertainty. However, the modeling is thought by the EID to be a valid basis for comparing the remedial action options.

3.2.2 Bedrock Aquifers

In 1983, at the request of the EID, QMC performed downhole investigations in shafts and ventilation holes to determine the potentiometric surfaces and water quality in the bedrock aquifers at the site.

QMC's investigations determined that all of the bedrock formations were dewatered down to and including the Westwater Canyon Member of the Morrison Formation. Water quality of basal saturation in the Tres Hermanos b Sandstone (Trb) and Dakota Sandstone has been impacted by tailings seepage over substantial areas. Unlined tailings ponds and evaporation ponds were located over the outcrops and subcrops of the Trb and Dakota. Tailings seepage has moved downdip to the north in these aquifers. The removal of unlined ponds 3 through 8 will prevent further tailings seepage from entering the Dakota. However, as the tailings Ponds 1 and 2 are situated over the subcrop of the Trb, seepage impacts to this aquifer will continue. Some seepage impacts in the Tres Hermanos a Sandstone (Tra) may become increasingly evident because part of the newly expanded unlined tailings Pond 2 will cover the subcrop of the Tra.

QMC has satisfactorily demonstrated to the EID by the downhole investigations and the use of a numerical model that tailings seepage in the bedrock aquifers should be captured

by the large potentiometric depression created by the mine shafts and ventilation holes. Furthermore, the WQCC numerical ground-water standards are not predicted to be violated at place of reasonably foreseeable future use, because when the aquifers are repressurized many years from now, residual tailings seepage will be diluted to below the WQCC numerical ground water standards.

3.2.2.1 Hydrogeologic Description

The bedrock units of hydrogeologic significance at the site consist in descending order of the Mancos Shale, Tres Hermanos Sandstones, Dakota Sandstone, and the Brushy Basin and Westwater Canyon Members of the Morrison Formation. A cross-section through wells 8 miles northwest of the QMC operation showing the structural relationship of these formations and the equivalent position of the mill site is shown on Figure 3. The bedrock units dip gently to the north from the Zuni Uplift into the San Juan Basin. Faults and associated fractures are common in the site area and exhibit a predominant northerly trend (Figure 1). The site area is located in the upthrown fault block, a horst bounded by the Ambrosia fault (approximately 4 miles west of the mill) and by the San Mateo fault (approximately 4 miles east of the mill). Generally, older faults and fractures are partially annealed and retard ground-water flow, while relatively recent faults and fractures increase the rate of ground-water movement. Some of the shaley sedimentary layers between aquifers contain significant bentonitic material which retard interaquifer communication in fractured or faulted areas. The mill site (Figure 3) is located on the Mancos Shale with younger rock units exposed as cliffs to the northeast of the mill and older units outcropping to the south of the mill site.

Formations of hydrologic interest are shown on Figure 3. The Westwater Canyon Member (hereafter designated WCM) is the ore zone and also an aquifer. Since mining activity ordinarily does not penetrate a significant distance beneath the WCM, this study will be limited to the WCM, the Bluff Sandstone (the first aquifer beneath the WCM) and the aquifers which are present from the ground surface to the ore body. The following discussion presents the formations of interest in descending order.

Mancos Shale and Tres Hermanos Sandstones

The Mancos Shale is typically dark gray in color and contains several sandstone beds which in the Ambrosia Lake area are identified as the Tres Hermanos sandstones. These three sandstone beds are referred to from the highest to the lowest in stratigraphic section as the Trc, Trb, and Tra. The sandstones are fine-grained and do not yield much water to a

well unless fractured. Very little water level data are available on the Tres Hermanos sandstones prior to mining activity in the area. These sandstones cap most of the low-lying hills around the QMC mill site. Much of the rock has become deeply weathered and has been mapped as saprolite.

Dakota Sandstone

The Dakota Sandstone was deposited over an erosional surface developed on the Brushy Basin Member of the Morrison Formation. The Dakota Sandstone is predominantly a fine-grained, clean sandstone with fair to good permeability. Historical data indicated the potentiometric surface of the Dakota Sandstone was slightly above that of the WCM, approximately 6600 feet. The Dakota Sandstone is 80 feet thick in the site area.

Morrison Formation

The Morrison Formation in the area is comprised of three members, listed in descending order. The Brush Basin Member of the Morrison Formation consists of bentonitic mudstones and some thin standstone lenses and conforms and intertongues with the upper WCM. It is generally less than 100 feet thick in the Ambrosia Lake area and acts as a good aquitard overlying the WCM. Uncased wells left open in the Brushy Basin Member will quickly seal off because of the expansive nature of the bentonitic clay. For this reason, it is logical to conclude that faults and fractures do not remain open to permit interaquifer communication through this formation unless there is a significant difference in potentiometric pressure between aquifers.

The Westwater Canyon Member (WCM) of the Morrison Formation is the uranium ore body and a significant aquifer. The arkosic sandstone of the WCM is fine to coarse grained and generally poorly sorted. Clay beds in the aquifer have fair lateral continuity which affect local ground-water movement and drainage from the aquifer.

Prior to mining in the area, several water supply wells were constructed into the WCM. Early testing on the WCM was done by most uranium mining companies to determine the difficulty of attempting to dewater the ore body. Early data indicate the potentiometric surface of the WCM was between the 6550 and 6600 ft elevation. Water quality was generally good where the aquifer was less than 1000 feet deep. Basinward or northward, the WCM becomes more brackish in quality. The WCM is approximately 200 feet thick in the site area.

The Recapture Member of the Morrison Formation is composed of intra-stratified siltstone, shale and fine sandstone.

Generally, the Recapture Member is considered to be an aquitard. Leakage of groundwater between the Bluff Sandstone and the WCM appears to be negligible on account of the low permeability of the Recapture Member. In the Ambrosia Lake area, the Recapture Member is about 100 feet thick. Most shafts in the area commonly penetrate about 50 feet or more into the Recapture Member.

Bluff Sandstone

The Bluff Sandstone is not widely used as an aquifer in the Ambrosia Lake area because of low yield and poor quality. In the area, the Bluff Sandstone is reported to be about 220 feet thick and is underlain by the finely-bedded sandstone, siltstone, and shale of the Summerville Formation. No pre-mining groundwater data in the subject area could be found for the Bluff Sandstone.

3.2.2.2 Water Levels

Under natural conditions, before mining and milling of uranium in the Ambrosia Lake area, most of the bedrock aquifers at the site were saturated some distance downdip from their outcrop area and confined at greater distances downdip. Recharge to these formations occurred in outcrop areas (Figure 4) to the southwest of the mill site. Ground water within the bedrock formations flows primarily downdip to topographically low areas in the northeast.

However, these conditions were modified by the sinking of shafts and ventilation holes that dewatered the aquifers in the mill site down to and including the WCM (Figure 5).

By 1957, several companies were sinking shafts and testing the Westwater aquifer to determine pumping requirements for mining uranium in the Ambrosia Lake area. Much of the early pumping discharge was put into the Arroyo del Puerto or its tributaries, creating a line source of recharge to the alluvium. A perennial stream condition across the alluvial valley was created. Within several months after continued pumping began, surface water in the Arroyo del Puerto had reached San Mateo Creek several miles to the south (Figure 1), indicating that discharge rates were high relative to infiltration capacity of the creek bed. This discharge was good quality water primarily from the WCM. Where shaft sinking encountered significant amounts of water in the Tres Hermanos and the Dakota Sandstones, these aquifers were also pumped for a period of time.

Before mine development could proceed, ventilation holes had to be drilled near the shaft and subsequently throughout the mine area. Some 5 to 10 ventilation holes are needed for most

mines. Typical construction on a ventilation hole in the Ambrosia Lake area involves installation of 30-to 60-inch diameter casing to the mine level. Three circumferential openings, 2 inches by 6 inches in size, are made every 20 feet to avoid hydrostatic pressure buildup and possible casing collapse from external pressure. Any water-bearing zone from the surface to the mine level is permitted to drain into the ventilation holes. This has created a major potentiometric depression in aquifers above the WCM across the site area. Therefore, the entire mine area can be viewed as a groundwater depression or trough, not only in the Westwater because of the pumping, but also in the shallower aquifers because of drainage by ventilation holes.

To confirm that the mine shafts and ventilation holes had dewatered the bedrock aquifers down to and including the Dakota Sandstone, the EID requested that QMC perform down hole investigations to determine the extent of saturation, the yield and water quality. QMC personnel were sent down the shafts and ventholes to perform these investigations. Results of these investigations indicate that the Tra was generally dry, minimal basal saturation was present in the Trb, Trc and Dakota Sandstone and no discharges occurred from the Bushy Basin Member. Where seeps occurred, discharge measurements were made and were usually found to be less than 1 gpm. Water quality samples were obtained from each of the seeps and the water quality analyses are discussed in the following section.

QMC contends that all bedrock seepage from tailings facilities at the site discharges to the shafts and ventholes and therefore will not migrate to a place of foreseeable future use. As insufficient monitoring wells are available to create potentiometric maps for the bedrock aquifers, the EID requested that QMC perform numerical modeling to generate a potentiometric map for the area. The modeling effort, discussed in Section 3.2.2.5.1 of this report, indicates that a substantial potentiometric depression has developed in the bedrock aquifers and they are largely dewatered except for a few feet of basal saturation in some areas. Furthermore, QMC's model adequately demonstrated that all flow lines originating at the tailings facilities discharge to the potentiometric depression created by shaft and venthole dewatering.

3.2.2.3 Water Quality

In the Discharge Plan, DP-169, prepared by QMC in 1980, bedrock contamination resulting from unlined tailings ponds and unlined evaporation pond operations was characterized as being essentially contained at the site area by the natural and man-made features. Any contaminant which could enter the bedrock near the tailings area was assumed by QMC to move downdip in one or more sandstone units and be intercepted by

the open draining vent holes and mine shafts in the mining area to the north of the mill site. At the request of the EID, a closer investigation of this bedrock contamination has been made. The extent of contamination for each of the Tres Hermanos and the Dakota Sandstones is discussed herein.

The surface geologic information and fault trends, used by QMC in this study, was taken from Santos and Thaden (1966). Chloride concentration was considered to be the primary indicator of contamination in the water analyses. The extent of migration of the chloride concentration front is shown on Figures 6, 7, 15 and 16. The other studies pertinent to this discussion include the downhole survey of ventilation holes and the computer model simulation of aquifer drainage by vent holes.

Figure 14 provides a general location map for the site area, showing shafts and ventilation holes for eight QMC mines and three Homestake mines, and the QMC mill, tailings ponds and evaporation ponds. The two deep QMC mines in the eastern portion of the area (Sec tions 35 and 36) are not included in the study because the vent holes at these mines are cemented from surface to mine depth to prevent large inflow rates which would interfere with air circulation. Therefore, these vent holes do not represent drainage points for the overlying aquifers.

Tres Hermanos c Sandstone (Trc)

The outcrop areas of the uppermost Tres Hermanos sandstone are shown on Figure 15. The mill area largely rests on the weathered outcrop of Trc. In the valley to the north of the mill, the Trc appears to be missing because of erosion, but the Trc does appear again at the surface, flanking the Ambrosia dome to the northwest. Three wells have been completed in the Trc (31-02, 36-03 and 36-04). Two wells in Section 36 have been reported by QMC to be dry since completion. However, one well in Section 31, completed in both the Trc and Trb, shows a water level slightly below the base of the Trc. QMC believes that the water quality in this well is influenced primarily by fluid movement in the Trb rather than in the Trc. In the vent hole drainage survey, no Trc zone fluid was observed in 17 vent holes. It is concluded that there has been no detectable impact to the Trc sandstone due to QMC operations.

Tres Hermanos b Sandstone (Trb)

The outcrop area of the middle unit of the Tres Hermanos Sandstone and the extent of contamination delineated by chloride concentrations are shown in Figure 6. It can be seen that tailings Ponds 1 and 2 rest on the outcrops or subcrops

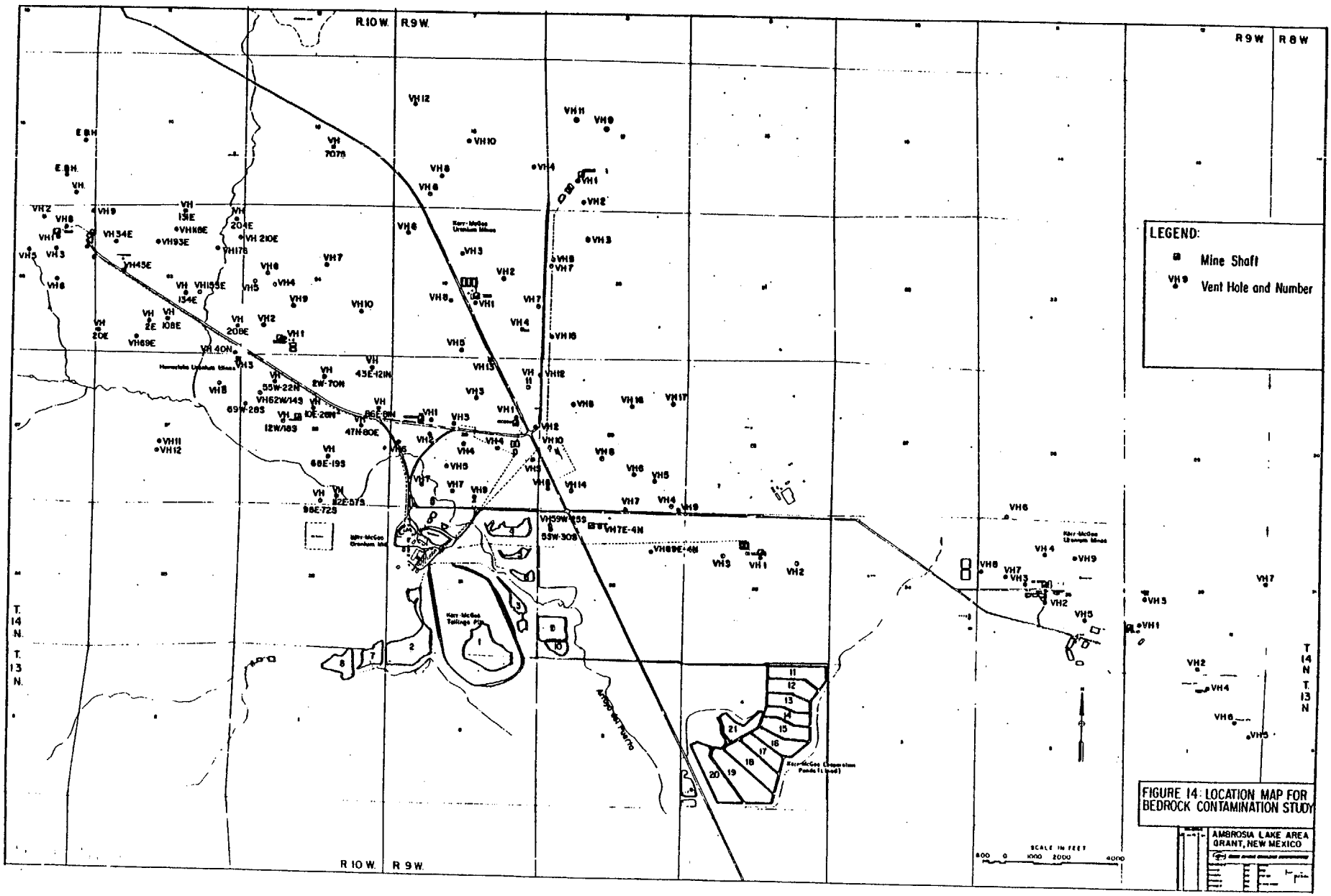


FIGURE 14: LOCATION MAP FOR BEDROCK CONTAMINATION STUDY

AMBROSIA LAKE AREA
GRANT, NEW MEXICO

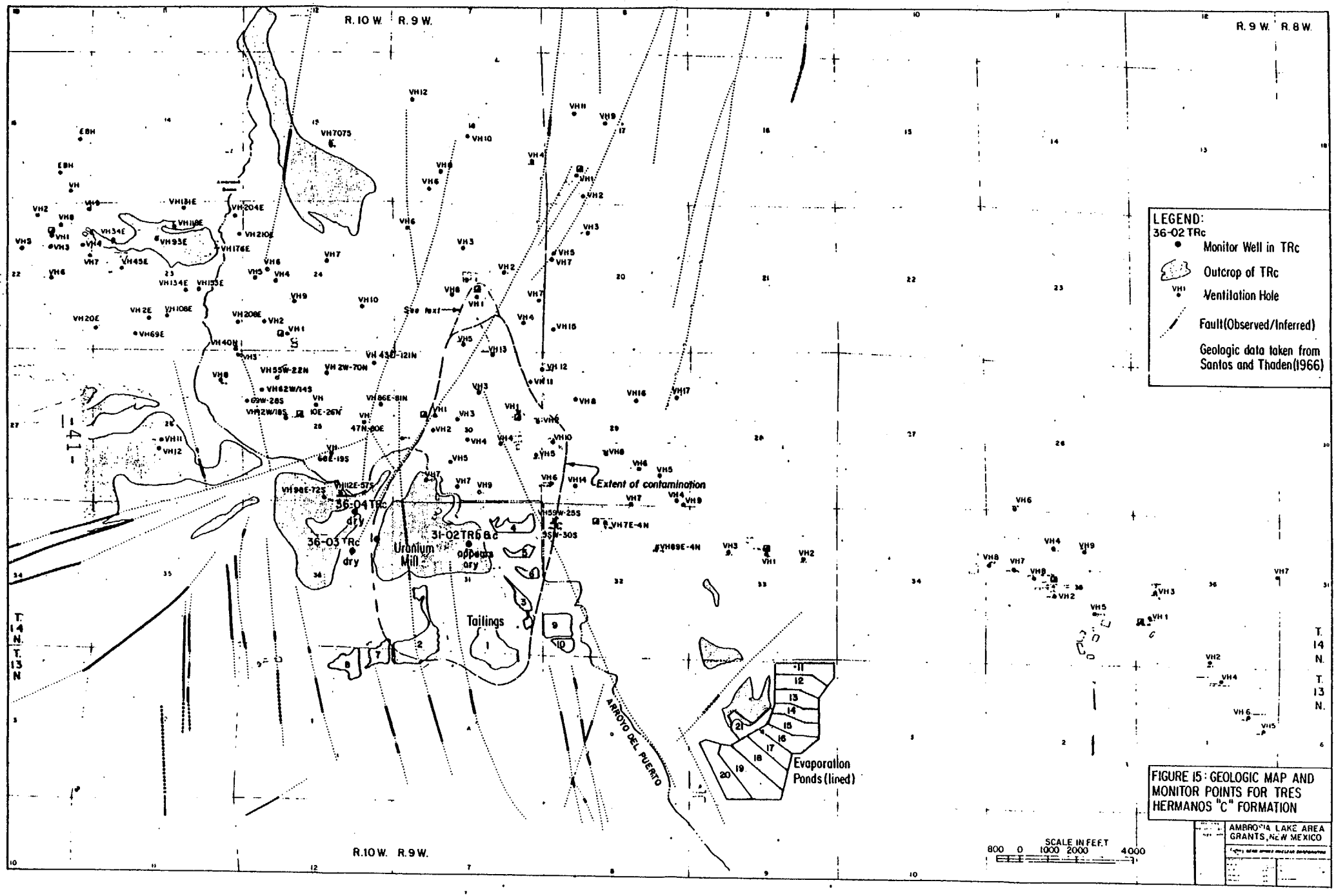


FIGURE 15: GEOLOGIC MAP AND MONITOR POINTS FOR TRES HERMANOS "C" FORMATION

of the Trb. The Trb is continuous from the outcrop area near the mill to the mining area to the northeast of the mill. Pond seepage has moved downdip to the northeast in the Trb. Beginning in 1972, wells were constructed by QMC into the Trb near the mill to investigate ground-water quality impacts.

Data tabulated for the Trb bedrock contamination study are presented in Table 4. Two wells in Section 36 (36-01 and 36-02) show the greatest degree of water-quality impact with respect to chlorides. QMC believes the water-quality impacts are associated with faulting and related fractures trending in a generally northern direction from ponds 2, 7, and 8. Well 31-02 in Section 31 was completed in 1977 to determine water-quality impacts directly downdip from the tailings ponds. Slightly elevated chloride concentrations are evident. Well 32-44 in Section 32 shows no water quality impacts in the Trb to the east of the tailings area. Several alluvial wells in Section 32 and Section 5 bottomed in the Trb subcrop. However, these wells are influenced by alluvial water more than Trb zone water and are not representative of water quality in the Trb. Also, the downward-hydraulic gradient from the alluvium prevents natural Trb zone water to enter the well.

During recent months, the vent hole survey north of the mill area found that a total of about 2 gpm is being captured by vent holes completed through the Trb zone. The majority of the 16 vent holes yielding water from the Trb showed a slight to moderate degree of water quality impacts. Vent holes more distant from Ponds 2, 7 and 8 are probably influenced by facture control of fluid flow, because the distances involved would not be consistent with the inner granular permeability and ground-water velocity typically associated with the Tres Hermanos sandstones. Water-quality analyses from selected ventholes and wells in the Trb are presented in Table 5. The WQCC numerical ground-water standards are exceeded by silver, arsenic, cadmium, chromium, manganese, nickel, lead, selenium, chloride, nitrate, sulfate and TDS in the area defined by the extent of chloride contamination on Figure 6.

Tres Hermanos a Sandstone (Tra)

The outcrop of the Tra is shown on Figure 7. Pond 8 is situated near the Tra outcrop. However, the outcrop is on the hillside at an elevation higher than the pond. It is unlikely that any pond fluid could enter the Tra at this point near the mill. To date, chloride concentrations indicate no pond seepage has reached the Tra except in the vicinity of well 30-01. Well 36-02 in Section 36 shows a dry Tra zone and wells in Sections 25, 30, 31 and 33 have no seepage from the Tra horizon. Section 30 Mine Vent Hole #2, had a plugged weephole opposite the Tra horizon. However, after cleanout,

Table 4: Tres Hermanos b - Bedrock Contamination Study

Wells

Sec.	No.	Chloride (mg/l)	Date	Remarks
31	02	414	4/18/80	Chloride value taken in 1980 before well was damaged
32	44	6.6	5/18/83	
36	01	1380	5/18/83	
36	02	1620	5/18/83	

Vent Holes

Sec.	No.	Chloride (mg/l)	Date	Assoc. Flow Rate (gpm)
30	2	83	5/13/83	1
30	7	910	5/20/83	1
30	10	900	5/21/83	1

Samples collected and flow rates measured by QMC.

Table 5 Water Quality Analyses from Selected Ventholes and Wells in the Tres Hermanos b

Parameter	Well Numbers: Sect 30W-VH-2 6/21/83	Sect 30W-VH-1 Depth 120' 5/21/83	Sect 30W-VH-10 5/21/83	31-02 8/16/83	32-44 11/14/83	36-01 5/24/83	WQCC Numerical Standard	Units
Ag	0.040	0.14	0.12	0.065	<0.020	0.035	0.05	mg/l
Al	<0.2	0.48	0.41	0.24	<0.008	0.22	5.0	mg/l
As	0.16	0.47	0.25	0.18	0.032	0.21	0.1	mg/l
B	0.33	0.33	0.37	0.45	0.26	0.25	0.75	mg/l
Ba	<0.02	<0.020	0.026	0.014	<0.013	<0.02	1.0	mg/l
Ca	350	910	760	210	65	430	---	mg/l
Cd	0.011	0.030	0.023	0.010	<0.007	0.017	0.01	mg/l
Co	<0.04	0.069	0.059	0.029	<0.011	<0.04	---	mg/l
Cr	0.051	0.095	0.092	0.036	<0.026	0.10	0.05	mg/l
Cu	0.03	0.086	0.079	0.052	<0.017	<0.03	1.0	mg/l
Fe	0.053	0.19	0.064	0.14	0.14	28	1.0	mg/l
Hg	<0.0004	<0.0004	<0.0004	<0.00041	<0.0005	<0.0004	0.002	mg/l
K	12	11	0.9	9.0	7.0	11	---	mg/l
Mg	420	730	300	83	84	1900	---	mg/l
Mn	0.92	0.25	0.031	0.11	0.41	1.7	0.2	mg/l
Mo	<0.02	0.056	0.043	0.019	<0.018	0.031	1.0	mg/l
Na	820	540	620	110	320	730	---	mg/l
Ni	<0.08	0.15	0.11	0.077	<0.038	0.075	0.02	mg/l
Pb	0.22	0.56	0.45	0.19	0.030	0.27	0.05	mg/l
Se	0.15	0.40	0.48	0.21	0.015	0.24	0.05	mg/l
V	<0.04	0.10	0.086	0.046	0.007	0.040	10	mg/l
Zn	0.18	0.31	0.16	0.045	0.022	0.70	---	mg/l
F	3	<1	<1	<1	<1	<1	1.6	mg/l
Cl	93	910	900	18	25	1840	250	mg/l
CN	<1	<1	<1	<.01	<1	<1	0.2	mg/l
HCO3	215	1225	530	220	120	210	---	mg/l
CO3	<10	<10	<10	<10	<10	<10	---	mg/l
NO3(N)	<1	2	28	<1	<1	6	10	mg/l
SO4	3740	3620	2210	960	1120	7630	600	mg/l
TDS	5410	7360	5380	1480	1640	12700	1000	mg/l
pH	6.8	7.1	7.3	7.3	7.5	6.2	Between 6 & 9	mg/l
Ra-226	0.66±0.09	0.74±0.02	0.71±0.40	1.10±0.31	0.66±0.13	0.77±0.07	30	pCi/l
Ra-228	---	---	---	---	<3.2 at 2	<1.1 at 2	30	pCi/l
U238	0.04	0.04	0.08	0.016	0.003	0.08	5.0	mg/l
Benzene				0.001mg	<0.001mg	0.002	0.01	mg/l
TOC				6.0	24.0	18.0	---	mg/l

. Samples collected and analyzed by QMC.

no additional seepage came in, indicating the probable source of fluid in the weephole is the overlying Trb sandstone.

Water-quality analyses from selected wells in the Tres Hermanos a are presented in Table 6. Well 30-01 has concentrations of silver, manganese, nickel, lead, selenium, chloride, sulfate and TDS that exceeded the WQCC numerical ground-water standards. This well is included in the monitoring program to determine whether the new expansion of Tailings Pond 2 will cause additional seepage through the Tra subcrop in the area.

Dakota Sandstone (Kd)

The outcrop for the Dakota Sandstone is shown on Figure 16. Pond 8 is located adjacent to and over the Dakota Sandstone. QMC believes this is the area where contamination may have entered the Dakota. The extent of contamination using chloride as the defining parameter is shown in Figure 16. The direction and orientation of the contaminant plume appears to be a combination of the dip, fracture and fault occurrence, and drainage effects.

Wells and vent holes used in the Dakota study and the data collected are tabulated on Table 7. Several wells have been drilled since 1975 to determine the degree of water quality impacts to the Dakota. Two wells in the northern part of Section 36 (36-01 and 36-04) exhibited water quality impacts from pond seepage. However, well 36-05 drilled immediately north of Pond 8, shows no water-quality impacts from pond seepage. Ground-water flow is largely controlled by fractures and faults in this area. The wells in Sections 25 and 31 show no probable impact. Wells in Section 30 which are downdip and down-hydraulic gradient of Pond 8, along the northeasterly trending fractured pathways, exhibit some water quality impacts from pond seepage. In the vent hole survey north of the mill area, 7 of the 15 vent holes show inflow from the Dakota with some degree of water-quality impact. The 30 West shaft survey which was conducted along with the vent hole survey also shows inflow and water quality impact. The inflow from the Dakota to vent holes and shafts ranged from 6.5 gpm to less than 1 gpm. The total of all Dakota inflows observed was approximately 25 gpm, but actual inflows may be twice this amount because of access problems or difficulties in determining the sources of water to the various collection systems.

While wells in Section 5 to the southeast are not affected, some contamination was noted in Section 32. QMC believes that the contamination indicated in Section 32 is not related to the plume described above but is a localized condition, probably due to well-annulus leakage. It was suggested in

Table 6 Water Quality Analyses from Selected Wells in the Tres Hermanos a

Parameter	Well Numbers 25-02 8/15/83	31.01 8/16/83	WQCC Numerical Standard	Units
Ag	<0.02	0.060	0.05	mg/1
Al	<0.04	0.32	5.0	mg/1
As	<0.1	<0.1	0.1	mg/1
B	0.38	0.28	0.75	mg/1
Ba	0.021	0.017	1.0	mg/1
Ca	22	230	—	mg/1
Cd	<0.007	0.008	0.01	mg/1
Co	<0.01	0.023	—	mg/1
Cr	<0.03	0.047	0.05	mg/1
Cu	<0.02	0.051	1.0	mg/1
Fe	0.028	0.26	1.0	mg/1
Hg	<0.00030	<0.00030	0.002	mg/1
K	8.9	17	—	mg/1
Mg	3.7	230	—	mg/1
Mn	0.017	0.83	0.2	mg/1
Mo	<0.02	0.019	1.0	mg/1
Na	3.3	320	—	mg/1
Ni	<0.04	0.072	0.02	mg/1
Pb	<0.07	0.18	0.05	mg/1
Se	<0.1	0.17	0.05	mg/1
V	<0.005	0.059	10	mg/1
Zn	<0.008	0.10	—	mg/1
F	0.30	<1	1.6	mg/1
Cl	2.4	510	250	mg/1
CN	<0.1	<0.1	0.2	mg/1
HCO3	70	36	—	mg/1
CO3	<10	<10	—	mg/1
NH3(N)	<0.1	<0.1	10	
NO3(N)	<1	<1	10	mg/1
SO4	28	1650	600	mg/1
TDS	120	2940	1000	mg/1
TOC	21	12	—	
pH	8.2	7.4	Between 6 & 9	mg/1
Ra-226s	0.52±0.07	9.65±0.17	30	pCi/1
Ra-228s	<2.9-at2	<1.8-at2	30	pCi/1
U238	0.005	0.016	5.0	mg/1
Benzene	<0.001mg	0.001mg	0.01	

Samples collected and analysed by QMC

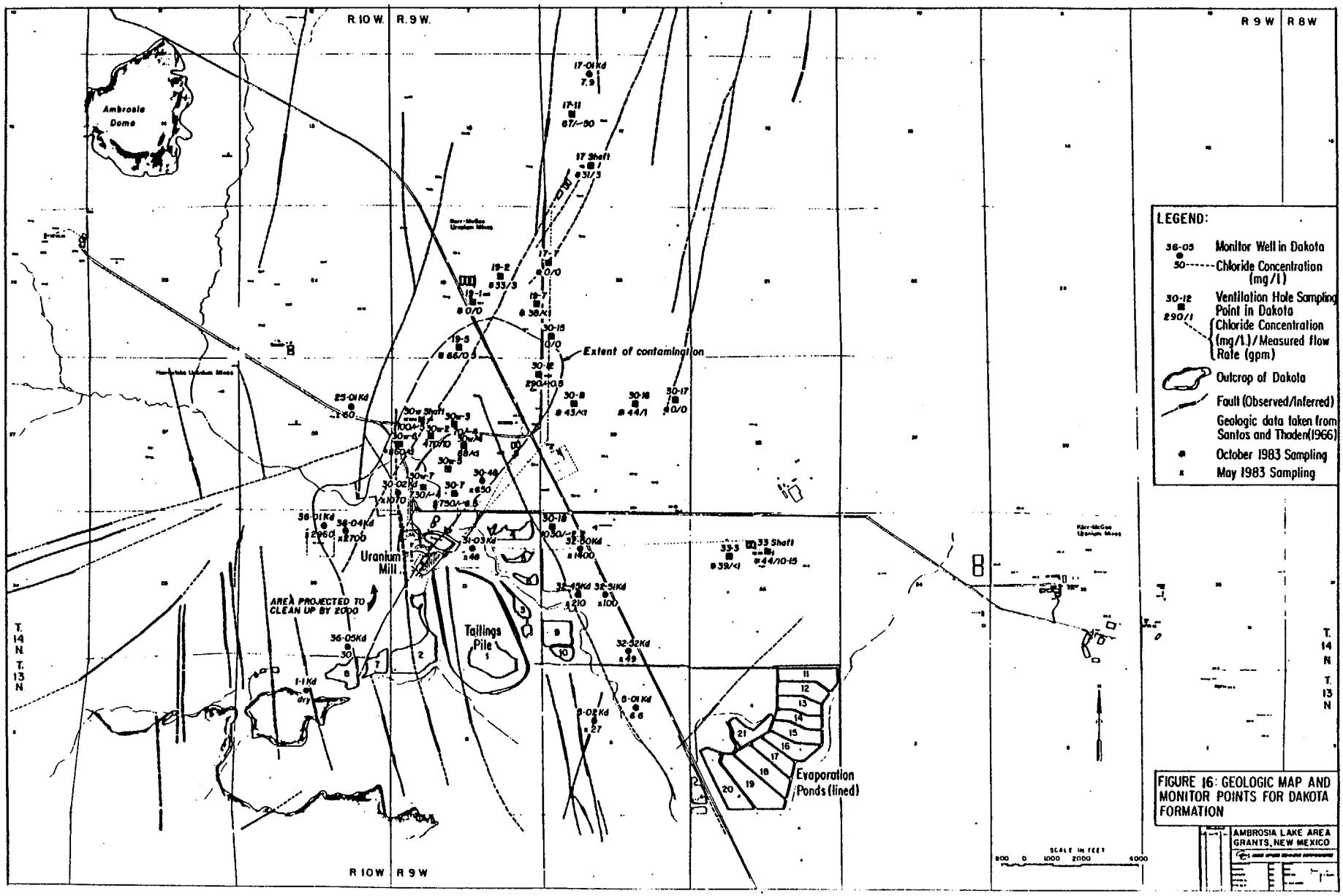


FIGURE 16: GEOLOGIC MAP AND MONITOR POINTS FOR DAKOTA FORMATION

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

Table 7: Dakota - Bedrock Contamination Study

Wells

Sec.	No.	Chloride (mg/l)	Date	Remarks
1	1	-	-	Dry since constructed in 1972
5	01	6.6	5/18/83	
5	02	<1	5/18/83	
17	01	7.9	5/18/83	
25	01	60	5/18/83	
30	02	888	5/18/83	
30	48	378	5/18/83	
31	03	26.5	5/18/83	
32	45	152	5/18/83	
32	50	1160	5/18/83	Believed to be leaking well; see discussion in text
32	51	<1	5/18/83	
32	52	19.8	5/18/83	
36	01	2630	5/18/83	
36	04	2320	5/18/83	
36	05	30	4/80	Csg. collapse in 1980; well showed no contamination, 1977 to 1980

Vent Holes

Sec.	No.	Chloride (mg/l)	Date	Assoc. Flow	Remarks
17	11	37	5/21/83	50	
30W	Shaft	100	5/21/83	5	
30W	2	470	5/21/83	10	
30W	3	170	5/21/83	4	
30W	4	88	5/21/83	1	
30W	5	110	5/21/83	2.5	
30W	6	860	5/21/83	1	
30W	7	730	5/21/83	4	
30	7	750	5/21/83	6.5	
30	12	290	5/21/83	0.5	
30	18	1030	5/21/83	2.2	App. to be infl. by leaking well 32-50

Samples collected and flow rates measured by QMC.

Discharge Plan DP-169 that well 32-50 Kd showed anomalous water quality. The anomaly was noted in 1980 when the water level elevation was observed to be about 20 feet higher than expected because the well is within 1000 feet of two vent holes and a shaft, all of which should have effectively drained the Dakota. Instead, the Dakota exhibited over 40 feet of saturation in well 32-50 Kd, twice the saturated thickness in nearby wells. Also, the well was bailer tested in 1982 and the water-level elevation was found to quickly return to the same anomalous static level. This behavior suggests ongoing leakage to the well from some overlying source of water. To further check this phenomenon, the chemical data from this well was plotted on a stiff diagram along with the data from nearby wells. These diagrams are shown on Figure 17. Also plotted are the data from the nearby vent hole which is draining the Dakota. The alluvial water in well 32-50 Kd, the Dakota water in well 32-50 Kd, and the vent hole #18 water are remarkably similar and very much different than water from the two nearby Dakota wells, 32-45 Kd and 32-51 Kd. Contamination in the Dakota in this area is therefore very local in nature. Water quality analyses from selected vent holes and wells in the Dakota are presented in Tables 8 and 9. WQCC numerical ground-water standards are exceeded for silver, arsenic, cadmium, chromium, manganese, nickel, lead, selenium, fluoride, chloride, sulfate and TDS.

3.2.2.4 Aquifer Parameters

In 1983, QMC contracted Woodward-Clyde Consultants (WCC) to perform feasibility investigations for a slurry trench cutoff. Results of the study indicated that the slurry trench cutoff would not substantially reduce seepage from tailings Pond 1 and decant Pond 3 from moving through the alluvial channel toward the east. Instead, QMC decided that deepening the seepage interception ditch would adequately reduce seepage migration in the alluvial channel. However, WCC's investigations provided valuable measurements of the hydraulic conductivity of underlying bedrock materials.
The location of the seepage interception ditch (slurry trench cutoff area) is shown on Figures 2 and 11.

The subsurface materials in the seepage interception ditch area can be summarized as an interbedded sequence of relatively permeable and impermeable zones, as shown in the cross-section in Figure 18. As indicated in this cross-section, a relatively permeable zone consisting of the alluvium and the Trb Sandstone underlies Ponds 1 and 3 and extends eastward beyond the relocated Arroyo del Puerto. This zone is approximately 60 to 70 ft thick at the proposed alignment.

The in-situ hydraulic conductivity of the alluvium was

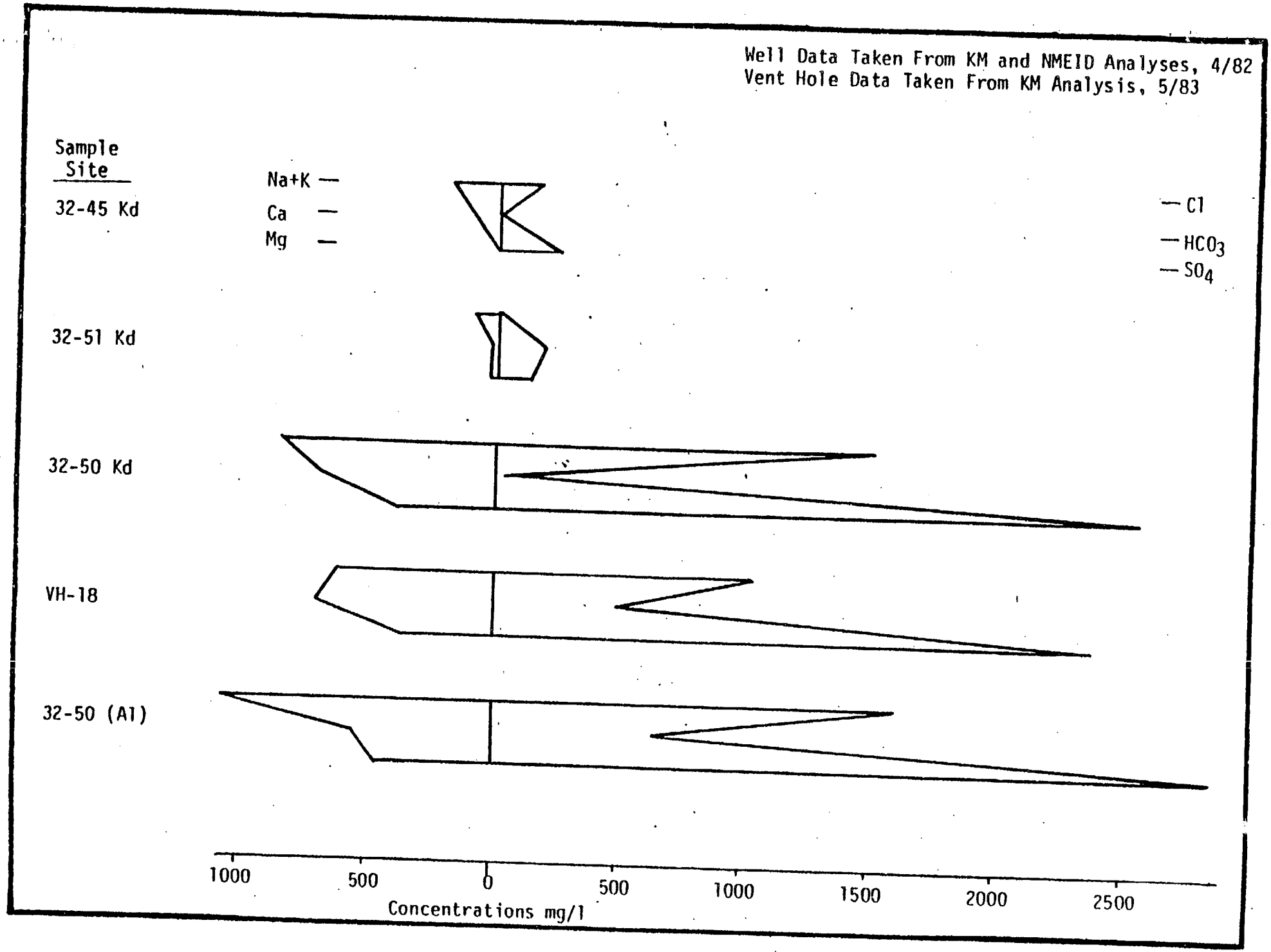


FIGURE 17: STIFF DIAGRAMS FOR GROUNDWATER IN SECTION 32

Table 8 Water Quality Analyses from Selected Ventholes in the Dakota

Parameter	Well Numbers and Collection Date					WQCC Numerical Standard	Units
	Sect 30W 1-3 Level 5/19/83	Sect 30W-VH-1 5/21/83	Sect 30W Mine 5/13/83	Sect 30W-VH-3 Depth 460' 5/21/83	Sec 30W-VH-3 Depth 570' 5/21/83		
Ag	0.084	0.085	0.099	0.098	0.10	0.05	mg/1
Al	0.084	0.084	0.37	0.37	0.42	5.0	mg/1
As	0.084	0.084	0.27	0.21	0.25	0.1	mg/1
B	0.084	0.084	0.33	0.31	0.31	0.75	mg/1
Ba	0.084	0.084	<0.02	<0.02	0.023	1.0	mg/1
Ca	0.084	0.084	720	620	630	—	mg/1
Cd	0.084	0.084	0.024	0.018	0.022	0.01	mg/1
Co	0.084	0.084	0.059	0.053	0.055	—	mg/1
CR	0.084	0.084	0.078	0.076	0.083	0.05	mg/1
Cu	0.084	0.084	0.066	0.060	0.065	1.0	mg/1
Fe	0.084	0.084	0.21	0.11	0.17	1.0	mg/1
Hg	0.084	0.084	<0.0004	<0.0004	<0.0004	0.002	mg/1
K	0.084	0.084	10	9.8	9.2	—	mg/1
Mg	0.084	0.084	410	300	300	—	mg/1
Mn	0.084	0.084	7.2	0.65	0.64	0.2	mg/1
Mo	0.084	0.084	0.076	0.12	0.12	1.0	mg/1
Na	0.084	0.084	410	250	250	—	mg/1
Ni	0.084	0.084	0.14	0.096	0.097	0.02	mg/1
Pb	0.084	0.084	0.48	0.36	0.38	0.05	mg/1
Se	0.084	0.084	0.30	0.23	0.28	0.05	mg/1
V	0.084	0.084	0.086	0.078	0.078	10	mg/1
Zn	0.084	0.084	0.22	0.14	0.16	—	mg/1
F	0.084	0.084	<1	<1	<1	1.6	mg/1
Cl	0.084	0.084	470	130	170	250	mg/1
CN	0.084	0.084	<1	<1	<1	0.2	mg/1
HCO3	0.084	0.084	730	440	445	—	mg/1
CO3	0.084	0.084	<10	<10	<10	—	mg/1
NO3(N)	0.084	0.084	<1	<1	<1	10	mg/1
SO4	0.084	0.084	2910	2720	2460	600	mg/1
TDS	0.084	0.084	5220	3940	3880	1000	mg/1
pH	0.084	0.084	6.9	7.2	7.2	Between 6 & 9	mg/1
Ra-226s	0.084	0.084	2.5±0.95	0.56±0.09	1.13±0.06	30	pCi/1
Ra-228s	0.084	0.084	—	—	—	30	pCi/1
U238	0.084	0.084	0.11	0.10	0.06	5.0	mg/1

Samples collected and analyzed by QMC

Table 8 (continued)

Parameter	Sect 30W-VH-4 5/20/83	Sect 30W-VH-5 Depth 410 5/20/83	Sect 30W-VH-5 Bottom of VH 5/20/83	Sect 30W-VH-6 5/13/83	Sect 30W-VH-7 5/13/83	WQCC Numerical Standard	Units
	Well Numbers and Collection Date						
Ag	0.064	0.090	0.096	0.11	0.099	0.05	mg/1
Al	0.25	0.35	0.39	0.44	0.37	5.0	mg/1
As	0.17	0.20	0.25	0.31	0.34	0.1	mg/1
B	0.29	0.25	0.23	0.26	0.28	0.75	mg/1
Ba	<0.02	<0.02	0.025	0.026	<0.02	1.0	mg/1
Ca	520	580	580	830	740	—	mg/1
Cd	0.015	0.018	0.023	0.023	0.023	0.01	mg/1
Co	0.041	0.055	0.055	0.063	0.058	—	mg/1
CR	0.055	0.070	0.083	0.098	0.090	0.05	mg/1
Cu	0.046	0.057	0.064	0.074	0.072	1.0	mg/1
Fe	0.064	0.079	0.23	0.22	0.079	1.0	mg/1
Hg	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	0.002	mg/1
K	18	8.9	8.6	12	12	—	mg/1
Mg	120	230	220	440	420	—	mg/1
Mn	0.043	0.76	0.041	2.0	1.5	0.2	mg/1
Mo	0.30	0.25	0.28	0.49	0.64	1.0	mg/1
Na	380	210	210	480	460	—	mg/1
Ni	0.080	0.10	0.081	0.21	0.15	0.02	mg/1
Pb	0.27	0.33	0.42	0.45	0.39	0.05	mg/1
Se	0.17	0.25	0.27	0.36	0.33	0.05	mg/1
V	0.052	0.076	0.078	0.098	0.086	10	mg/1
Zn	0.12	0.14	0.15	0.20	0.22	—	mg/1
F	<1	6	4	<1	<1	1.6	mg/1
Cl	88	110	310	860	730	250	mg/1
CN	<1	<1	<1	<1	<1	0.2	mg/1
HCO3	235	340	360	630	630	—	mg/1
CO3	<10	<10	<10	<10	<10	—	mg/1
NO3(N)	<1	<1	<1	<1	3	10	mg/1
SO4	2230	2160	2350	2760	2480	600	mg/1
TDS	3130	3400	3400	5540	4900	1000	mg/1
pH	8.0	7.4	7.7	7.4	7.2	Between 6 & 9	mg/1
Ra-226s	1.72±0.53	1.43±0.17	0.46±0.38	4.04±0.27	0.41±0.02	30	pCi/1
Ra-228s	—	—	—	—	—	30	pCi/1
U238	0.07	0.29	0.30	0.03	0.014	5.0	mg/1

1 Samples collected and analyzed by QMC

Table 8 (continued)

Parameter	Sect 30-VH7 Depth 290' 5/20/83	Sect 17-VH-11 5/13/83	Sect 17-VH-12 5/21/83	Sect 30W-VH-18 5/21/83	WQCC Numerical Standard	Units
	Well Numbers and Collection Date					
Ag	0.11	0.041	0.073	0.11	0.05	mg/l
Al	0.44	<0.2	<0.2	0.41	5.0	mg/l
As	0.37	0.16	0.13	0.30	0.1	mg/l
B	0.31	0.13	0.17	0.33	0.75	mg/l
Ba	<0.02	<0.02	0.022	0.026	1.0	mg/l
Ca	810	170	600	700	—	mg/l
Cd	0.024	<0.01	0.014	0.025	0.01	mg/l
Co	0.057	<0.04	0.042	0.064	—	mg/l
CR	0.10	<0.03	0.041	0.098	0.05	mg/l
Cu	0.067	<0.03	0.041	0.072	1.0	mg/l
Fe	0.071	<0.05	<0.05	0.093	1.0	mg/l
Hg	<0.0004	<0.0004	<0.0004	<0.0004	0.002	mg/l
K	11	5.8	8.9	9.0	—	mg/l
Mg	670	60	140	350	—	mg/l
Mn	0.24	<0.02	2.0	0.98	0.2	mg/l
Mo	0.054	<0.02	<0.02	0.097	1.0	mg/l
Na	490	300	330	600	—	mg/l
Ni	0.11	<0.08	<0.08	0.11	0.02	mg/l
Pb	0.46	0.14	0.28	0.44	0.05	mg/l
Se	0.40	<0.1	0.18	0.33	0.05	mg/l
V	0.092	<0.04	0.048	0.086	10	mg/l
Zn	0.35	0.055	0.082	0.18	—	mg/l
F	<1	<1	4	<1	1.6	mg/l
Cl	750	37	290	1030	250	mg/l
CN	<1	<1	<1	<1	0.2	mg/l
HCO3	675	320	385	495	—	mg/l
CO3	<10	<10	<10	<10	—	mg/l
NO3(N)	<1	<1	<1	<1	10	mg/l
SO4	3730	880	1800	2580	600	mg/l
TDS	6600	1560	3340	5200	1000	mg/l
pH	7.5	7.6	7.2	7.8	Between 6 & 9	mg/l
Ra-226s	0.433±0.12	0.87±0.55	1.12±0.20	1.21±0.25	30	pCi/l
Ra-228s	—	—	—	—	30	pCi/l
U238	0.02	0.004	0.01	0.04	5.0	mg/l

1 Samples collected and analyzed by QMC

Table 9 Water Quality Analyses from Selected Wells in the Dakota

Parameter	Well Numbers 5-01 5/25/83	5-02 5/26/83	25-01 11/14/83	30-02 5/26/83	30-48 8/15/83	31-03 8/18/83	WQCC Numerical Standard	Units
Ag	<0.03	<0.03	<0.020	0.10	0.14	0.041	0.05	mg/1
Al	<0.2	<0.2	0.091	0.43	0.52	0.14	5.0	mg/1
As	0.11	<0.1	0.057	0.18	0.45	0.12	0.1	mg/1
B	<0.05	<0.05	4.7	0.48	0.36	0.23	0.75	mg/1
Ba	<0.02	0.050	0.046	0.034	0.021	0.017	1.0	mg/1
Ca	4.9	110	110	760	640	180	—	mg/1
Cd	<0.01	<0.01	<0.007	0.029	0.020	0.008	0.01	mg/1
Co	<0.04	<0.04	<0.011	0.066	0.072	0.015	—	mg/1
CR	<0.03	<0.03	<0.026	0.096	0.096	<0.026	0.05	mg/1
Cu	<0.03	<0.03	<0.017	0.073	0.12	0.036	1.0	mg/1
Fe	<0.05	<0.05	<0.024	33	0.82	0.025	1.0	mg/1
Hg	<0.0012	<0.0004	<0.0005	<0.0004	<0.00030	<0.00030	0.002	mg/1
K	6.3	10	16	26	15	12	—	mg/1
Mg	21	56	9.9	330	440	44	—	mg/1
Mn	<0.02	0.60	<0.003	2.9	2.8	0.025	0.2	mg/1
Mo	0.023	<0.02	0.021	0.040	0.055	0.041	1.0	mg/1
Na	110	56	190	500	330	280	—	mg/1
Ni	<0.08	<0.08	<0.038	0.18	0.14	0.049	0.02	mg/1
Pb	0.033	0.047	0.023	0.46	0.39	0.14	0.05	mg/1
Se	0.086	0.048	0.041	0.26	0.49	0.12	0.05	mg/1
V	<0.04	<0.04	<0.005	0.091	0.098	0.032	10	mg/1
Zn	0.014	0.044	<0.008	0.23	0.14	0.030	—	mg/1
F	<1	—	<1	4	1.1	<1	1.6	mg/1
Cl	<1	27	90	1070	770	95	250	mg/1
CN	<1	<1	<1	<1	<0.1	<0.1	0.2	mg/1
HCO3	420	110	20	<10	630	120	—	mg/1
CO3	<10	<10	<10	<10	<10	<10	—	mg/1
NO3(N)	<0.1	—	1	2	<0.1	<0.1	10	mg/1
NO3(N)	<1	1	<1	2	<1	<1		
SO4	36	420	590	2770	2590	900	600	mg/1
TDS	390	—	1120	4880	5380	1560	1000	mg/1
TOC	<5	—	14	<5	16	23		
pH	8.8	—	9.8	5.0	6.7	7.4	Between 6 & 9	mg/1
Ra-226s	0.13±0.08	—	0.03±0.02	2.86±0.15	1.71±0.18	2.33±0.04	30	pCi/1
Ra-228s	<1.5 at 2	<1.3 at 3	<3.8 at 2	<1.1 at 2	<3.3 at 2	<2.0 at 2	30	pCi/1
U238	0.008	0.004	0.004	0.004	0.038	0.022	5.0	mg/1
Benzene	0.002	0.002	0.001	<0.001	0.001	0.002	0.01	mg/1

Samples collected and analyzed by QMC.

Table 9 (continued)

Parameter	Well Numbers 32-45 5/25/83	32-30 11/14/83	32-51 5/25/83	32-52 5/24/83	36-01 5/26/83	36-04 8/16/83	WQCC Numerical Standard	Units
Ag	<0.5	0.028	<0.03	<0.03	<0.03	0.14	0.05	mg/1
Al	0.51	0.15	<0.2	<0.2	<0.2	0.65	5.0	mg/1
As	<0.2	0.064	<0.1	<0.1	0.36	0.26	0.1	mg/1
B	0.54	0.44	0.074	<0.05	1.4	1.3	0.75	mg/1
Ba	0.060	0.014	<0.02	0.025	0.021	0.028	1.0	mg/1
Ca	110	240	7.1	140	130	510	—	mg/1
Cd	<0.5	<0.007	<0.01	<0.01	<0.01	0.042	0.01	mg/1
Co	<0.5	0.014	<0.04	<0.04	<0.04	0.074	—	mg/1
CR	<0.5	0.038	<0.03	0.032	0.058	0.12	0.05	mg/1
Cu	<0.5	0.019	<0.03	<0.03	<0.03	0.12	1.0	mg/1
Fe	<0.25	0.17	<0.05	<0.05	0.072	500	1.0	mg/1
Hg	0.0007	<0.0005	0.0006	<0.0004	0.0004	<0.00030	0.002	mg/1
K	9.4	7.7	5.2	9.2	29	28	—	mg/1
Mg	<0.5	510	12	52	1300	700	—	mg/1
Mn	<0.05	0.70	<0.02	<0.02	1.3	10	0.2	mg/1
Mo	<0.011	<0.018	<0.02	<0.02	0.034	0.058	1.0	mg/1
Na	170	1000	86	130	2300	1200	—	mg/1
Ni	<0.01	<0.038	<0.08	<0.08	<0.08	0.17	0.02	mg/1
Pb	0.027	0.033	0.036	0.024	0.17	0.46	0.05	mg/1
Se	0.053	0.11	0.057	0.052	0.34	0.43	0.05	mg/1
V	<0.04	0.021	<0.04	<0.04	<0.04	0.12	10	mg/1
Zn	0.013	0.14	0.028	0.040	0.55	0.25	—	mg/1
F	1	<1	<1	<1	<1	9.9	1.6	mg/1
Cl	210	1310	<1	49	2960	2630	250	mg/1
CN	<1	<1	<1	6	<1	<0.1	0.2	mg/1
HCO3	<10	20	145	<10	1040	<10	—	mg/1
CO3	<10	<10	<10	<10	<10	<10	—	mg/1
NO3(N)	1.5	10	<0.1	0.9	300	9.2	10	mg/1
NO3(N)	<1	<1	<1	<1	10	<1		
SO4	220	2630	120	760	6050	3770	600	mg/1
TDS	820	6270	310	1220	13500	9320	1000	mg/1
TOC	7	4	11	<5	<5	38		
pH	11.4	6.0	9.4	9.0	7.3	4.6	Between 6 & 9	mg/1
Ra-226s	0.71±0.17	2.42±0.62	0.21±0.01	3.16±0.29	0.36±0.05	1.59±0.09	30	pCi/1
Ra-228s	<2.0 at 2	<3.6 at 2	<1.1 at 2	<1.4 at 2	<1.8 at 2	<2.3 at 2	30	pCi/1
U238	0.006	0.015	0.006	0.008	0.08	0.003	5.0	mg/1
Benzene	0.003	<0.001	0.001	0.002	<0.001	0.001	0.01	mg/1

Samples collected and analyzed by QMC.

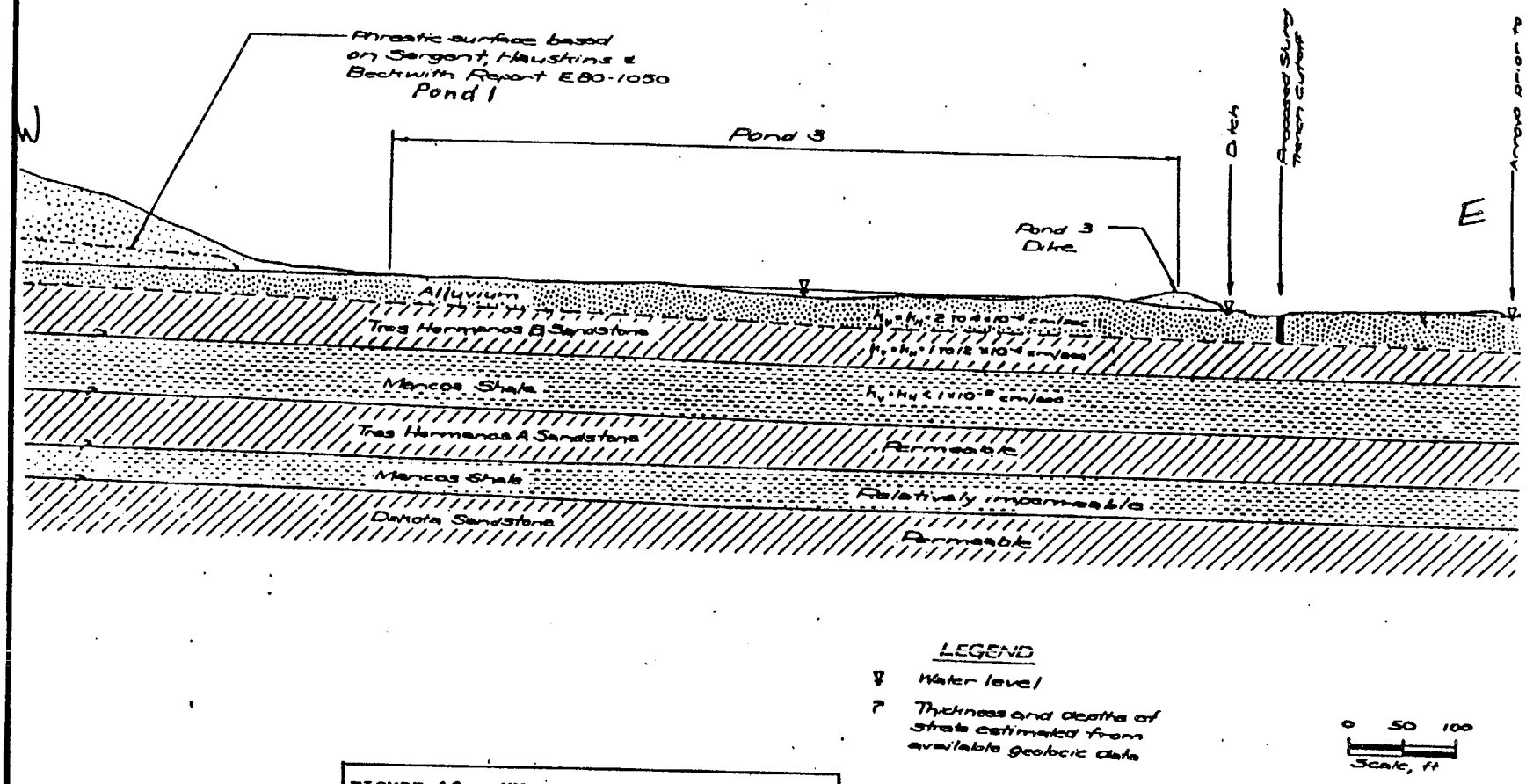


FIGURE 18: HYDROLOGIC CROSS-SECTION FOR BEDROCK AQUIFERS WITH RELATIVE HYDRAULIC CONDUCTIVITIES.

KERR-McGEE NUCLEAR CORPORATION
AMBROSIA LAKE, NEW MEXICO

80C466-4	28 July 1983

Woodward-Clyde Consult

estimated from two pumping tests carried out by QMC in 1980. Results from these tests indicated the hydraulic conductivity of the alluvial materials to range between 4 gpd/ft^2 to 10 gpd/ft^2. The magnitude of these hydraulic conductivities measured in the field corresponds well with reported permeabilities of similar materials. Grain size distribution curves of various alluvial samples collected during the WCC field program correlated well with these field test results.

Flow rates measured in WCC field packer permeability tests indicate that the in-situ hydraulic conductivity of the Trb Sandstone ranges approximately from 2 gpd/ft^2 to 20 gpd/ft^2. Analysis of the test data also indicates a tendency for the permeability to decrease towards the bottom of the strata where the sandstone gradually grades into the underlying Mancos Shale.

The field permeability tests indicate the two layers (alluvium and Trb Sandstone) in the uppermost zone in the slurry trench cutoff area have very similar permeabilities. The measured difference in the permeabilities of these two layers is small and therefore, in a worst case analysis, it is QMC's judgment that they can be considered as a single hydraulic unit with equal horizontal and vertical permeabilities.

The underlying shale unit of the Mancos Formation is commonly reported to be relatively impermeable. In-situ testing of the lower portion of the Trb Sandstone yielded hydraulic conductivity values of 4×10^{-1} gpd/ft^2. Lower hydraulic conductivity values are expected in the unweathered shale formation below. This indicates the hydraulic conductivities measured in the upper and middle portions of the Trb Sandstone and in the alluvium are at least one order of magnitude greater than those of the shale. As a consequence, the shale unit is considered impervious with respect to the alluvium and sandstone layers above. The hydraulic conductivities of the stratigraphically lower Tra Sandstone and the Dakota are qualitatively indicated on Figure 19. QMC has reported a hydraulic conductivity of 10 gpd/ft^2 in the Dakota from bailer tests performed in 1982.

3.2.2.5 Bedrock-Venthole Modeling

Ground-water quality monitoring of the Tres Hermanos and Dakota sandstones by QMC has indicated tailings seepage has impacted substantial areas of these formations. The EID requested QMC to perform numerical modeling of the potentiometric surface created by venthole drainage in the Ambrosia Lake mining district to determine whether the ventholes were capturing tailings seepage and whether the formations were substantially dewatered. The modeling was performed in conjunction with venthole investigations that

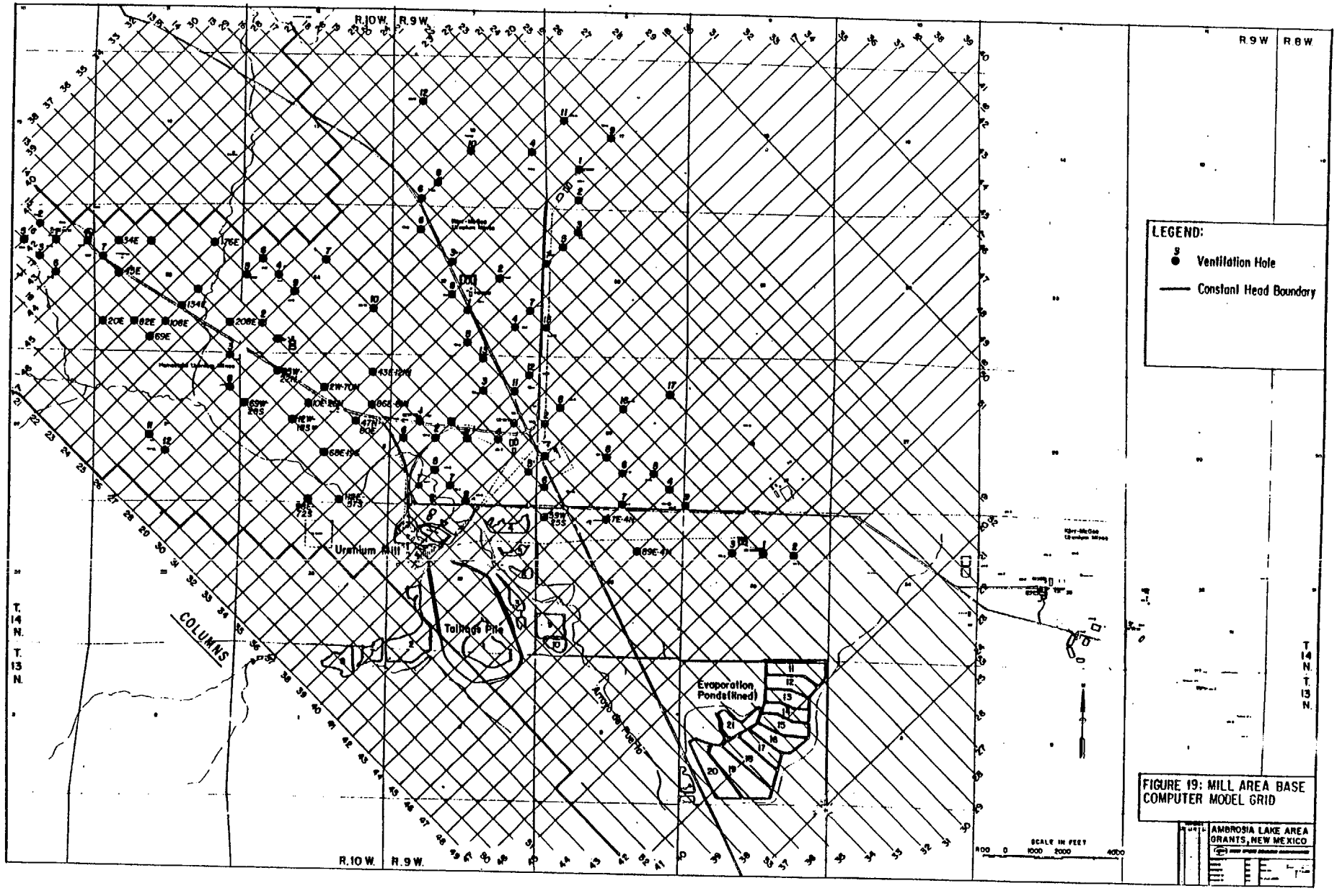


FIGURE 19: MILL AREA BASE COMPUTER MODEL GRID

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

measured the discharge from each of the ventholes. QMC demonstrated from the modeling and venthole investigations that the ventholes capture all tailings seepage in the Tres Hermanos and Dakota sandstones. QMC also demonstrated to the EID that repressurization of these formations by ground water from the WCM will not cause the WQCC numerical ground-water standards to be violated at a place of foreseeable future use because residual tailings seepage will be substantially diluted.

3.2.2.5.1 Numerical Modeling

The potentiometric surface in the Dakota Sandstone was simulated by QMC using a numerical model developed at the Illinois State Water Survey (Prickett and Lohnquist, 1971). The program was modified by QMC, as necessary, for this application.

Ventilation holes constructed in the Ambrosia Lake uranium mining area are designed to drain bedrock aquifers overlying the Westwater. Typically, the vent holes are five feet in diameter and extend vertically from the ground surface into the mines. Ground water in alluvial sediments is grouted off. The vent holes are lined with steel casing but are not cemented into place along the bedrock borehole length. The casing has weepholes which prevent hydrostatic pressure buildup outside of the casing. Drainage is permitted to move down to the mine level where it is captured. A total of 96 vent holes were used in this computer study, including several in United Nuclear-Homestake mines. All vent holes were not included in the simulation due to incomplete data.

Pre-mining steady-state hydrologic conditions were simulated using the model and ventilation hole drainage points were introduced at the time of their construction (Table 10). Drainage of water lowers the head around the vent hole in the formation creating a pressure relief cone. With time the pressure relief cone at each vent hole expands in size. The lateral extent of this pressure relief expansion leads to the interconnection of cones into a large and continuous pressure relief trough.

Because of the complexity of conditions, including sloping initial water level surface, dipping aquifer beds, multiple drainage points with drawdown interference effects and varying times for initiation, the EID requested that QMC use a digital computer for solution. QMC used a conservative approach, because of some uncertainties in the data. However, even under conservative conditions, a continuous pressure relief trough is demonstrated to result from ventilation hole drainage.

Table 10: Dakota Venthole Data

Construction Date	Location	Node I,J	Mid-Point Elev. H
1958	Sec.32 7E-4N	43,32	6650
1958	Sec.24 VH-1	27,37	6540
1959	Sec.22 VH-1	17,41	6730
1959	Sec.30 VH-1	37,32	6650
1959	Sec.33 VH-1	49,28	6600
1959	Sec.22 VH-2	16,41	6740
7-59	Sec.17 VH-1	31,22	6490
12-59	Sec.22 VH-3	17,42	6720
9-59	Sec.24 VH-2	26,37	6560
10-59	Sec.24 VH-3	26,39	6590
1959	Sec.30 VH-2	38,31	6650
12-59	Sec.33 VH-2	50,27	6585
1959	Sec.23 34E-910N	19,39	6730
4-60	Sec.17 VH-2	32,23	6525
1960	Sec.22 VH-4	18,40	6740
1960	Sec.22 VH-5	16,42	6740
2-60	Sec.24 VH-4	25,35	6670
10-60	Sec.24 VH-5	24,36	6650
12-60	Sec.24 VH-6	24,35	6720
5-60	Sec.33 VH-3	48,29	6615
3-61	Sec.30 VH-3	35,32	6650
6-61	Sec.30 VH-4	37,33	6640
5-62	Sec.17 VH-3	33,24	6560
5-62	Sec.30 VH-5	39,33	6650
10-62	Sec.17 VH-4	29,23	6525
7-62	Sec.22 VH-6	18,42	6700
2-64	Sec.33 VH-4	44,29	6615
2-64	Sec.30 VH-7	37,36	6640
12-64	Sec.30 VH-6	40,33	6660
1964	Sec.23 153E-840S	23,38	6620
6-65	Sec.17 VH-5	33,25	6550
6-65	Sec.33 VH-9	45,29	6615
9-65	Sec.33 VH-5	43,29	6615
8-66	Sec.24 VH-7	26,33	6740
1966	Sec.25 92E-72S	33,41	6700
1966	Sec.25 68E-15S	32,39	6620
1-67	Sec.17 VH-6	27,28	6640
12-67	Sec.22 VH-7	19,40	6690
6-67	Sec.24 VH-8	27,40	6620
10-67	Sec.24 VH-9	26,35	6630
3-67	Sec.30 VH-8	38,30	6630
11-67	Sec.30 VH-10	39,32	6650
1967	Sec.23 208E-1950S	25,38	6570
1967	Sec.25 112E-56S	34,40	6690
2-68	Sec.17 VH-7	33,26	6590
3-68	Sec.17 VH-9	31,20	6415
1-68	Sec.30 VH-9	38,36	6660
10-68	Sec.33 VH-6	42,30	6630

Table 10 (cont'd)

Construction Date	Location	Node I,J	Mid-Point Elev. H
1968	Sec.23 176E-700N	22,36	6740
1968	Sec.23 134E-850S	23,39	6610
1968	Sec.25 68W-29S	28,40	6620
1968	Sec.32 58W-28S	41,34	6660
3-69	Sec.30W VH-1	34,35	6640
4-69	Sec.30 VH-11	36,31	6650
4-69	Sec.30 VH-12	36,30	6630
1969	Sec.25 10E-26N	30,38	6550
8-70	Sec.17 VH-10	27,25	6580
2-70	Sec.17 VH-8	27,27	6630
4-70	Sec.30W VH-2	35,35	6640
9-70	Sec.30W VH-3	35,34	6640
6-70	Sec.33 VH-7	43,31	6640
7-70	Sec.33 VH-8	41,30	6630
9-70	Sec.30W VH-4	36,34	6640
1970	Sec.25 2W-70N	30,37	6530
1970	Sec.32 88E-4N	45,32	6650
2-71	Sec.24 VH-10	29,33	6610
7-71	Sec.30 VH-13	34,31	6650
1971	Sec.25 12W-15S	30,39	6580
4-73	Sec.19 VH-1	32,30	6610
8-74	Sec.30W VH-5	36,36	6640
10-75	Sec.19 VH-2	32,28	6630
8-75	Sec.19 VH-3	30,29	6640
8-75	Sec.30W VH-6	34,36	6580
1975	Sec.23 69E-2350S	23,41	6630
4-76	Sec.19 VH-4	34,29	6610
10-76	Sec.30 VH-15	35,28	6600
1976	Sec.25 80E-47N	32,37	6530
10-77	Sec.17 VH-11	29,21	6440
11-77	Sec.17 VH-12	24,25	6620
1977	Sec.23 82E-1850S	22,41	6630
2-78	Sec.19 VH-5	33,31	6590
2-78	Sec.24 VH-11	26,44	6720
2-78	Sec.30 VH-16	40,28	6600
1978	Sec.23 93E-900N	20,38	6730
1978	Sec.23 45E-125S	20,40	6660
1978	Sec.25 43E-121N	31,35	6490
11-78	Sec.19 VH-6	28,29	6640
1978	Sec.25 86E-81N	32,36	6570
1979	Sec.23 108E-1770S	23,40	6610
1979	Sec.23 20E-2000S	21,42	6640
1979	Sec.25 55W-22N	28,38	6560
3-80	Sec.19 VH-7	34,28	6600
6-80	Sec.19 VH-8	31,30	6640
3-80	Sec.24 VH-12	27,44	6720
11-80	Sec.30W VH-7	36,37	6650
2-81	Sec.30 VH-17	41,26	6580

Grid

The study area was descretized with a 63 x 47 finite difference grid. The area simulated is chosen to be extensive in order to minimize the model boundary effects. As shown on the map, the spacing between rows and columns is reduced in the immediate Ambrosia Lake area to provide additional control in the subject area. The area with reduced grid spacing is shown at a larger scale in Figure 19. Rows 19-47 and columns 13-51 are spaced 800 feet apart, four times closer than in the rest of the grid. The larger scale map is used in subsequent maps presenting input parameters and results. The grid system is oriented 45° from north for convenience in data input.

Geologic Input

The Dakota Sandstone in the site area dips northeast into the San Juan Basin. Figure 20 shows the generalized base of Dakota structure used as data input in the simulation. Maps from QMC's Mineral Exploration Division were used as well as a report by Brod (1979). At nodes other than in the immediate area of interest, the geologic structure has been further simplified to ease data input. The grid rows are assumed parallel to the bed strike and hence are input as lines of equal structural elevation. This simplifying assumption affects the results very little due to the decreasing drawdown influence at points distant from the drainage points.

Hydrologic Input

Water levels in the Dakota prior to mining roughly parallel the geologic structure. A map by Brod (1979, p. 79-80) indicates the natural pre-mining hydraulic gradient to be 25 feet per mile in the underlying WCM. Water level equipotential lines are oriented at approximately N45°W. The hydraulic gradient in the Dakota is assumed to be equivalent to that in the WCM. Cooper and John (1968, p. 76) report that pre-mining Dakota water levels at the Phillips Mine to be 6678 feet above mean sea level. Using the assumed hydraulic gradient and this control point, an approximate Dakota pre-mining water level map was drawn. The map, shown as Figure 21, was used as model input for initial heads.

The transmissivity (T) of the Dakota Sandstone is assumed to be 1000 gpd/ft (Brod, 1979, p. 78). For an 80 foot thick unit, the hydraulic conductivity (K) is 12 gpd/ft^2. These values are assumed to be constants throughout the grid, with the exception of the unsaturated areas where T and K are assigned zero values. This is approximately the same as that reported by QMC for the Tres Hermanos Sandstone at the site (2 to 20 gpd/ft^2). The model is capable of converting from confined to water table conditions at each node, so storage

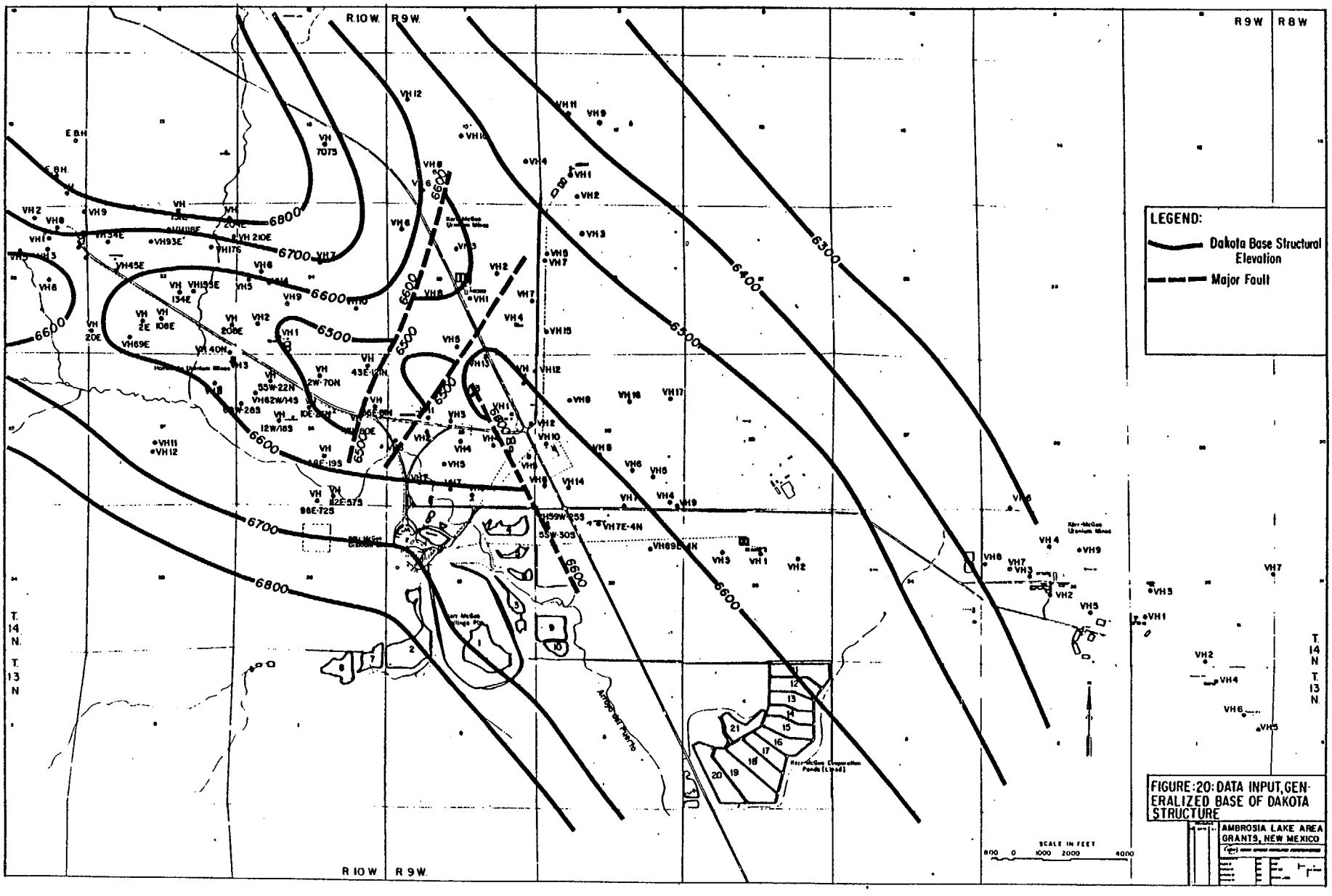


FIGURE: 20: DATA INPUT, GENERALIZED BASE OF DAKOTA STRUCTURE

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

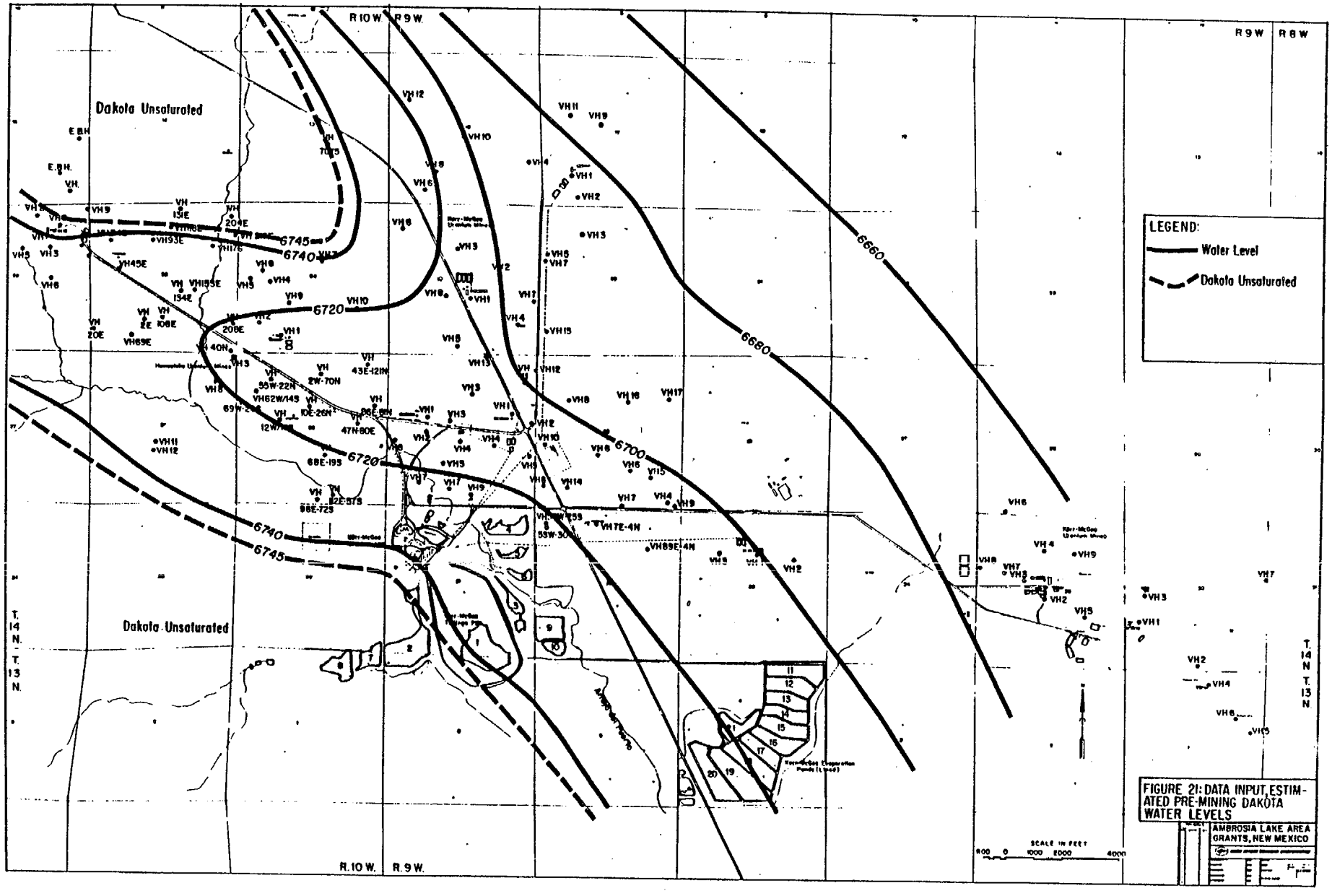


FIGURE 21: DATA INPUT, ESTIMATED PRE-MINING DAKOTA WATER LEVELS

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

coefficient values for each condition are input for each node. Water table storage coefficient is assumed to be 0.10. Confined storage coefficient is estimated as 1×10^{-6} per foot of thickness (Lohman, 1972, p. 53). For the fully saturated Dakota this storage coefficient is conservatively approximated as 1×10^{-4}. Leakage from and through the overlying Mancos and underlying Brushy Basin Member is considered to be negligible.

Steady-State Calibration

Before adding vent hole drainage points, the model was set up for steady-state hydrologic conditions to ensure that subsequent computed water level changes were, in fact, the result of the vent hole drainage. In the natural system, steady-state conditions are present when ground-water recharge and discharge are in balance. Because recharge is taken as zero in this simulation, water levels must be stabilized by another technique. In this case, the saturated/unsaturated line on Figure 21 was modeled as a constant head line. This has the effect of not allowing any drawdown or rise in water levels along the line. The constant head used was 6745 feet. This assumption produces controlled recharge. Setting row 1 (uppermost NW-SE line in the grid) at a constant head of 6405 ft forces the nodes between the two constant head lines to assume intermediate values. Water levels across the area adjusted with time until no further changes occurred; the model eventually established steady-state conditions. Estimated initial head values were assigned to each node to decrease the time needed to stablilize water levels.

Constant head boundaries were assigned an essentially infinite storage factor (1×10^{21}) at points along the boundary. In addition, the node points had to be capable of transmitting the stored water or the constant head line would fail to deliver sufficient "recharge" for stability. For instance, it was found that given a constant hydraulic conductivity, a saturated thickness of five feet along the 6745 constant head line was insufficient to prevent model-wide water level drops with time. Raising the saturated thickness to 80 feet produced an acceptably stable head configuration throughout the model after ten timesteps. Therefore, in this modeling study, drainage points were first introduced in the eleventh timestep. Figure 22 shows the computer generated pre-mining water levels.

Previously, it was stated that transmissivity of the unsaturated nodes was taken as zero. This assumption is necessary to prevent head rises in the unsaturated area resulting from the 6745 foot constant head line "recharge."

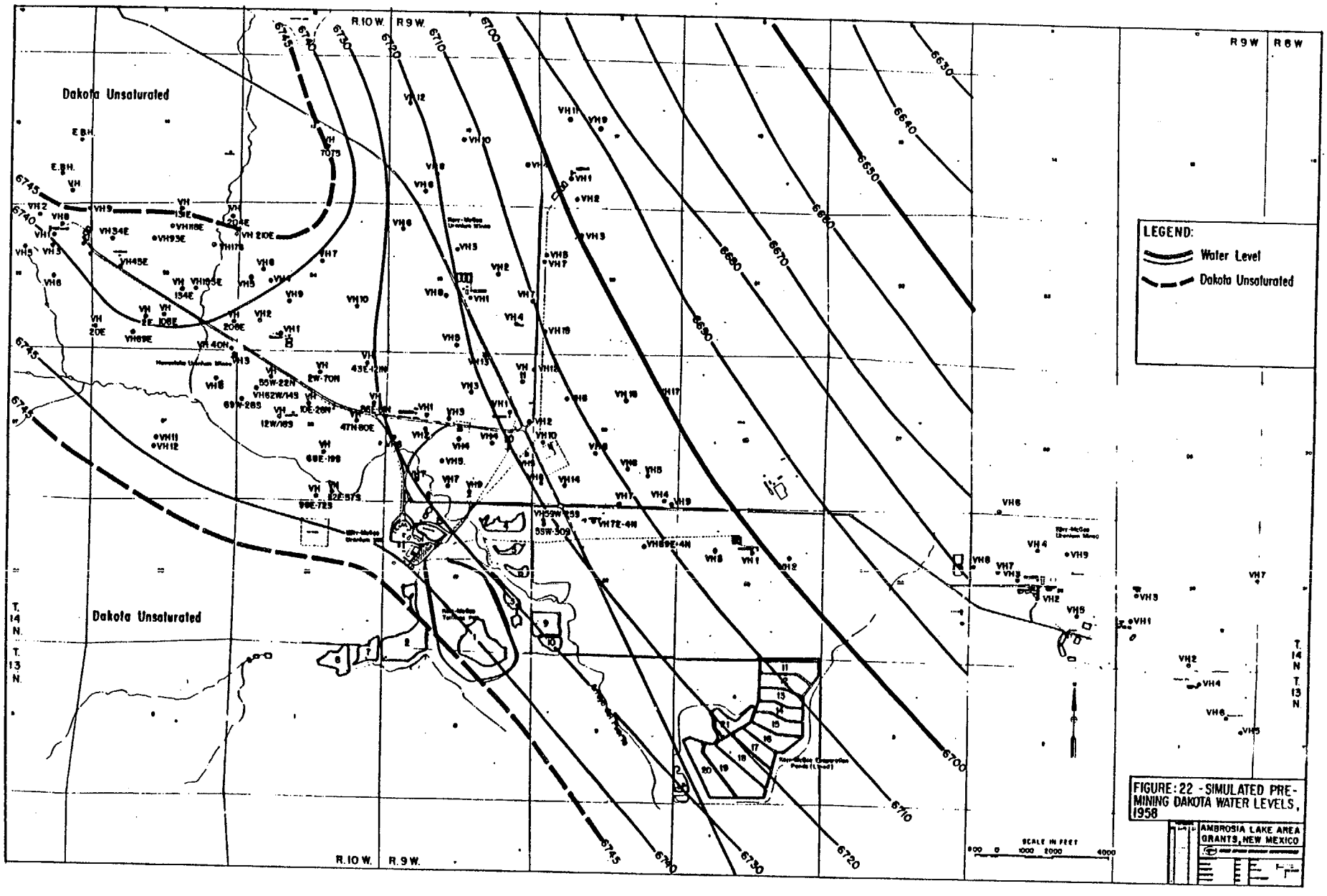


FIGURE: 22 - SIMULATED PRE-MINING DAKOTA WATER LEVELS, 1958

AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

Ventilation Hole Simulation

Simulation of drainage points was achieved by placing constant heads at vent hole nodes. The approach used here was to instantaneously draw down water levels at vent hole locations to aquifer mid-point. Mid-point was assumed to allow the lower half of the aquifer to be a seepage face in the vent hole. Actual drawdown would likely be more, but this was used as a conservative assumption. The storage factor was changed at these nodes to approach infinity (1×10^{21}) so that water levels at the drainage node would not change with time. With successive timesteps, however, water levels in adjacent nodes adjusted downward in response to the head drop at the drainage node.

It was discovered during the modeling process that some correction for the drainage node size was required. Most vent holes in the Ambrosia Lake area are five feet in diameter. The model grid spacing in the vent hole area is 800 feet; therefore, the model assumes the drainage point is a square with 800-foot sides rather than the actual 5-foot diameter circle. Consequently, at any given time for constant hydrogeologic parameters, considerably more drainage would be expected through the uncorrected model than would actually occur. This would produce unrealistically high drawdown around the drainage points and would not be a conservative approach. This has been corrected by lowering the model drainage node transmissivity to 40% of actual, thereby producing drainage rates more consistent with the actual 5-foot diameter ventholes. Consequently, the corrected model conservatively estimates drawdown at surrounding nodes.

Results

Figures 23 and 24 demonstrate the effect of ventilation holes on Dakota water levels. Figure 23 is a map of simulated water levels in February 1965. Comparison to the pre-mining configuration shows the development of a significant area of pressure relief. Ground-water flow paths are altered dramatically and in some cases reversed in direction. Further changes occurred from that time to the present as shown in Figure 24, the simulated water level map for March 1983.

Examination of the water level maps indicates that the pressure relief trough was firmly established soon after mining commenced. As additional vent holes were constructed, the pressure relief trough continued to expand as well as grow downward.

Figures 23 and 24 indicate all seepage into the bedrock from the tailings disposal area is prevented from migrating beyond the pressure relief influence of the ventilation holes.

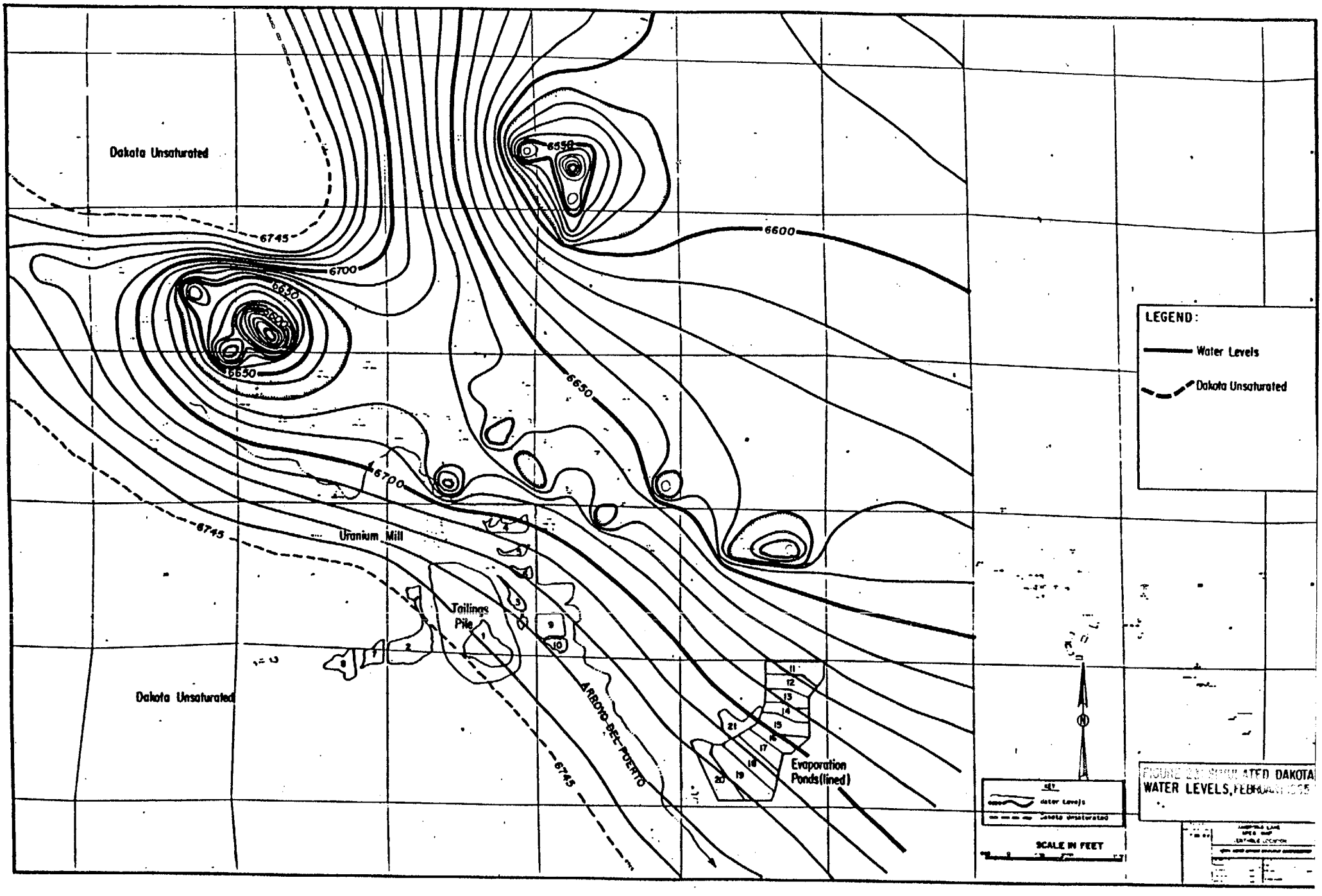


FIGURE 2.2: SIMULATED DAKOTA WATER LEVELS, FEBRUARY 1985

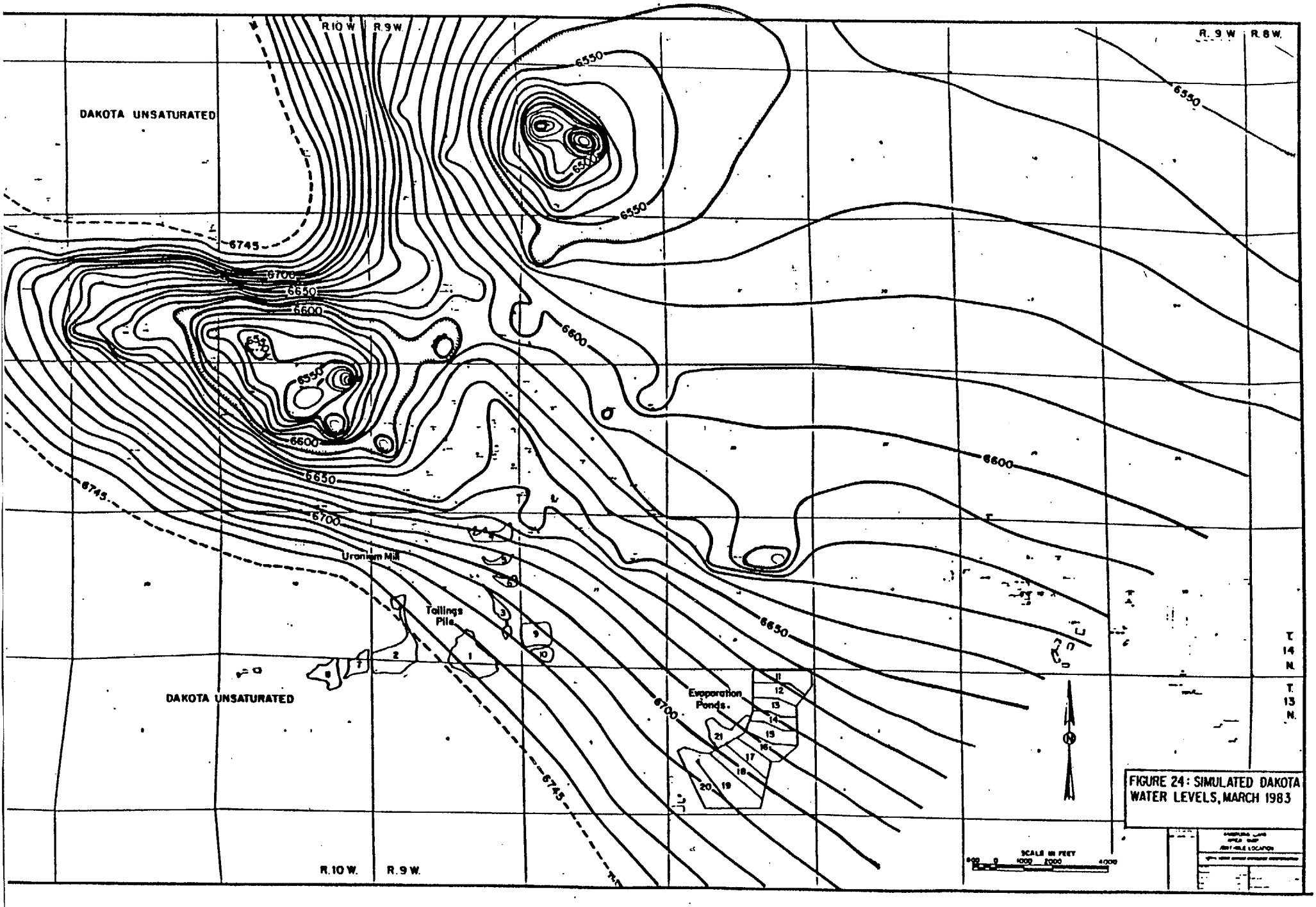


FIGURE 24: SIMULATED DAKOTA WATER LEVELS, MARCH 1983

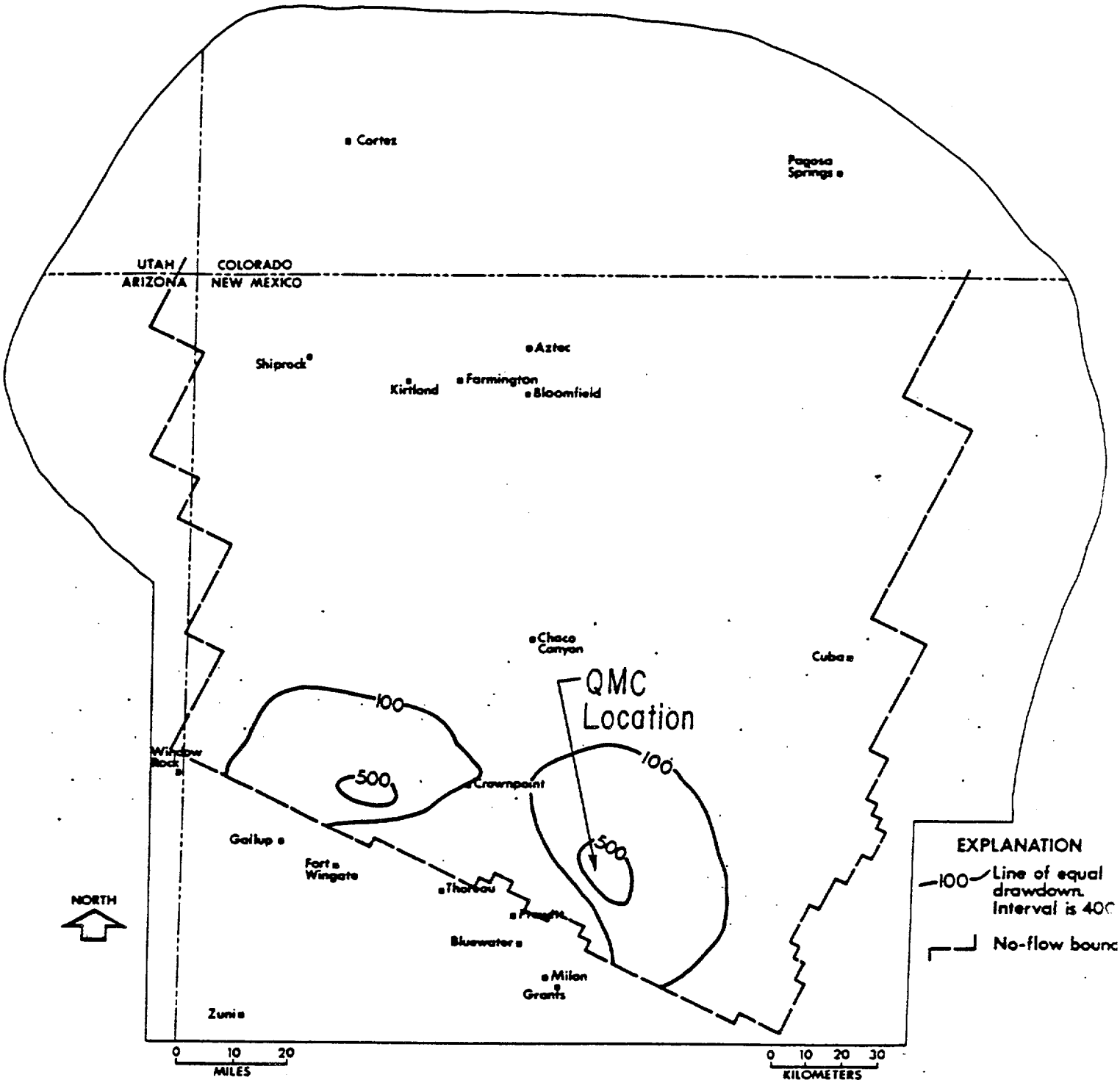
3.2.2.5.2 Water Quality Modeling

QMC speculates that the milling and mining operations may cease in the year 2000, at which time water level recovery in the mines would begin. At that time, the tailings ponds would contain fluid which would continue to drain laterally to a surface catchment as well as downward into the Trb sandstone. Water levels in the Trb, for the 2000-year period, would be similar to that presented in Figure 24 as steady state conditions would persist.

Water quality in the Dakota will change because ponds 7 and 8 were removed from operation in 1983. After 1983, the Dakota Sandstone should no longer be receiving significant quantities of tailings seepage. Using the permeability value of the Dakota taken from bailer tests conducted in 1982 (10 gpd/ft^2), the bedrock dip value in the mill area (200 ft. in 3000 ft.) and a porosity of 10%, the velocity and travel time of the flow in the Dakota can be approximated. By the year 2000, 17 years of flow will transfer the plume approximately one mile downgradient from its present-day source, as shown in Figure 16.

Several hundred thousand acre-feet of ground water have been removed from the subsurface in the Ambrosia Lake mining district since 1957. The greatest portion of this water has come from Westwater Canyon Member dewatering for mining. However, a significant quantity of water has come from draining the Dakota and Tres Hermanos sandstones in the mining area. The mine dewatering and drainage has produced a very extensive pressure-relief trough in the WCM as well as in the Dakota and Tres Hermanos sandstones.

In recent years, a number of computer models of the ground-water system of the San Juan Basin have been constructed. The primary purpose of these models has been to determine major effects of withdrawals from the WCM aquifer on water rights. Basin-wide models have been prepared by USGS, Phillips, Mobil, Conoco and QMC. Whenever the Ambrosia Lake area is simulated in these models, a large area of pressure relief is noted for the WCM. For instance, the USGS model shows an area of approximately 80 square miles to have a pressure relief in excess of 500 feet and an area of about 1000 square miles to have at least 100 feet of pressure relief (Figure 25) caused by mine dewatering from 1957 to 1980. Other models show a similar magnitude of pressure relief. Recovery simulations, related to these studies, indicate that hundreds of years will be required before any of the major mine dewatering centers will fully recover, even if all other pumping is stopped. Until full recovery for a pumping center is reached, an inward gradient will prevail,



MODELED DRAWDOWN IN THE MORRISON FORMATION BY THE YEAR 1980

Source: Lyford, Forest; Frenzel, Peter and Stone, William - Modeled Effects of Uranium Mine Dewatering on Water Resources in Northwestern New Mexico. Final San Juan Basin Regional Uranium Study.

FIGURE 25 Regional Pressure Relief for Ambrosia Lake Area

which will not allow outward flow for a very long period of time.

To predict the long range ground-water quality in the Ambrosia Lake mining district resulting from aquifer recovery and the ground-water contamination to the bedrock from the tailings pond, all sources of natural and man-related recovery were identified. Table 11 shows the estimated volumes and chemical properties associated with natural recovery and with the man-related features, such as bedrock contamination, tailings pond drainage and mine-stope backfilling. The sources of these data are footnoted in Table 11.

The resultant total shows that full recovery will involve an estimated 416,222 acre-feet of water yielding a chloride concentration of 26 mg/l, sulfate concentration of 401 mg/l, and selenium concentration of 0.034 mg/l.

The above analysis is considered to be a worst case scenario in that the greatest possible contributor of contamination to the ground water is from the tailings ponds and all drainable fluid from the ponds is assumed to reach the bedrock recovery area. Under field conditions, a major portion of the tailings fluid in the ponds migrates by lateral flow and will be captured by surface ditches and impoundments and not be an impact to the bedrock ground-water recovery volume. Additionally, this scenario includes the volume of bedrock contaminant, in both the Dakota and Tres Hermanos sandstones, which entered the ground prior to the promulgation of the New Mexico WQCC ground-water regulations (1977) and which is still in transit to the vent hole capture area.

A worst case scenario of the bedrock aquifer impact, resulting from mixing all of the tailings pond drainage with all other recovery water, does not cause the ground water in the mining area to exceed WQCC numerical ground-water standards for the indicator parameters (chloride, sulfate and selenium) in the foreseeable future. Furthermore, as ground-water recovery proceeds when mine pumping stops, an inward flow to the area will persist for hundreds of years, preventing outward migration of any fluid until full recovery and dilution are reached.

Table 11. Water Quality Data for Aquifer Recovery at Ambrosia Lake

Aquifer/Source	Natural Recovery Volume AF	Natural Recovery Volume %	Natural Recovery Cl (mg/l)	Natural Recovery SO_4 (mg/l)	Natural Recovery Se (mg/l)	Impacted Recovery Volume AF	Impacted Recovery Volume %	Impacted Recovery Cl (mg/l)	Impacted Recovery SO_4 (mg/l)	Impacted Recovery Se (mg/l)
Tres Hermanos c	2000[1]	0.48	6.6[4]	895[4]	0.017[4]					
Tres Hermanos b	3000[1]	0.72	6.6[5]	928[5]	0.025[6]	1300[8]	0.31	1620[5]	5483[5]	0.470[6]
Tres Hermanos a	5000[1]	1.20	6.6[5]	862[5]	0.009[6]					
Dakota	35000[2]	8.41	7.9[5]	433[5]	0.019[6]	640[9]	0.15	2630[5]	5177[5]	0.470[6]
Westwater	368000[3]	88.41	9.4[7]	278[7]	0.032[7]					
Sand Fill						82[7]	0.02	196[7]	24160[7]	0.873[7]
Tailings Pond						1200[10]	0.29	2800[3]	25100[3]	0.380[3]

Result of Mixing Volumes and Concentrations from above

	Volume AF	Volume %	Cl	SO_4 (mg/l)	Se
Total	416222	100	26	401	0.034

Footnotes

1. Assumed values, based on comparison with Dakota.
2. Approx. value from Dakota drainage map; conservative value due to lack of data on areal extent of cone.
3. QMC submittal to EID, W.J. Shelley to K. Souder, May 5, 1983.
4. No background dta available for TRc; assumed values are averages for TRa and TRb.
5. QMC monitor well analyses, May 18, 1983.
6. Discharge Plan 169; Hydrologic Assessment of Ambrosia Lake Area, W.J. Ganus, 1980.
7. QMC submittal to EID, W.J. Shelley to K. Souder, April 22, 1983.
8. Calculated from plume map, Plate 3; area=2 sq. miles; sat. thickness=10 ft; specific yield=10%.
9. Calculated from plume map, Plate 5; area=1 sq. mile; sat. thickness=10 ft; specific yield=10%.
10. QMC calc., see App. A; entire tailings pile drainage assumed to enter TRb as bedrock recovery.

4.0 GROUND-WATER QUALITY IMPACTS FROM THE MILL FACILITY

Operating accidents resulting in leaks and spills of solutions and slurries from tanks and piping within the mill may be caused by human error or equipment failures. Such failures within the confines of the processing areas would be contained within the area, mostly in sumps, and therefore would not reach the unrestricted environment.

A large spill in the mill facility from any of the processing vessels would be contained by the Spill Prevention, Control and Countermeasure (SPCC) system, which drains such a spill to the east into the former water course of the Arroyo del Puerto. Flow downstream off the Quivira site is prevented by the presence of a dam which is equipped with a float-controlled pump, which returns the fluid to the decant pond.

The EID's analysis of the site's geology and hydrology and the engineering designs incorporated into the mill supports QMC's conclusion that minimal impacts to ground water should result from a spill from within the mill facility.

5.0 GROUND-WATER QUALITY IMPACTS FROM THE POTENTIAL RELEASES OF RADIOACTIVITY AND OTHER CONTAMINANTS FROM THE TAILINGS SLURRY PIPELINE AND TAILINGS DAM

Two sections of the QMC Application for License Renewal discuss potential releases of radioactivity from the tailings-slurry pipeline and tailings dam. Chapter 8 of the Application presents a discussion of the effects of all accidents, including a break in the pipe from the decant pond pumps to Section 4. Appendix F of the Application describes the contingency plan for release of radioactive material to restricted areas.

A tailings slurry pipeline rupture between the impoundment and the Section 4 evaporation ponds could result in release of radioactive mill tailings fluid to an unrestricted area. The pipeline is buried for its entire length from the pumps at the decant pond to the evaporation ponds in Section 4, except for two places where the pipeline crosses the former creek channel near Pond 3 and where it crosses the Arroyo del Puerto. However, QMC believes that a rupture of the buried portion is not a credible accident. A release at the two points of exposure can be readily contained. At the Arroyo del Puerto crossing, the pipeline is supported on a bridge and encased in a wooden structure, which will control leakage in a fashion so that it will flow to the edges of the bridge abutment. The flow to the east would be captured by the soil and removed in accordance with the contingency plan. The flow to the west would be contained on the Quivira site. Similarly, a rupture at the former creek bed would be contained by the creek bed, which serves as a channel for QMC's spill control system.

At the time of installation, the pipe was tested at a maximum working pressure of 150 pounds. This is considerably above its average normal operating pressure of 45 pounds. Since the pipe is buried in a trench, a rupture is a credible accident. Moreover, the pressure on the pipe during use is monitored continuously; and in the event of low or high pressure, the monitor signals an alarm and shuts down the pumps in the mill.

A break in the tailings dam is not a probable event due to the daily monitoring, the operating criteria that maintains a minimum beach length, and the quarterly safety evaluation required by the State Engineer. Such an accidental release would be handled by the procedure described in Appendix F, permitting prompt containment and cleanup.

Seepage of tailings solution through the soils at the site is promptly neutralized by the excess calcium carbonate found in the soil. Neutralization results in the precipitation of heavy metal and radionuclides. Soil contaminated from spills

would be removed and replaced with clean soil. The contaminated soil will be placed on the tailings pond.

The EID believes that potential releases of radioactivity and other contaminants from the tailings-slurry pipeline and tailings dam are unlikely. However, should an accidental release occur, ground water-quality impacts would be negligible because of engineering design features and the contingency plan.

6.0 GROUND WATER QUALITY IMPACTS FROM FLOODING

The EID requested that the New Mexico State Engineers Office review the flooding analyses submitted by QMC for the 100 year storm and the probable maximum precipitation (PMP) reoccurrance interval storm. Of salient interest to the EID were the ground-water quality impacts resulting from floods in the Arroyo del Puerto and the West Arroyo (which contains former evaporation ponds 7 and 8 as shown on Figure 2).

QMC has demonstrated to the EID that flooding resulting from the 100 year storm in the Arroyo del Puerto and the West Arroyo will not cause flood waters to come in contact with either the mill or tailings facility. Floods resulting from the 100 year storm in the Arroyo del Puerto are well below the mill and tailings facility and the tailings are protected from a 100 year flood in the west arroyo by a diversion ditch, designed to contain the 100 year flood, shown on Figure 26.

Although the EID concurs with QMC that protection from the PMP is not necessary during mill operations, long-term PMP protection of the tailings embankment is a justifiable concern. The State Engineer's analysis of the PMP in Arroyo del Puerto indicates that a 6 hour storm with a peak flow of 128,100 cubic feet per second (CFS) reaches a high water surface of 6926.3 feet. This confirms that flooding in the Arroyo del Puerto will not exceed elevation 6930, the base of the tailings dam.

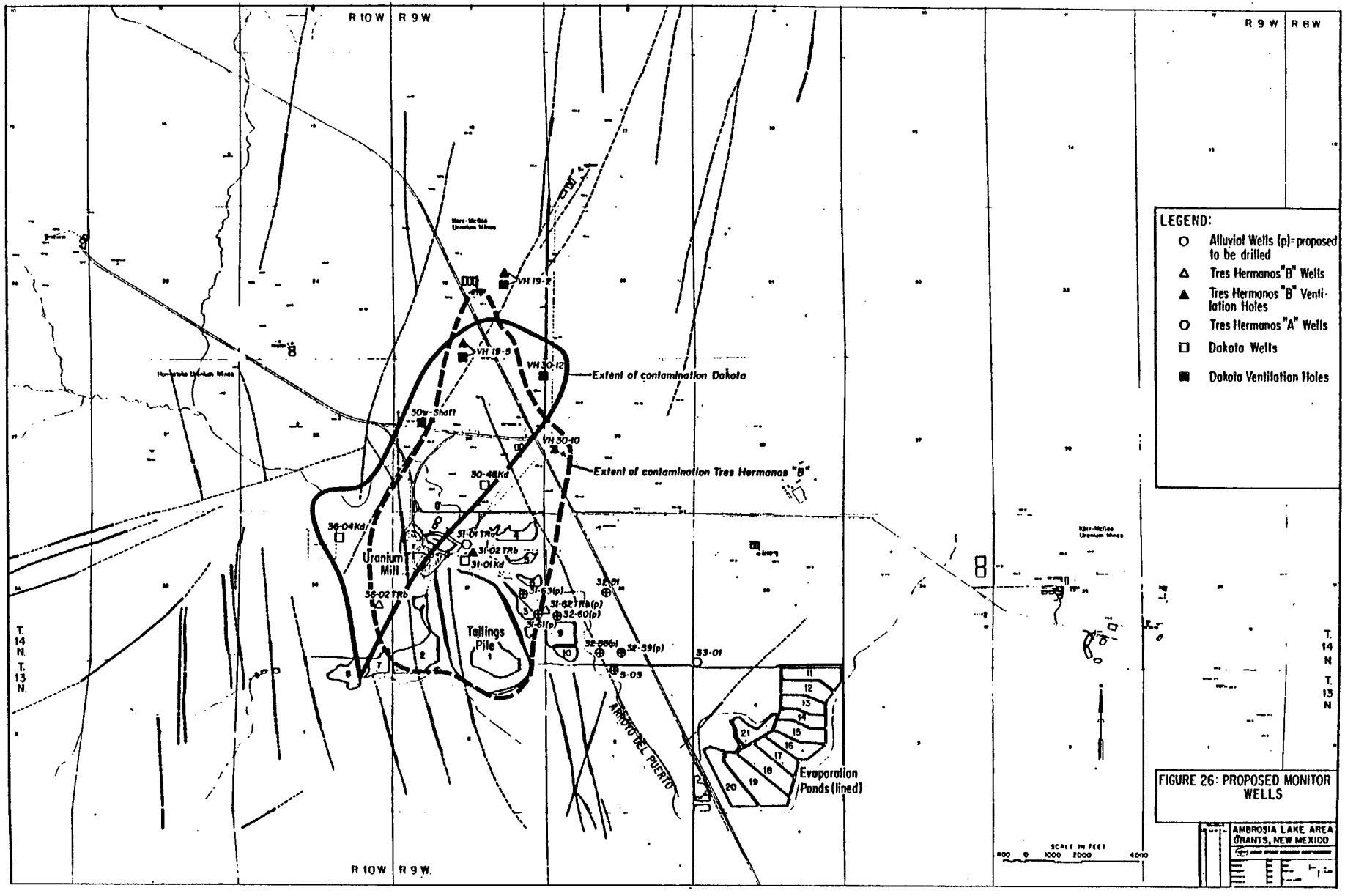
However, PMP flows in the West Arroyo overtop the diversion ditch and come in contact with the tailings. The State Engineer calculated that a one hour peak flow for a PMP in the West Arroyo is 12,000 CFS. QMC then analysed cross-sections between the diversion ditch and the tailings pond embankment to determine the maximum flood elevations and velocities. The State Engineer believes that the QMC proposed rip rap protection is adequate to stabilize the channel surfaces of the stabilized tailings ponds during a PMP event.

In regard to the effect of a PMP on the stabilized tailings pond, the EID believes that the planned cover, consisting of six inches of Mancos shale and eight inches of four-inch Todilto limestone, will prevent erosion of the pond embankment and provide sufficient cover to prevent the infiltration of rainwater. Most rainfall will run off the surface and the amount infiltrating will evaporate promptly. In the event of significant infiltration, liquid passing through the stabilized pond will be intercepted by the seepage interception ditch planned for the area immediately east of the pond. A more complete description of QMC reclamation plans are found in Chapter 11 of the Application for License Renewal submitted to the Radiation Protection Bureau.

7.0 MONITORING REQUIREMENTS AND COMMITMENTS

QMC has proposed an extensive monitoring schedule to protect water quality in the alluvial and bedrock aquifers. The schedule is designed to detect possible migration of existing concentrations of contaminants or increases in existing concentrations. The locations of the proposed monitor wells are shown on Figure 26.

EID believes the monitoring schedule and monitor well locations proposed by QMC are sufficient to detect any additional migration of tailings seepage or possible increase in existing concentrations. This will assure that QMC's activities will not cause the WQCC ground-water standards (existing concentrations) to be exceeded in the alluvium. When the bedrock aquifers repressurize, the WQCC numerical ground-water standards will not be exceeded.


R 10 W
R 9 W
R 8 W
T. 14 N.
T. 13 N.
LEGEND:
Alluvial Wells (p)=proposed to be drilled
Tres Hermanos "B" Wells
Tres Hermanos "B" Ventilation Holes
Tres Hermanos "A" Wells
Dakota Wells
Dakota Ventilation Holes
Extent of contamination Dakota
Extent of contamination Tres Hermanos "B"
VH 19-8
VH 19-9
VH 30-12
VH 30-10
30w-Shaft
30-48Kd
36-04Kd
36-02 TRb
31-01 TRb
31-02 TRb
31-01Kd
Uranium Mill
Tailings Pile
31-63(p)
31-62 TRb(p)
32-60(p)
31-61(p)
32-01
32-59(p)
33-01
8-03
ARROYO DEL PUERTO
Evaporation Ponds (lined)
SCALE IN FEET
1000
2000
4000
FIGURE 26: PROPOSED MONITOR WELLS
AMBROSIA LAKE AREA
GRANTS, NEW MEXICO

AMBROSIA LAKE GROUND-WATER DISCHARGE PLAN
MONITORING SCHEDULE

The following monitor wells will be sampled on a quarterly basis.

Alluvial Wells
5-03; 32-51; 32-58; 32-59; 32-60; 31-61; 31-63

Tres Hermanos b Sandstone Wells
31-62 Trb; 36-02 Trb; 31-02 Trb

Tres Hermanos a Sandstone Wells
33-01 Tra; 31-01 Tra

Dakota Sandstone Wells
36-04 kd; 30-48 kd; 31-01 kd

The above wells will be analyzed quarterly for indicator parameters to include:

pH
chloride
total dissolved solids
sulfate
specific conductivity

In the 2nd quarterly sampling, to be conducted in April and reported in June of each year, the sampling will be expanded to also include the following ventilation holes for the purpose of an annual report.

Tres Hermanos b Sandstone Ventilation Holes
19-2; 19-5; 30-10

Dakota Sandstone Ventilation Holes
19-2; 19-5; 30-12; 30W-Shaft

The 2nd quarterly samplings collected from the monitor wells and ventilation holes will be analyzed for the following:

Ag	F	Zn	pH
Al	K	F	Ra-226
As	Mg	Cl	U238
B	Mn	HCO_3	specific conductivity
Ba	Mo	CO_3	
Ca	Na	NH_3 (N)	
Cd	Ni	NO_3 (N)	
Co	Pb	SO_4	
Cr	Se	TDS	
Cu	V	TOC	

1984	1st Qtr	#2nd Qtr	3rd Qtr	4th Qtr
Obtain Samples	02-01	04-19	07-20	10-19
Complete Analyses	03-01	05-31	08-31	11-30
Report Assembled	03-05	06-05	09-05	12-05
Mail to EID	03-12	06-12	09-12	12-12

1985	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Obtain Samples	01-16	04-17	07-17	10-16
Complete Analyses	02-27	05-29	08-28	11-27
Report Assembled	03-05	06-04	09-03	12-03
Mail to EID	03-12	06-11	09-01	12-10

1986	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Obtain Samples	01-15	04-16	07-18	10-16
Complete Analyses	02-26	05-28	08-29	11-27
Report Assembled	03-04	06-03	09-02	12-02
Mail to EID	03-11	06-10	09-09	12-09

1987	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Obtain Samples	01-14	04-16	07-20	10-19
Complete Analyses	02-25	05-28	08-31	11-30
Report Assembled	03-02	06-02	09-03	12-03
Mail to EID	03-09	06-09	09-10	12-10

1988	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
Obtain Samples	01-18	04-19	07-19	10-18
Complete Analyses	02-29	05-31	08-30	11-29
Report Assembled	03-03	*06-03	09-02	12-02
Mail to EID	03-10	06-10	09-09	12-09

! Date: month-day

* A summary report of the five annual reports will be submitted with the June 10, 1988 report.

\# Samples will be collected from monitor wells and ventilation holes in the second quarter of each year. Full chemical analyses will be run and the results submitted as an annual report.

Note: 1. A sample of the fluid discharged from the mill to Pond 1 will be removed from the decant line annually and analyzed for the elements listed in paragraph 3-103 of the New Mexico Groundwater WQCC regulations. The results will be reported to the EID at the same time as the annual samples for complete analyses are reported for the monitor wells.

2. The liquid discharged from the mill reservoir pond into the Arroyo del Puerto will be sampled and analyzed annually for the

parameters listed in paragraphs 3-301 of the New Mexico ground-water WQCC regulations. The results of the analysis will be reported to the EID at the same time as the annual samples for complete analyses are reported for the monitor wells.

LIST OF COMMITMENTS TO EID
MADE IN DP-169 AND SUBSEQUENT COMMUNICATIONS

Date	Commitment
03/30/81	1. Original Discharge Plan to minimize any possible ground-water contamination from mine water employed in the mill
	a. Modify the mill circuit to increase the use of recycled water
	*b. Extend tailings pile to cover Ponds 2, 7 and 8
	*c. Abandon unlined Ponds 4, 5 and 6; and repair lined Ponds 9 and 10
	*d. Install slurry trench and pump collected seepage to lined ponds
	*e. Install a new diversion ditch to the north.
	2. Discharge of yellowcake filtrate to Ponds 9 and 10 will be measured by a flow meter.
	3. Sampling to detect seepage is conducted on a regular basis.
	4. Take appropriate remedial action to repair failed liners.
	5. QMC requires a minimum of 24 months from date of approval to complete various modifications called for in the plan.
04/12/83	Part of the Assurance of Discontinuance (A of D);
	1. After September 1, 1983, QMC shall maintain Ponds 4, 5, 6, 7 and 8 with no standing fluids.
	2. QMC agrees to repair lined Pond 10 prior to any further discharge of fluids into Pond 10.
8/22/83	1. The tailings will be protected from 100-year storm runoff by improvement of the existing diversion channel.

* Changed by later commitment.

Date	Commitment
08/22/83	2. Changes in the flood protection plan required by the State Engineers Office will be submitted to EID as they are generated for the SEO.
09/01/83	Proposed Seepage Interception System
	1. Abandon Pond 3 and drain.
	2. Direct decant system to Pond 9 prior to construction of ditch.
	3. Complete construction by October 1985.
11/23/83	1. Vent holes will be plugged at the surface.
	*2. Well 33-01 will be added to the list of bedrock monitor wells, and analyses reported quarterly to EID.
	3. Pond 10 will no longer be used.
	4. Continue to evaluate results obtained from existing and new wells in the Trb to determine seepage impacts due to Ponds 9 and 10.
	5. Seepage collected in the proposed seepage interception ditch will be discharged into Pond 9, which will replace Pond 3 as the decant pond. From Pond 9, collected seepage will be pumped to lined ponds in Section 4 or returned to the mill for recycling.
	6. Upon completion of construction of the ditch, "as built" drawings will be submitted showing the details of the ditch and the locations of pumping systems and pipelines.
	7. Ponds 4, 5, 6, 7, and 8: Drainage from Ponds 7 and 8 will flow into Pond 2 and that from Ponds 4, 5 and 6 will flow into the SPCC collection system. Residual salts and contaminated ground surface will be removed to the tailings pile for permanent disposal. Clean material will be placed on the areas to allow appropriate drainage. The clean material will be graded to allow appropriate drainage. Drainage will be directed into the Arroyo del Puerto.

Date		Commitment
	8.	Additional new monitoring wells will be installed to permit the monitoring of contaminated liquid in to Trb sandstone.
	9.	Two additional monitor wells will be installed in Section 32 immediately north of the Section 5 boundary. One well will be installed on the east side of the Arroyo del Puerto, and the second well will be installed on the west side of the Arroyo. Well 5-03 will continue to be used.
12/22/83	*1.	Groundwater monitoring plan.
01/24/84	1.	Groundwater monitoring program and schedule: -15 wells quarterly, indicator parameters only -7 vent holes annually, full analysis for all samples in the second quarter of each year.
01/25/84	1.	Riprap at toe of tailings pile altered to provide PMP flood protection: - Section 1 to 6: 9" over 4" - Section 4 to 6: 2' over 9" - Section 5.1 to 6: 5' over 2'
02/09/84	1.	Soil contaminated from spills would be removed and replaced with clean soil. Contaminated soil will be placed on the tailings pile.
03/02/84	1.	Sample of tailings fluid analyzed for 3-301 elements and reported annually.
	2.	Sample of mill pond liquid analyzed for 3-301 elements and reported annually.
	3.	Grade Pond 3 after draining and construct a sump at the lowest elevation from which a culvert will be installed through the berm into the interception ditch.
	4.	Revise the cross section of the water course at Section 2 and 3 to achieve velocities at Section 1.2 reference drawing "Cross Sections of PMF Floodway." (7/6/83).

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APPENDIX A

GROUND-WATER DISCHARGE PLAN ANALYSIS

for

QUIVIRA MINING COMPANY AMBROSIA LAKE SECTION 4 EVAPORATION POND PLAN DP-71

Prepared by

Paul Clement
Principal Investigator

Ground Water/Hazardous Waste Bureau
State of New Mexico
Environmental Improvement Division

October 1985

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SUMMARY

Quivira Mining Company (QMC) applied for renewal of its ground-water discharge plan (DP-71) in March, 1984. DP-71 covers QMC's 255 acres of Section 4 evaporation ponds located at Ambrosia Lake near Grants in McKinley County, New Mexico (T13N, R9W, Section 4). The Environmental Improvement Division (EID) approved QMC's DP-71 renewal request, in August, 1984, based on the following conclusions:

- The evaporation pond effluent presents a substantial risk for contamination of ground water because of its low pH, high TDS, high ammonium nitrogen concentration, and high metals content.

- Ground-water level data collected from 31 alluvial monitor wells indicates that water levels have declined in most wells, with the only exceptions being wells MW22, MW23, MW24, and MW31.

- Water levels and water quality in monitor wells MW22, MW23, MW24, and MW31 are influenced by infiltration of water into the alluvium along the Arroyo del Puerto.

- Nitrogen contamination of ground water occurs in monitor wells both up-hydraulic and down-hydraulic gradient from the evaporation ponds. Monitor wells MW18, MW22, MW23, and MW24 are the down-hydraulic gradient wells exhibiting high nitrogen levels.

- It is unlikely that the evaporation ponds contaminated monitor wells MW22, MW23, and MW24 with nitrogen because of the high ground-water velocity that would be required to achieve that contamination. Water quality in these three wells is mostly influenced by ground water flowing from the Arroyo del Puerto.

- There are no significant increasing trends, for ground-water quality parameters such as NO_3, TDS, SO_4, Cl, and pH, indicative of ground-water contamination from the evaporation ponds. Heavy metals were not analyzed for in alluvial ground-water samples.

The existance of elevated nitrogen levels in ground water, in the area of the Section 4 evaporation ponds, indicates that ground water has been contaminated; however, the source of this contamination is unknown and should be investigated further.

Introduction

Quivira Mining Company (QMC and formerly Kerr-McGee Nuclear Corporation) applied for renewal of its ground-water discharge plan (DP-71) in March 1984. DP-71 covers QMC's eleven Section 4 evaporation ponds (numbers 11 through 21), located at Ambrosia Lake near Grants in McKinley County, New Mexico (T13N, R9W, Sec. 4). The Director of the Environmental Improvement Division (EID) notified QMC by letter dated August 6, 1984, that its ground water discharge plan renewal request was approved. QMC's DP-71 renewal application was submitted pursuant to Section 3-106 of the New Mexico Water Quality Control Commission (WQCC) Regulations, and approved pursuant to Section 3-109 of the same regulations. Evaporation ponds numbers 16 and 17 were previously approved August 7, 1979, and ponds numbers 11 through 15 and 18 through 21 were previously approved September 18, 1979.

The eleven PVC and Hypalon lined evaporation ponds receive an estimated maximum discharge of 1660 gallons per minute of acidic uranium mill decant liquid. The 255 acres of ponds are surrounded by 31 alluvial ground-water monitoring wells that are sampled monthly and analyzed for chloride (Cl), sulfate (SO_4), nitrate (NO_3), total dissolved solids (TDS), and pH. The average depth to ground water is 33 ft, with an average TDS of 3470 mg/l.

Evaporation Pond Details

The location of the eleven Section 4 evaporation ponds are illustrated in Figure 1. Pond numbers 11 through 15 have 10 mil PVC liners on the bottoms and 20 mil PVC liners on the slopes. Pond numbers 16 through 21 have 20 mil PVC liners on the bottoms and 36 mil

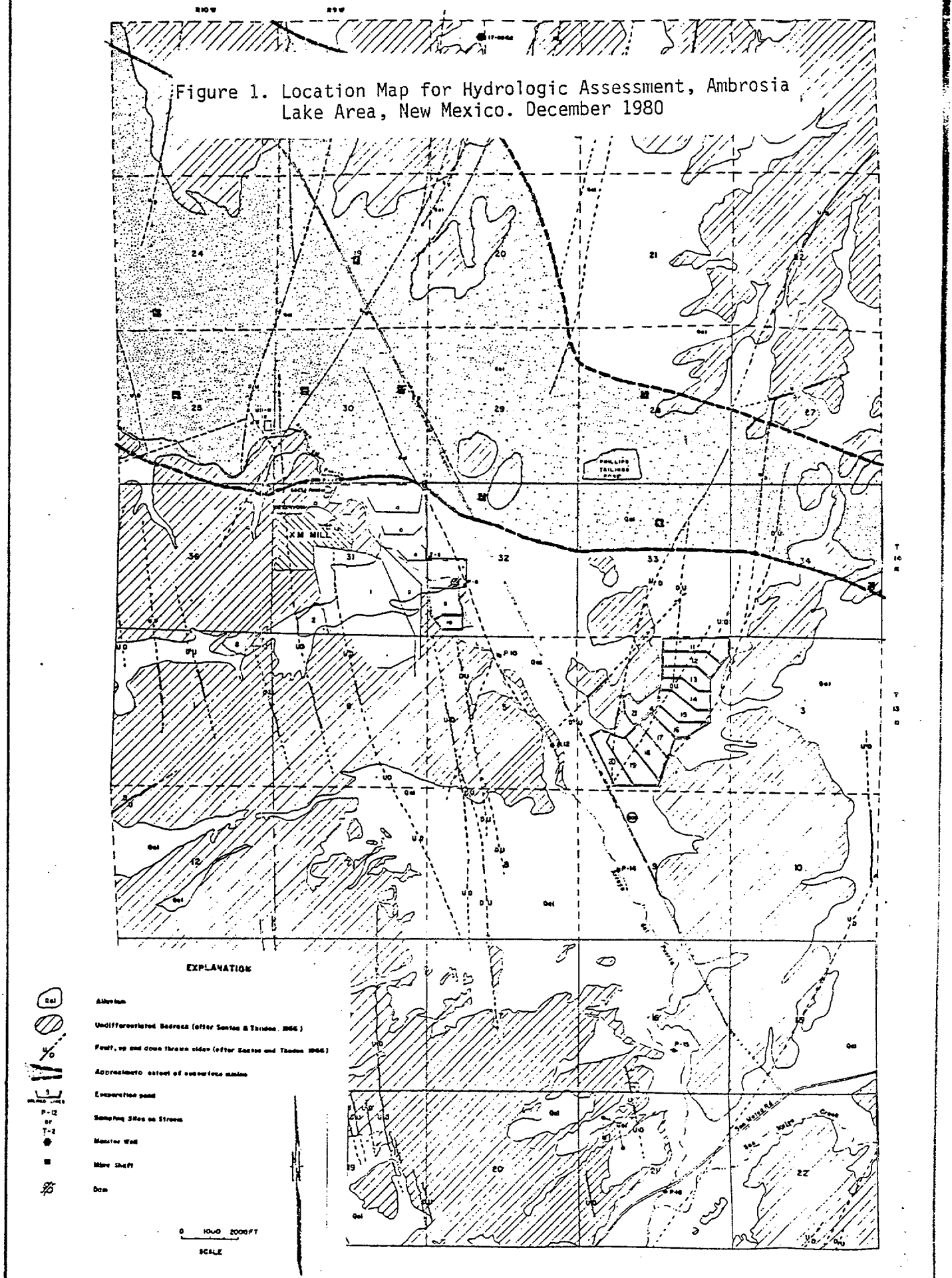


Figure 1. Location Map for Hydrologic Assessment, Ambrosia Lake Area, New Mexico. December 1980

Hypalon liners on the slopes. The liners have a layer of fill covering them. All of the evaporation ponds have 3:1 side slopes. QMC is to maintain a minimum liquid freeboard of 3 feet to the top of pond berms and 2 feet to the top of pond liners. Liquid depths usually range from 0 to 7 feet with gravity flow from one pond to another through connecting pipes.

Permeabilities of the liner materials are reported to be very low. The 20 mil PVC liner material has a permeability of less than 1×10^{-7} cm/sec as reported by PANTASOTE, Inc., and the 36 mil hypalon has a permeability of less than 1×10^{-7} cm/sec, at a 12 foot head of water, as reported by Stevens Elastomeric and Plastic Products, Inc. Actual test data indicate that these liner materials may have permeabilities of less than 1×10^{-12} cm/sec, at 25 foot of water head, as reported by Staff Industries, Inc. Any seepage through these liner materials will probably occur at glued seams; however, to date no leaks have been reported by QMC.

QMC has approximately 255 acres of evaporation ponds in Section 4. Table #1 lists approximate surface areas and filling dates for each evaporation pond.

Table #1 - Section 4 Evaporation Pond Details

Pond #	Approximate Surface Area (acres)	Initial Filling Date
11	28.3	April 1977
12	22.4	July 1977
13	16.8	July 1977
14	20.8	July 1977
15	24.1	July 1977
16	19.5	September 1979
17	19.5	December 1979
18	22.2	January 1980
19	31.5	March 1980
20	29.0	May 1980
21	21.0	June 1980

QMC does not directly monitor inflow to the Section 4 evaporation ponds. The volume of discharge to the ponds is variable depending on whether one or two decant pumps are operating. The discharge to the ponds is also intermittent. Based on calculated pumping curves, the discharge with one and two pumps in operation is approximately 925 and 1660 gallons per minute respectively. There are pressure gauges located along the effluent pipeline, leading to the Section 4 evaporation ponds, that are used to maintain a record of pipeline operating pressures. When the pipeline was first installed it was pressure tested for 24 hours and no leaks were reported. No pipeline testing schedule is included in DP-71.

Monitor Well Details

Locations of the 31 alluvial monitor wells, used to monitor for potential ground-water contamination from evaporation pond seepage, are illustrated in Figure 2. The boreholes were completed to the top

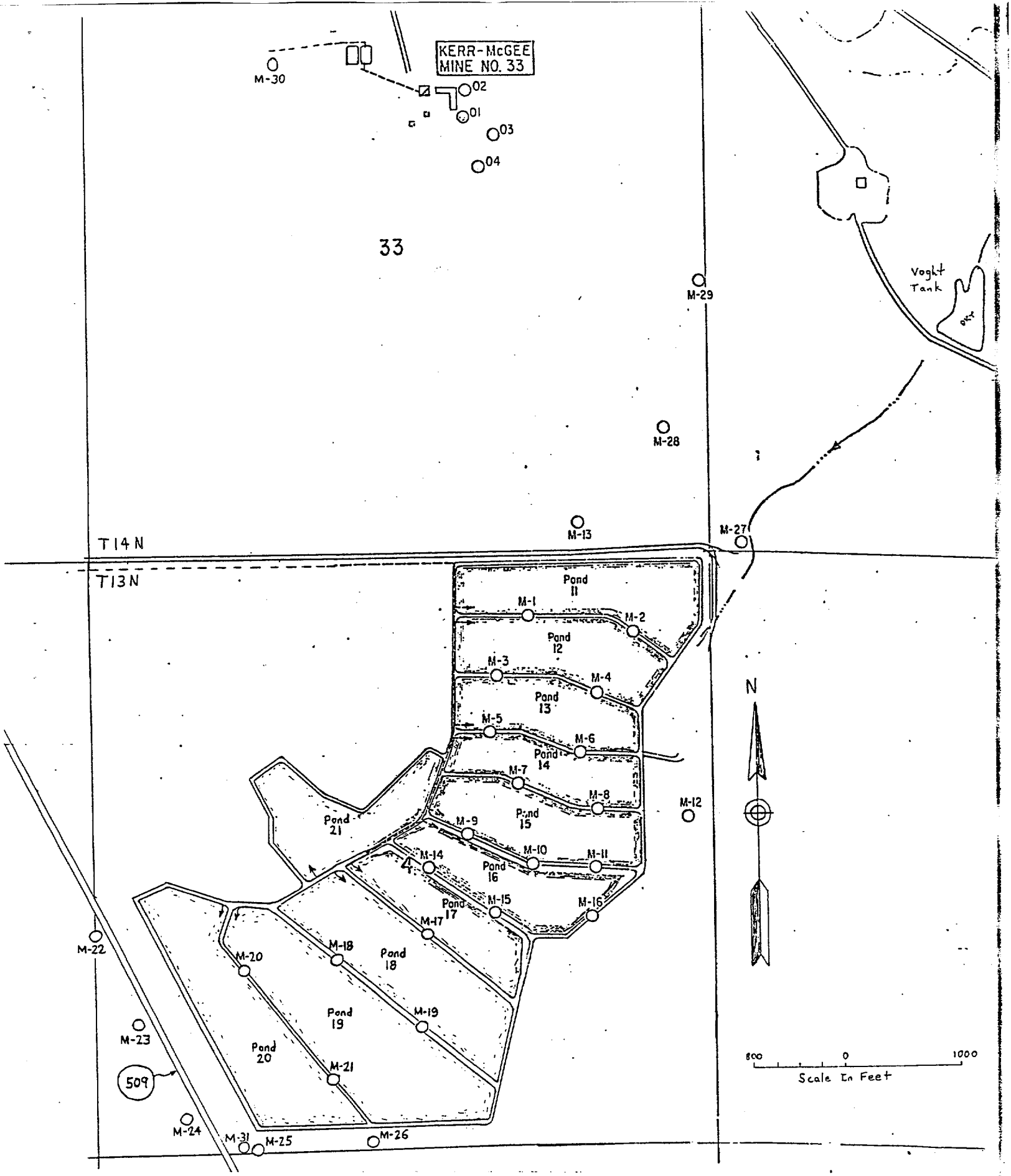


Figure 2. Locations of Section 4 Alluvial Monitor Wells

of competent bedrock or auger refusal and are perforated through the saturated zone in the alluvial sediments. The wells are typically screened through silty sand (See Fig. 3). A typical alluvial monitor well construction is shown in Figure 3. A 4 inch PVC casing was used with .01 slot size PVC screen installed below the water table. Typically, #2 blasting sand was used to gravel pack the well screen and the remaining length of borehole was backfilled with native fill to the surface. At ground level a cement seal protects the well annulus from surface runoff, and the well casing is protected by a PVC cap.

Approximate completion dates of the Section 4 alluvial monitor wells are listed in Table 2. The accumulation of silt in the monitor wells has been an ongoing problem due to the fine nature of the alluvium. Periodically the monitor wells are jetted with air or a combination of air and fresh water to purge the wells of these silt accumulations. Monitor wells MW1 through MW10 were accidentally covered in October 1983 by a road grader while performing routine road maintenance. The grader dislodged several well caps resulting in contamination of the wells by surface debris, and completely buried the tops of other monitor wells. Monitor wells MW1 through MW10 were repaired and cleaned prior to February 1984. There have also been frequent problems with rodents entering the monitor wells and contaminating them.

Figure 3. Typical Alluvial Monitor Well Construction

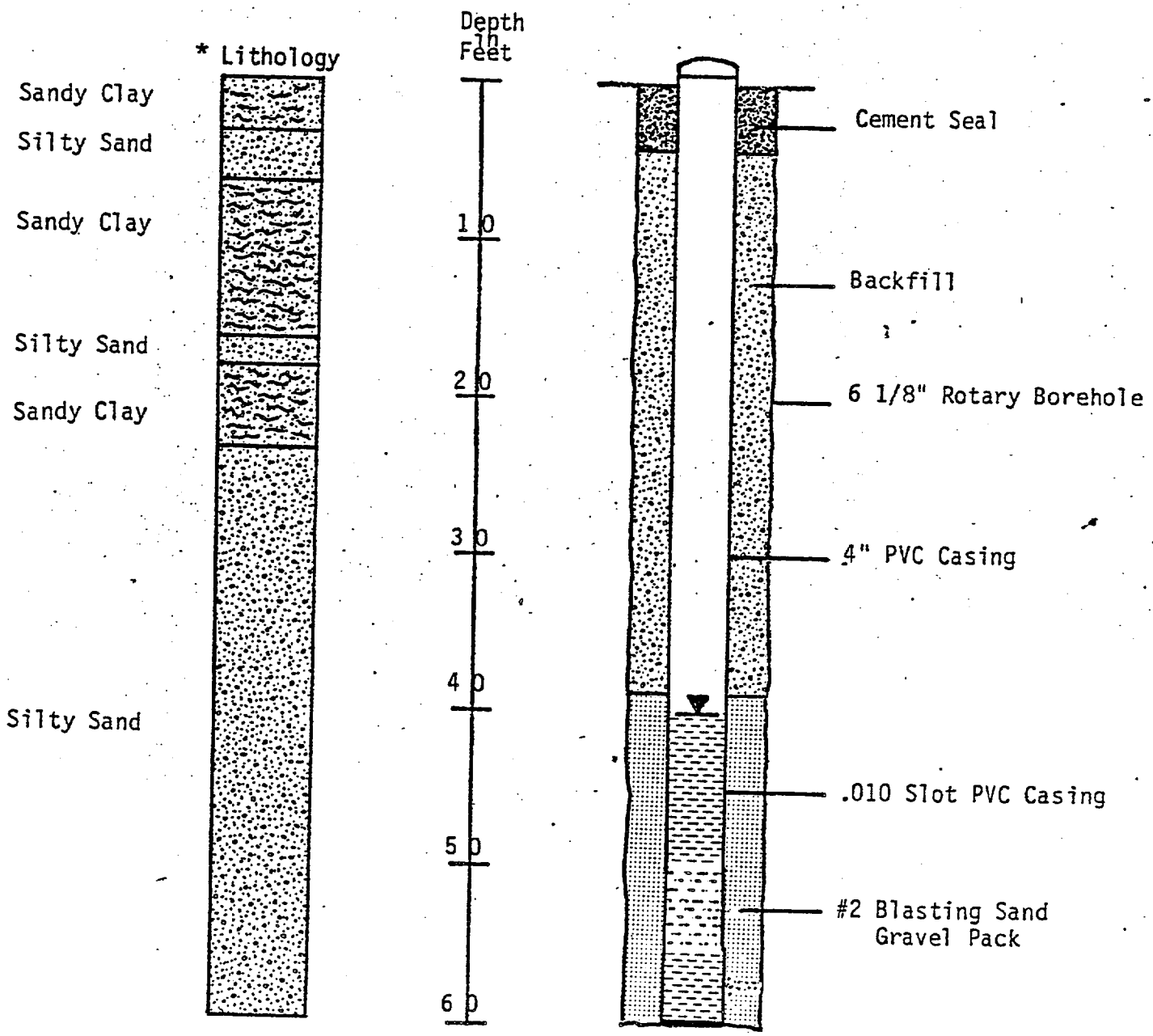


Table 2. Approximate Completion Dates of Section 4 Alluvial Monitor Wells.

Well #	Completion Date
MW1-MW12	February 1978
MW13	April 1980
MW14-MW26	January 1980
MW27-MW30	September 1980
MW31	August 1984

Geologic Setting

Geologic units underlying the Section 4 evaporation ponds are shown in Figure 4. In descending order the lithologic section consists of alluvium, Mancos Shale, Dakota Sandstone, and Morrison Formation. The lower part of the Mancos Shale contains three beds of silty sandstone known collectively as the Tres Hermanos Sandstone Member of the Mancos Shale. One or more of the Tres Hermanos Sandstones outcrop in the vicinity of the Section 4 evaporation ponds, and are very weathered. Well logs, from Section 4 monitor wells, show the alluvium to consist of alternating layers of clay, sandy clay, silty sand, and sand. Monitor wells MW22, MW23, and MW24, which are located to the west of state road 509, are an exception with their entire length drilled through silty sand.

Figure 1 shows that wells MW22, MW23, and MW24 are located along a fault, and possibly, on the downthrown side of the fault. The influence of this fault on ground-water flow through the alluvium, and the lithology of wells MW22, MW23, and MW24, is unknown. Possibly as many as six other faults exist in the vicinity of the evaporation

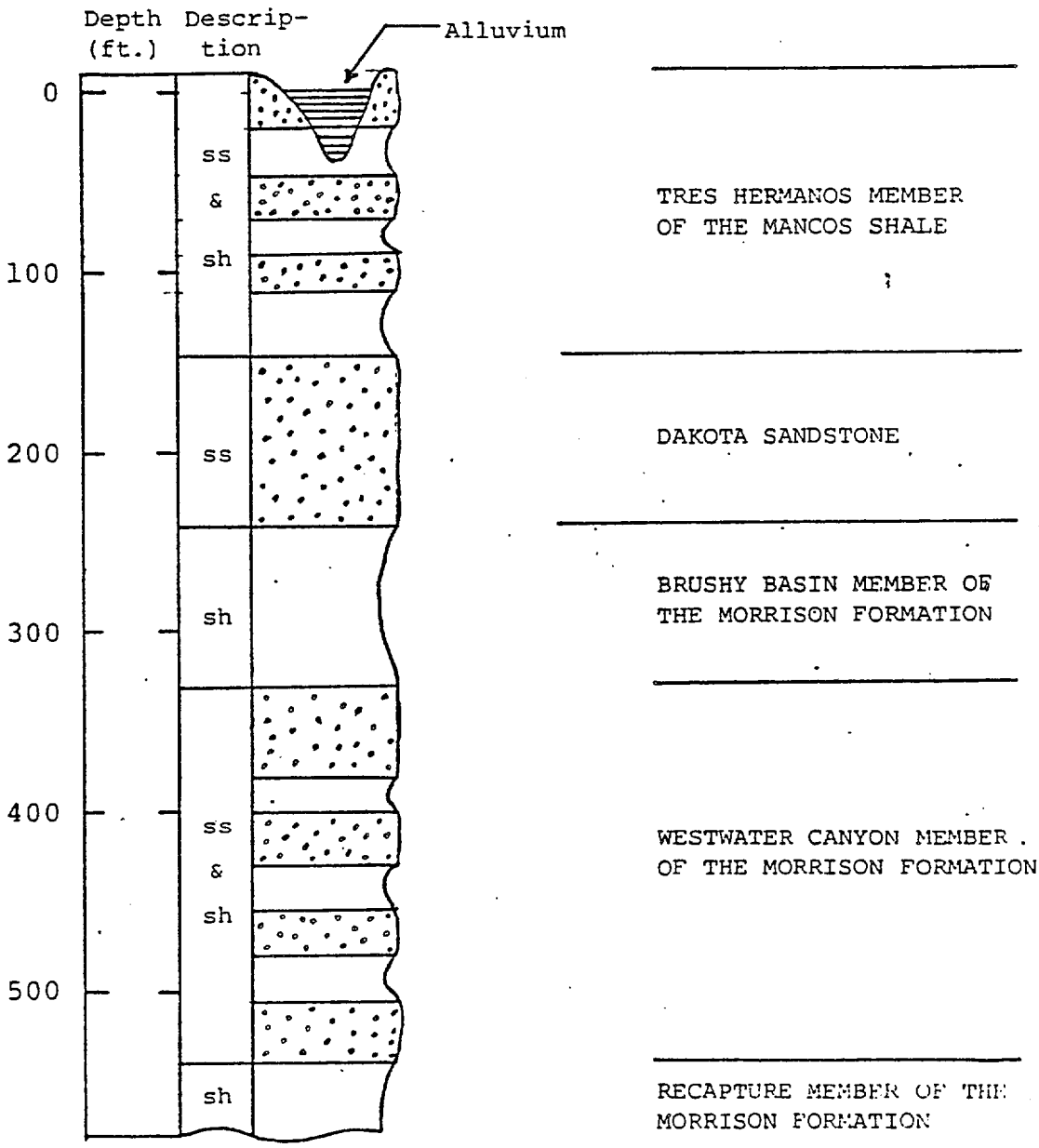


Figure 4. Geological Section for QMC Evaporation Ponds

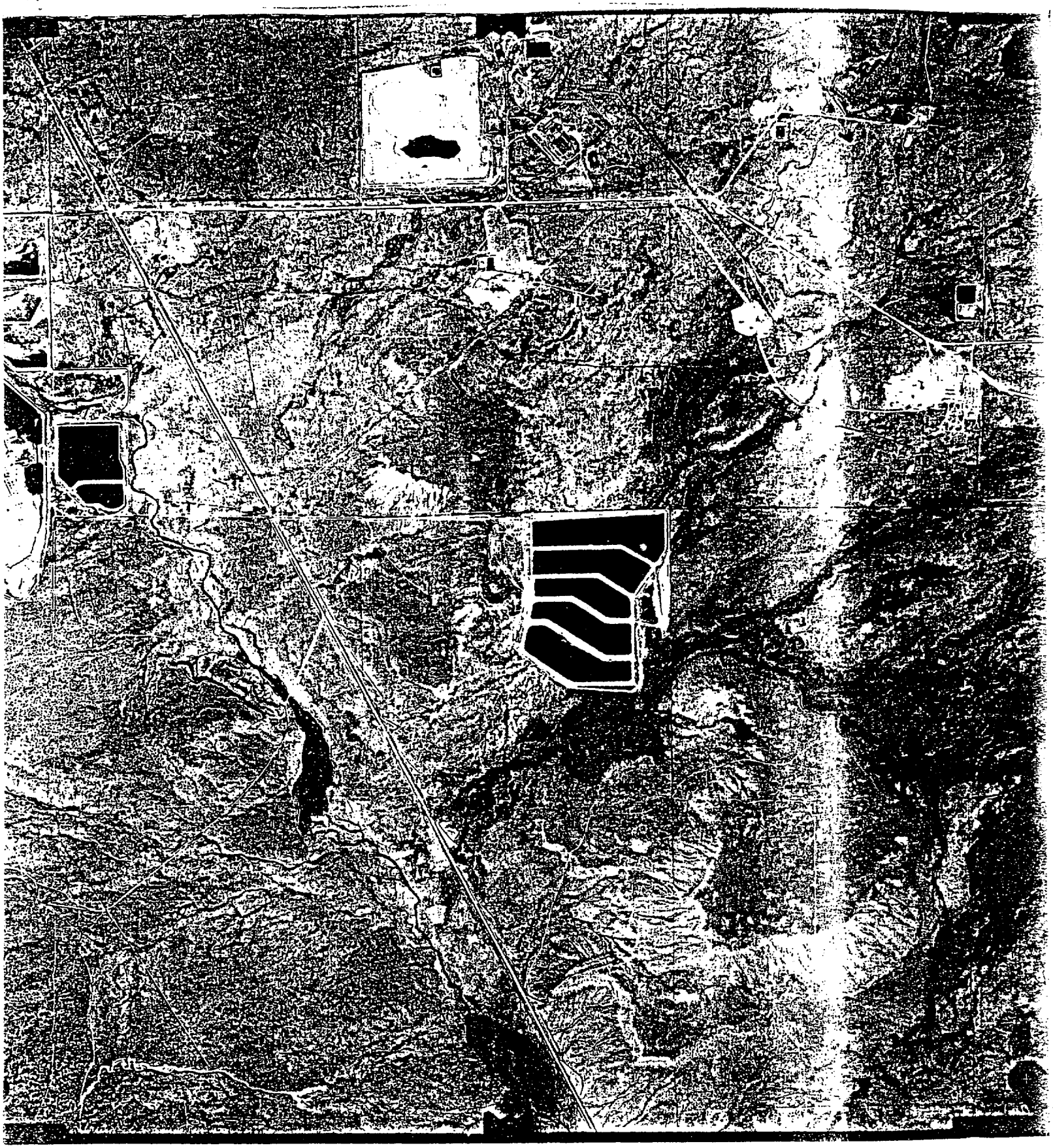
ponds, as indicated in Figure 1. QMC was notified by letter dated December 27, 1979, from the Radiation Protection Section of EID, that the ponds are located in a seismically active area with faults crossing the site; therefore, a stability analysis was requested.

The Section 4 evaporation ponds are located in the confluence of two shallow alluvial drainage channels, shown in Figure 5. One channel extends from the east and the other extends from the north of the Section 4 evaporation ponds. These two channels come together beneath the Section 4 evaporation ponds and drain into the Arroyo del Puerto to the southwest. Arroyo del Puerto is characterized as an intermittent stream on the Ambrosia Lake and Dos Lomas Quadrangles. A continuous flow has existed in the Arroyo del Puerto since 1958 as a result of treated mine water being released from mining and milling operations approximately two miles northwest of the evaporation ponds.

Hydrologic Setting

QMC conducted pumping tests on alluvial recovery wells AW-1 and AW-2 during February 1980 and September 1980, respectively. Test well AW-1 is located approximately 2 miles northwest of the evaporation ponds, and test well AW-2 is located approximately 3/4 miles northwest of the evaporation ponds. The results of the test on the stratified sediments surrounding well AW-1 indicate that the transmissivity ranges from 250 to 545 gallons per day per foot (gpd/ft). Dividing by the saturated thickness of the aquifer, these two transmissivities correspond to hydraulic conductivities ranging from 8.3 to 18.2 gpd/ft^2. The pumping test conducted on well AW-2 indicates that the alluvium transmissivity ranges from 220 to 225 gpd/ft. These two transmissivities correspond to hydraulic conductivities ranging from

Figure 5. Aerial Photograph Taken November 1, 1977



8.8 to 9.0 gpd/ft^2. Using a hydraulic conductivity ranging from 5 to 20 gpd/ft^2, a 20% alluvium porosity, and a hydraulic gradient of 0.014, the average ground-water velocity probably ranges from 17 to 68 ft/yr. This is a reasonable range for ground-water velocity in silty sand and probably represents the hydrologic setting under the Sec. 4 evaporation ponds.

Alluvial ground water flows under the Section 4 evaporation ponds from the northeast to the southwest. Figures 6a and 6b are water table maps constructed from data QMC submitted for October 1980 and June 1985, respectively. Water level measurements from wells MW6, MW7, MW8, MW13, MW27, and MW29 were used to establish the water-table contours under ponds 11, 12, and 13 in Figure 6b. The influence of ground-water recharge from Arroyo del Puerto can be seen in the water table elevation contour lines near wells MW22, MW23 and MW24. Near these wells alluvial ground water flows toward the southeast.

The average depth to ground water in Sec. 4 is approximately 33 feet, although ground water levels in the alluvium have declined over the period from 1978 to 1985. Water levels have dropped dramatically in most wells, leaving wells MW1 through MW7, MW9, MW11 through MW13, MW25, MW26, and MW28 dry. Well MW18 has shown a water-level decline of 12.1 feet since September 1980. The only exceptions are wells MW22, MW23, MW24, and MW31, which have shown a rise in water levels of as much as 2.1 feet since 1980. These wells are influenced by infiltration of water into the alluvium along the Arroyo del Puerto.

Evaporation Pond Effluent Quality

Effluent discharged to the Section 4 evaporation ponds originates from several sources. Decant liquor, from the end of the mill

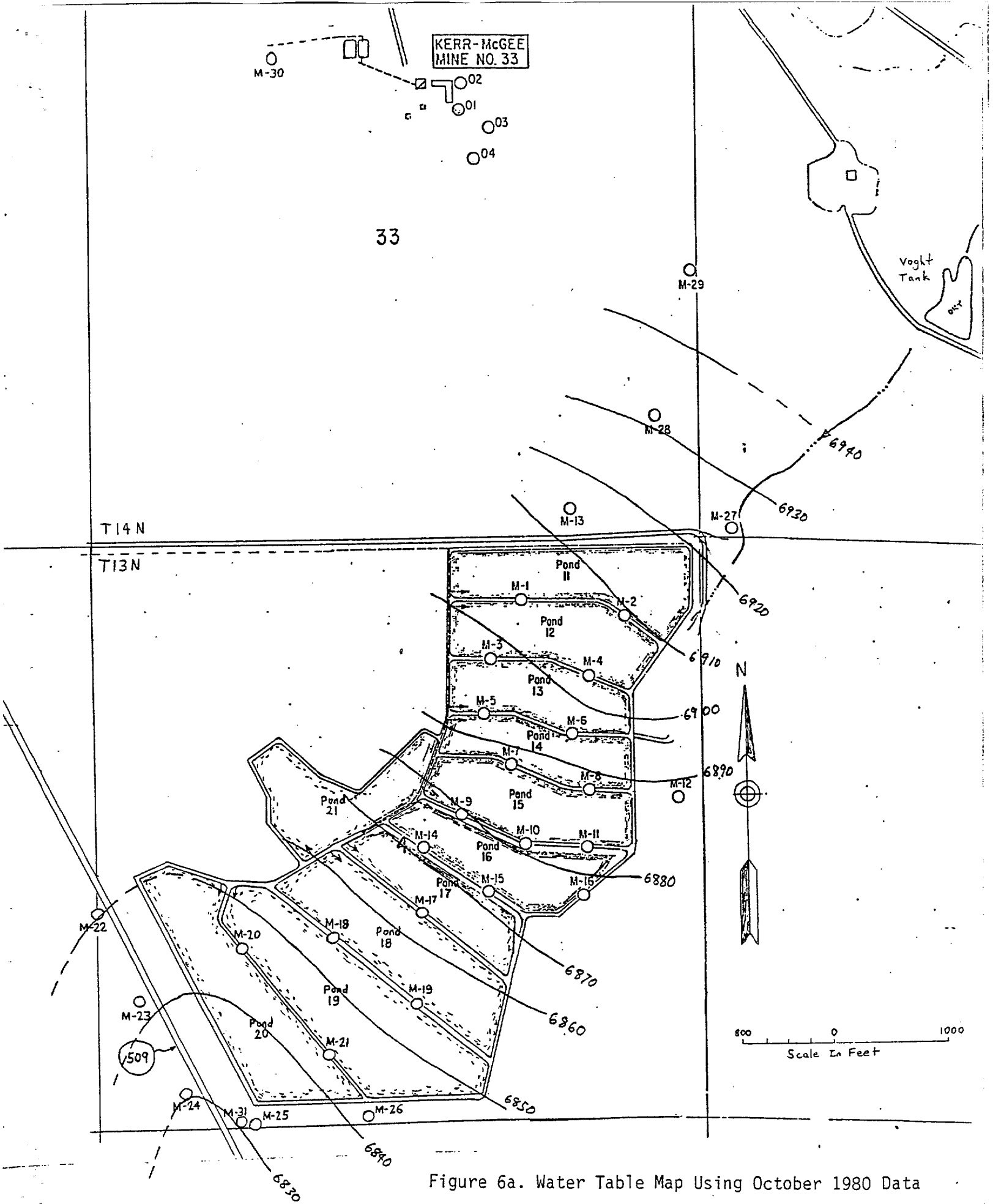


Figure 6a. Water Table Map Using October 1980 Data

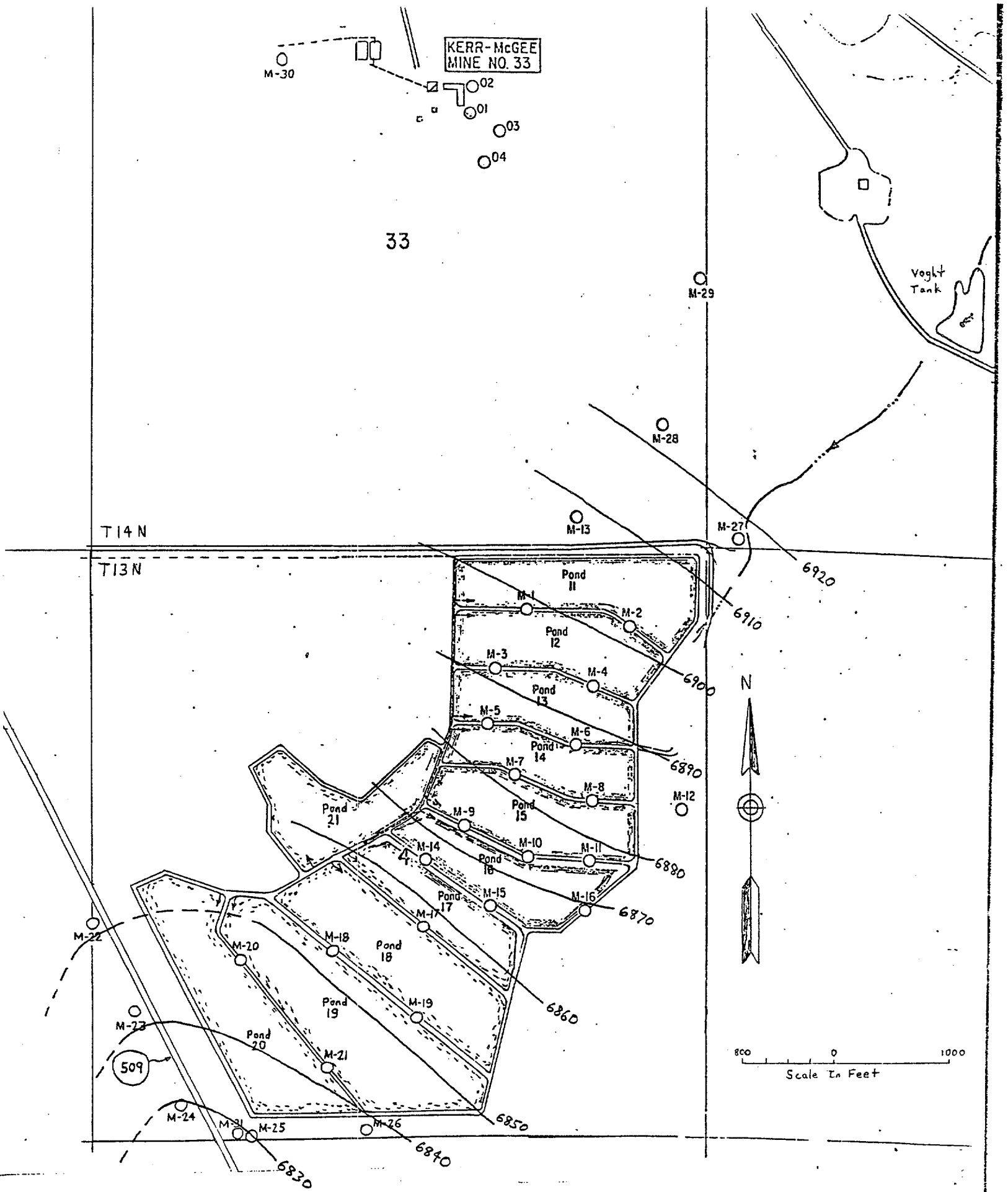


Figure 6b. Water Table Map Using June 1985 Data

circuit, tailings pond decant liquid, and tailings pond seepage interception ditch liquids all end up in the Section 4 evaporation ponds. Any spills from a failure of mill circuit components could also discharge to the Section 4 ponds. Both QMC and EID technical staff have collected samples of evaporation pond effluent over a period from November 1978 to March 1984. Ranges in concentration of many chemical constituents in the effluent are presented in Table 3. This effluent presents a substantial risk for contamination of ground water because of its low pH, high TDS, high ammonium nitrogen concentration, and high metals content.

Alluvial Ground Water Quality

There is no available pre-existing alluvial water quality data for the Section 4 evaporation ponds. Ground-water quality data has only been compiled since wells MW1 through MW12 were drilled in February 1978, which is almost a year after pond 11 was first filled. It is also important to remember that uranium mining activities have been present in the area since 1958. The absence of reliable pre-existing water quality data makes it difficult to determine if ground-water contamination has occurred, and if so, to identify the source.

Figures 7a and 7b show TDS data for selected alluvial wells, plotted over a period from 1981 to 1985, from one up-hydraulic gradient well (MW29) and 5 down-hydraulic gradient wells (MW8, MW18, MW19, MW20, MW23). TDS concentrations in wells MW1-MW31 have increased by a maximum of 1420 mg/l in one well and decreased by a maximum of 650 mg/l in another well, since wells MW1-MW31 were drilled. Four generalized regions of TDS concentration in the alluvial ground water are illustrated in Figure 8. The influence of

Table 3. Ranges in Concentration of Evaporation Pond Chemical Constituents Taken from Samples Collected from Ponds 7 Through 21.

Constituent	Concentration Range (mg/l except where noted)
Ag	<0.01-.099
Al	1720-5900
As	1.3-20.0
B	1.8-5.0
Ba	<0.015-.12
Cd	.002-0.54
Co	2.0-5.7
Cr	1.8-6.0
Cu	6.0-21.0
Fe	4,100-14,000
Mn	310-990
Mo	11-39
Ni	1.9-5.8
Pb	<0.5-2.4
Se	0.55-9.2
V	28-410
Zn	6-37
F	60-160
Ca	1451
K	222-304
Mg	891-6400
Na	10,028-12,834
HCO_3	<1
Cl	2230-14,310
SO_4	22,900-116,000
TDS	32,200-183,000
NO_3-N	0.6-28.0
NH_3-N	34.7-7753
TKN-N	2515-8648
pH	0.81-1.4
Ra(sol)	1418 pCi/L
Ra(insol)	52.6 pCi/L
Ra(total)	1470.6 pCi/L
U238	26-71
U	12.7-74.6

Figure 7a. Plot of TDS Concentrations in Alluvial Ground-Water Monitoring Wells

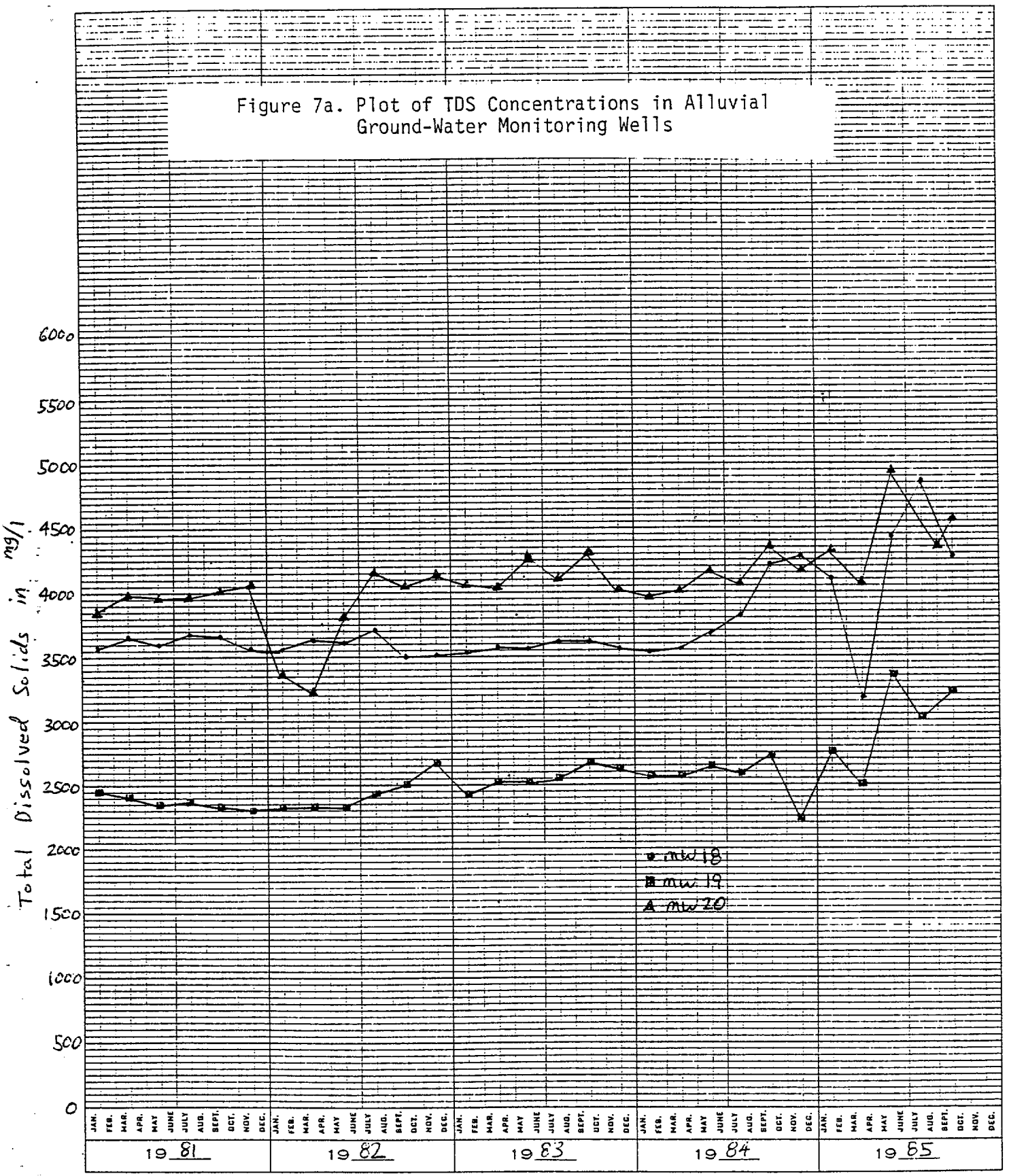
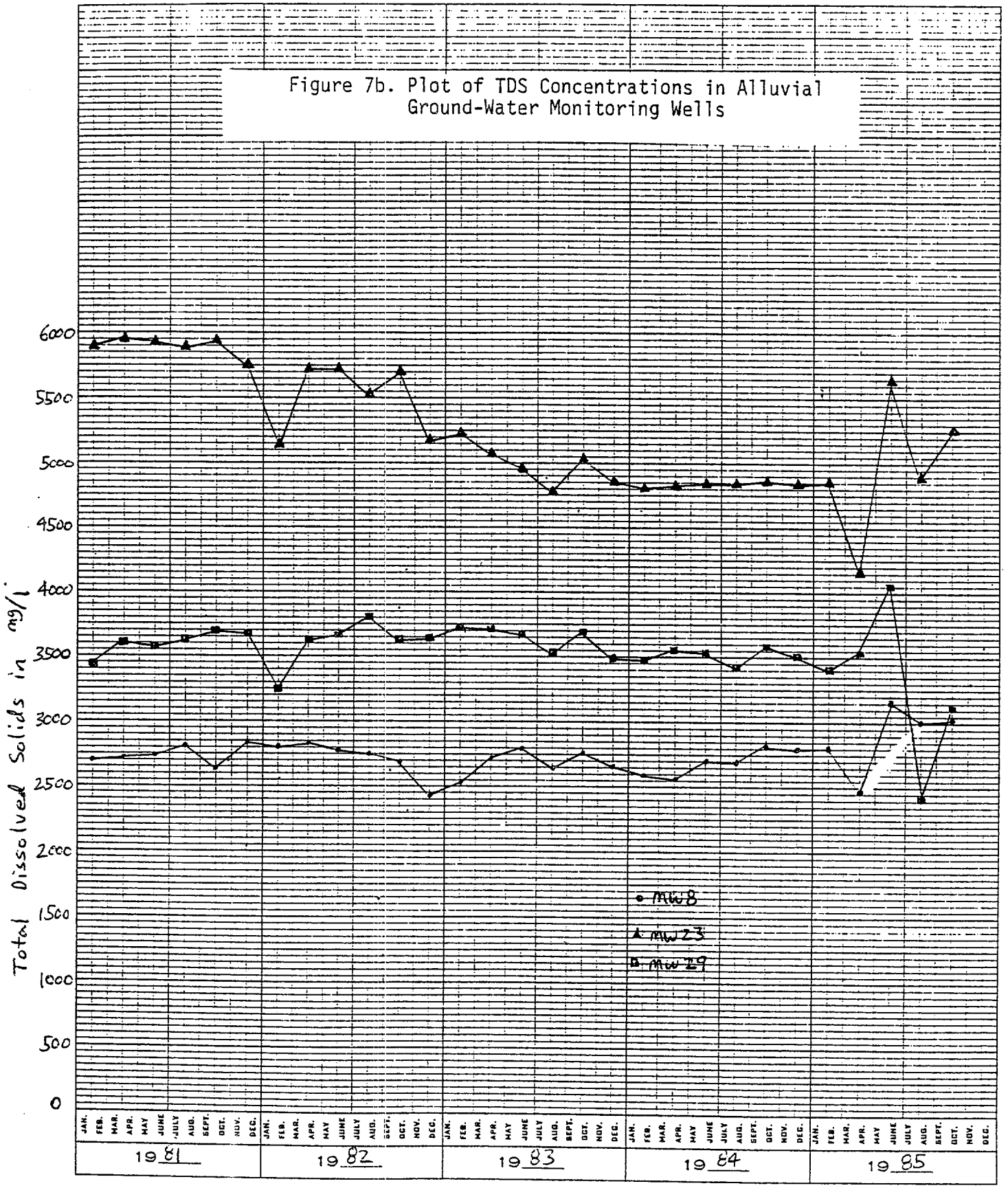


Figure 7b. Plot of TDS Concentrations in Alluvial Ground-Water Monitoring Wells



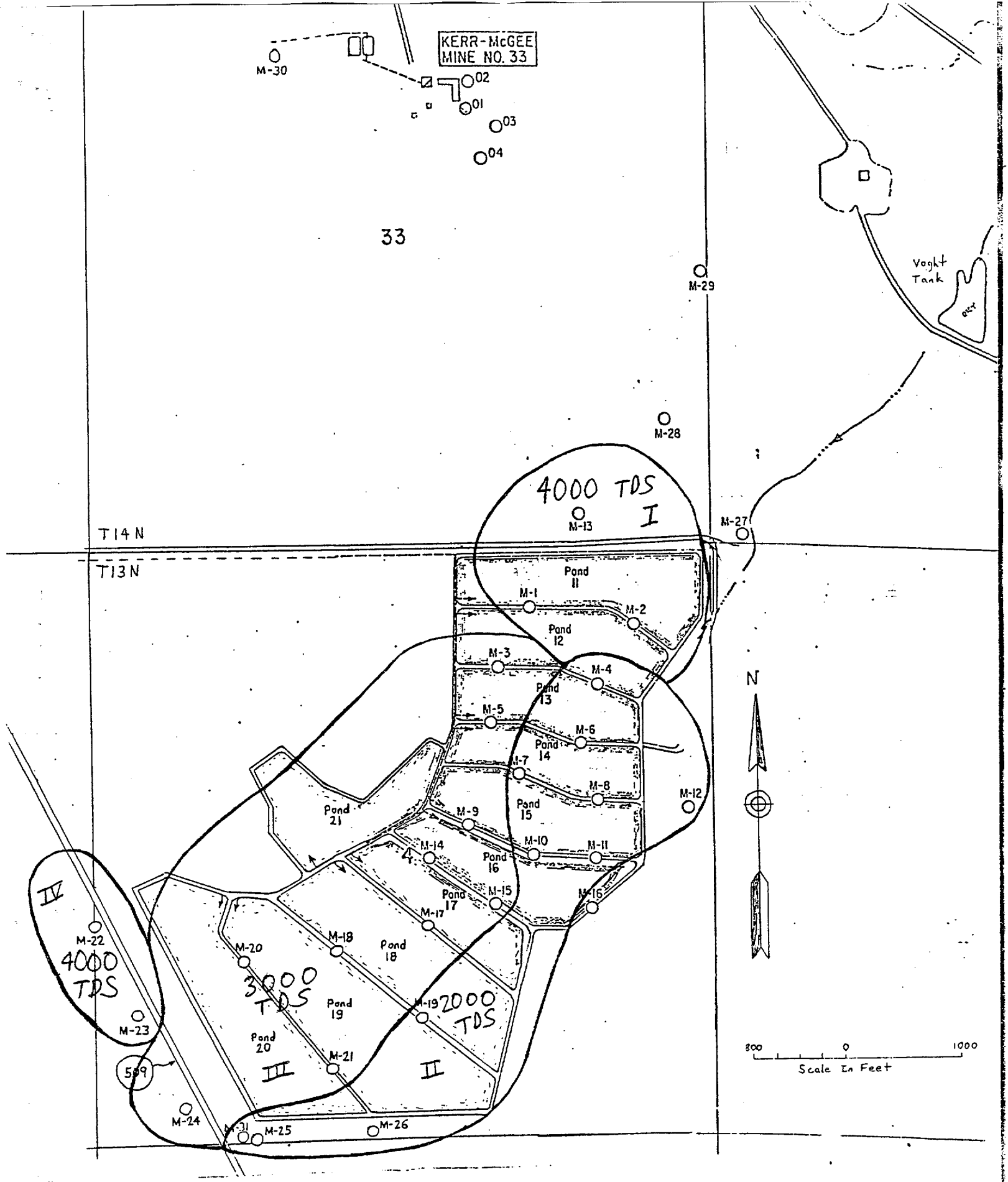


Figure 8. Regions of Similar TDS Cocentration in the Alluvial Ground Water. Third and Fourth Quarter Data From 1980

ground-water underflow in the alluvial drainage channel that extends from the evaporation ponds to the east is apparent. 2000 mg/l TDS water, flowing from the east in region II, mixes with 4000 mg/l TDS water, flowing from the north in region I, to create a 3000 mg/l TDS in region III. There also appears to be poor quality 4000 mg/l TDS water flowing from the northwest in region IV.

In addition to there being at least three different types of alluvial ground water, which mix under the Section 4 ponds, ground-water quality analyses have shown a large monthly variability. As an example, the chloride concentrations in monitor well MW4, during April, May, and June 1980, were 43, 110, and 42 mg/l, respectively. TDS and sulfate concentrations have been variable, but more stable than chloride levels.

Most pH levels in the monitor wells have been stable over the period from 1978 to 1985 with no identifiable pH trends in individual wells. Third through fourth quarter data for 1979 show a pH range of 6.8 to 8.3. Second quarter data for 1985 show a pH range of 7.0 to 8.1. In some instances, pH may not be the best ground-water contamination indicator parameter to monitor because of the natural buffering capacity of the alluvium. The amount of pond leakage that would be required to significantly lower the pH of ground water is unknown at the evaporation pond site.

Split sample analyses of alluvial ground water are listed in Tables 4 and 5. One analysis set is from QMC's technical center and the other is from the State of New Mexico Scientific Laboratory. These two analysis sets define recent ground-water quality around the evaporation ponds, and demonstrate the variability in reproducibility

Table 4. Analyses of Alluvial Ground Water Samples Collected by EID on May 17, 1984, and Analyzed by the State Scientific Laboratory

Well #	Ca	K	Mg	Na	HCO_3	Cl	SO_4	TDS	NO_3-N	NH_3-N
MW7	475	10	263	292	140	91	2588	3583	0.4	8.3
MW8	371	9	130	324	244	70	1471	2815	1.8	1.3
MW9	503	3	204	283	188	69	1785	3283	1.1	0.3
MW10	387	6	111	173	233	77	1242	2488	10.4	0.2
MW14	477	4	273	315	227	77	1893	3690	0.6	2.4
MW15	428	3	173	334	262	105	1593	3045	0.6	0.4
MW16	294	20	302	322	815	97	1105	2985	0.2	111.5
MW17	420	6	215	320	277	78	1846	3205	0.2	6.0
MW18	581	4	257	329	217	82	2248	4080	80.1	0.2
MW19	292	6	67	421	294	40	1385	2530	0.3	0.2
MW20	586	2	291	389	289	134	2324	4268	12.4	0.1
MW21	557	3	237	363	289	88	1765	3763	7.1	0.8
MW22	468	5	394	630	218	59	3091	5403	33.7	0.2
MW23	501	8	273	773	188	114	2385	5488	179.0	0.3
MW24	582	3	261	451	223	121	2104	4283	130.0	0.1
MW26	427	7	105	467	297	57	1628	4478	4.6	0.3
MW27	484	11	238	414	166	144	2025	3928	6.6	0.2
MW28	529	3	290	357	237	92	2186	4138	4.7	0.1
MW29	614	3	241	269	164	310	1864	3950	13.6	0.4
MW30	485	2	257	428	280	51	2013	3991	0.6	0.1

Table 5. Analyses of Alluvial Ground Water Samples Collected by QMC on May 17, 1984, and Analyzed by the QMC Technical Center

Well #	Ca	K	Mg	Na	HCO_3	Cl	SO_4	TDS	NO_3-N
MW7	510	10	190	290	290	120	2120	3400	7
MW8	400	8	110	290	260	150	1550	2700	4
MW9	520	3	120	280	280	90	1850	3090	1
MW10	370	5	100	170	240	190	1210	2210	17
MW14	480	4	180	320	330	89	2100	3380	3
MW15	430	2	130	350	410	130	1740	2920	3
MW16	300	19	250	340	1480	110	1120	2850	-
MW17	450	5	160	340	240	200	1930	3170	-
MW18	690	4	130	340	220	190	1930	3680	86
MW19	350	5	66	430	370	72	1640	2650	2
MW20	610	1	230	400	310	400	2320	4190	21
MW21	590	1	140	370	300	230	1810	3540	56
MW22	470	4	310	640	210	260	2930	4870	45
MW23	550	7	160	800	190	370	2180	4850	190
MW24	530	1	200	460	240	350	1900	4130	130
MW26	370	6	72	460	370	160	1720	3150	8
MW27	510	11	160	430	170	190	2280	3640	7
MW28	500	1	210	360	270	180	2330	3680	7
MW29	650	2	170	280	150	340	2110	3540	14
MW30	500	0	180	430	290	54	2290	3650	2

of different chemical analyses. Small to large differences in constituent concentrations are evident between the EID and QMC analyses.

Despite the variability in the data, all of the chemical analyses point out that monitor wells MW18, MW22, MW23 and MW24 have high nitrate concentrations. Nitrate concentrations in these wells were 17, 6, 260, and 58 mg/l, respectively, when QMC sampled them on November 20, 1980. EID technical staff found nitrate concentrations of 80, 34, 179, and 130 mg/l, respectively, when the same wells were sampled on May 17, 1984. There are five up-hydraulic gradient alluvial wells in the vicinity of the evaporation ponds, and their highest recorded nitrate levels, from available data, are 110, 22, 15, 17 and <10 mg/l for wells MW13, MW27, MW28, MW29, and MW30, respectively.

Alluvial Ground Water Quality Impacts

The absence of reliable pre-existing ground-water quality data makes it difficult to determine if the operation of the Section 4 evaporation ponds has contaminated alluvial ground water. There are no readily observable trends (since 1978) in the ground-water monitoring data, and any increases in constituent concentrations have not been of sufficient magnitude to indicate that seepage from the evaporation ponds has impacted ground water quality. Fluctuations in concentrations of chemical constituents in the ground water may mask any small scale trends.

While there are no increasing trends in NO_3 data, the existence of high nitrate concentrations in wells MW13, MW18, MW22, MW23, MW24, MW27, MW28, MW29, and MW30 indicates that ground water has been

historically contaminated. The Section 4 evaporation ponds could not have contaminated wells MW13, MW27, MW28, MW29, and MW30 because they are up-hydraulic gradient from the ponds. Furthermore, it is unlikely that the ponds contaminated wells MW22, MW23, and MW24 for the following reason. These three wells are approximately 525 feet down-hydraulic-gradient from pond number 20. It would take 7.7 years for ground water under pond 20 to reach MW22, MW23, or MW24 if the ground water velocity is 68 ft/year. Yet MW23 had a nitrate concentration of 260 mg/l as N when it was sampled approximately 6 months after pond number 20 was filled. The water table maps (see Fig. 6a and 6b) also indicate that ground water flowing from the northwest has a major influence on wells MW22, MW23, and MW24. It is possible that leakage from the evaporation ponds has resulted in high nitrate levels in well MW18; however, the other chemical constituents don't reflect leakage and the water level in MW18 has fallen since it was drilled.

The decline in water levels in all of the wells, except the wells along the Arroyo del Puerto, further supports the conclusion that the Section 4 evaporation ponds have not leaked and impacted ground-water quality. A major leak would have created a ground-water mound under the leaking ponds and would have been clearly evident from ground-water quality data. To assess whether existing nitrogen concentrations are the result of pond seepage it would be possible to run a computer model to determine the maximum amount of leakage that could occur and not create a ground-water mound. Given this maximum leakage rate, a thermodynamic-chemical equilibrium model could be used to indicate if the ground water would have a clear fingerprint

indicative of the effluent.

Monitoring Requirements and Commitments

QMC has committed to perform the following under its approved ground-water discharge plan (DP-71):

1) Monthly sampling of wells MW1 through MW31 for TDS, SO_4, Cl, NO_3, pH, temperature, specific conductivity, fluid level and well depth. Reports to EID are submitted on a quarterly basis.

2) Should the analytical results from a particular seepage detection well show a numerical value for TDS, sulfate, and/or chloride equal to or greater than twice the historical average obtained from up-hydraulic gradient wells MW13, MW27, MW28, MW29, and MW30, QMC will take the following steps:

   a. The well(s) will be immediately re-sampled for verification of the initial analysis.

   b. If the second analysis confirms the first, QMC will report this immediately to the Water Quality Section of the EID.

   c. QMC and EID will undertake an investigation to determine the cause of the aberrant sample(s).

   d. Upon determining the cause, QMC will take the appropriate action, in consultation with EID, to mitigate any malfunctions discovered.

3) QMC agrees to visually inspect the exterior berms of the ponds 16 through 21 in Section 4 on a weekly basis and immediately after heavy storms. Should a visual inspection of the berms reveal a serious condition or leak, QMC will notify EID of same and the corrective actions, if warranted, the company intends to take.

APPENDIX B

GROUND-WATER DISCHARGE PLAN ANALYSIS
for
QUIVIRA MINING COMPANY SAND BACKFILL OPERATIONS
AT AMBROSIA LAKE SECTION 35 AND 36
URANIUM MINES

Prepared by the Ground Water Section of
the Ground Water and Hazardous Waste Bureau,
New Mexico Environmental Improvement Division

Steven W. Sares
Hydrogeologist

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1.0 SUMMARY AND CONCLUSIONS

A technical analysis of a ground-water discharge plan submitted by Quivira Mining company (QMC) for backfilling sand fractions of mill tails into mine stopes in the Section 35 and 36 mines in the Ambrosia Lake mining district has been completed by staff of the Ground Water and Hazardous Waste Bureau of the Environmental Improvement Division. The discharge plan (DP-264) analyzes the potential impacts to ground-water quality which may result from backfilling of uranium-mill tailing sands into stopes within the Westwater Canyon Member of the Morrison Formation. Separate discharge plans were required for the QMC mill tailings impoundment, and evaporation ponds. QMC's discharge plan 264 was analyzed to determine whether ground water will be contaminated beyond the numerical standards set by the Water Quality Control Commission (WQCC) at a place of withdrawal for present or reasonably foreseeable future use. After analysis of the discharge plan application, subsequent QMC submittals, and results of independent research, EID determined the proposed plan satisfies the technical requirements of the WQCC regulations. The discharge plan was approved on May 27, 1983 for a period of two years and renewed on April 12, 1985 for a period of five years.

QMC has recently placed its Ambrosia Lake uranium mines on standby status. No ore removal operations are proceeding at this time; however, the mines are being maintained for future use, and old stope leaching is continuing in some of the Ambrosia Lake mines.

Each potential source of contamination was examined by EID staff to assess its possible effects on ground water. The only apparent possibility for ground-water contamination from backfilling in QMC's Section 35 and 36 mines occurs in the aquifer in which backfill is placed, the Westwater Canyon Member of the

Morrison Formation. This aquifer occurs at a depth of 800-1400 feet and has a average TDS content of 735 milligrams per liter (mg/l) (QMC, 4-22-85). Three major factors were analyzed in conjunction with this contamination source. These factors are: 1) the quality and fate of decant fluids as backfill is placed; 2) dilution of water contaminants as mines reflood; and 3) geochemical interactions among backfill contaminants and ground-water.

Decant fluid from sand backfilling does not pose a threat to ground-water quality standards at QMC's Section 35 and 36 mines although backfill decant generally has TDS concentrations of 3920 mg/l. The presence of mine shafts and drifts at atmospheric pressure underground creates a hydraulic pressure sink into the mine. Ground water flows from the aquifer into the mine. While the mines remain dewatered, there is no hydraulic pressure to drive the fluids back into the aquifer. It is, therefore, unlikely for decant fluids to pass through the walls or floor of the mine into the aquifer.

In lieu of presenting a contingency plan and plan for post operational monitoring, QMC presented worst case calculations of the amount of dilution of water contaminants which will occur as the mines reflood. Calculated refilled water quality for elements of concern are below WQCC numerical standards. Mine dewatering has created a large cone of potentiometric depression in the Ambrosia Lake mining district. It is estimated that several hundred years will be needed to refill the 368,000 acre feet of water drained from the Westwater Canyon Member aquifer. Until this occurs, a ground-water flow pattern into the mined area will be maintained, making excursions of fluids from the mined area unlikely.

In addition to calculations of contaminant dilution, theoretical studies were presented by QMC which indicate that geochemical reactions between backfilled material and formation water will remove many metals and sulfate salts from solution.

Runoff and flooding at the mine sites does not constitute a threat to backfilling operations as the mine sites lie above flood zones and most backfill material is stored near the mill in Section 31.

2.0 INTRODUCTION

2.1 BACKGROUND INFORMATION

Quivira Mining Company (QMC, formerly Kerr-McGee Nuclear Corporation) operates nine uranium mines in the Ambrosia Lake mining district, approximately 32 km (20 miles) north of Grants, New Mexico (Figure 1). As a part of mining operations, QMC has backfilled mine stopes in the Section 22, 30, 30W, 35 and 36 mines with a mixture consisting mostly of sand fractions of mill tailings.

On August 24, 1982, the Director of the Environmental Improvement Division (EID) requested that QMC submit a ground-water discharge plan for sand-backfilling activities in the Ambrosia Lake mines. Pursuant to sections 3-104 and 3-106 of the New Mexico Water Quality Control Commission (WQCC) regulations, QMC submitted a discharge plan application entitled "Groundwater Discharge Plan submitted by Kerr-McGee Nuclear Corporation, P.O. Box 128, Grants, New Mexico, for Kerr-McGee Mine Backfilling Operations" on December 15, 1982. This discharge plan (DP-264) was submitted with the opinion that no discharge plan is required because ". . . the discharge of the liquid adhering to the sand does not impact current or reasonably foreseeable future users and the sand backfilling is an essential and integral part of mining operations." The discharge plan and subsequent submittals address the potential impacts to ground water which may result from this project. The discharge plan was approved by the Director on May 27, 1983 for a period of two years and renewed for a period of five years on April 12, 1985.

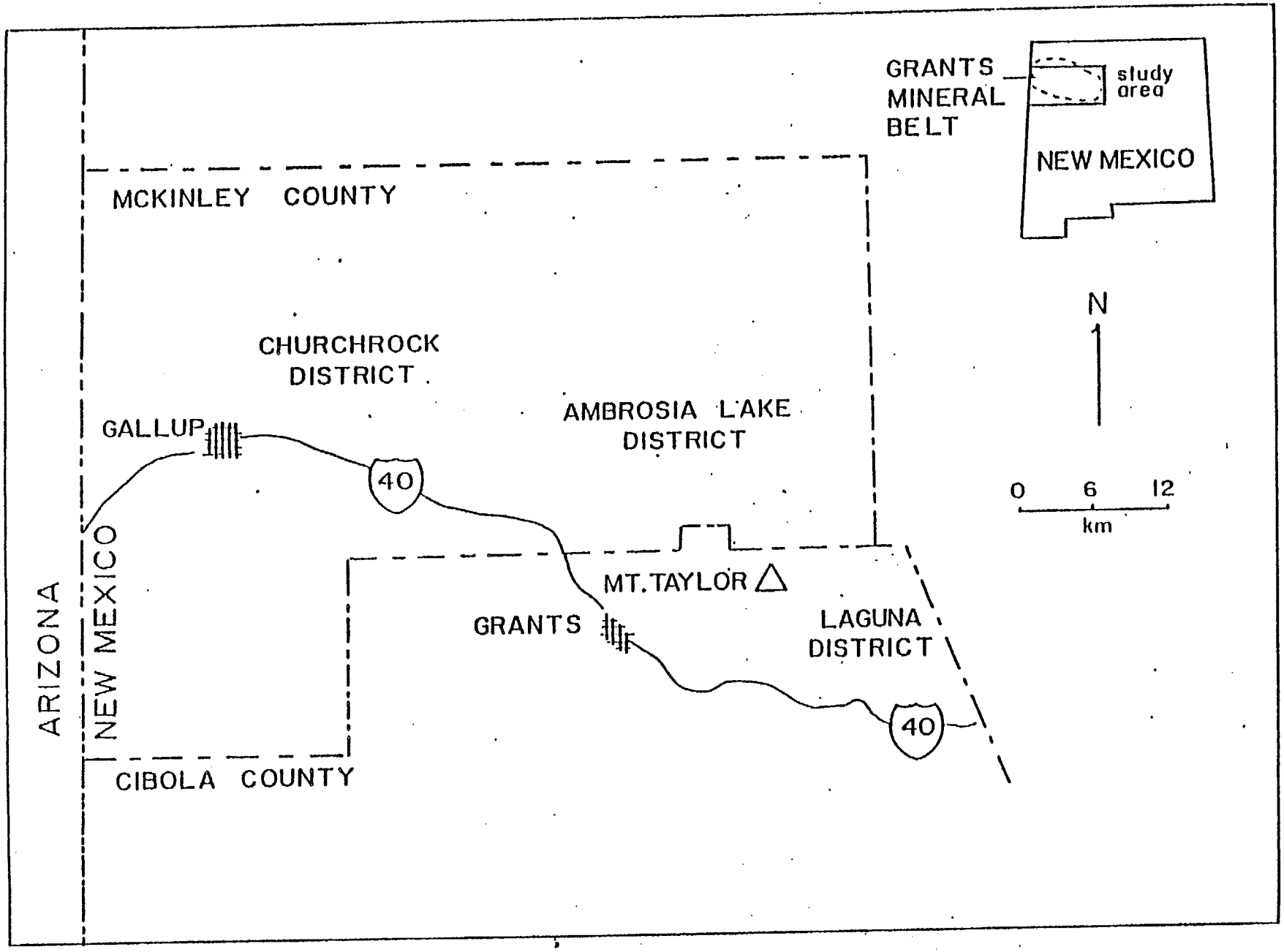


FIGURE 1. Location map of the study area. From Longmire (1985)

This report presents an analysis of QMC's discharge plan, conducted by Steve Sares of the Ground Water and Hazardous Waste Bureau of the EID. The analysis consists of a review of: the original discharge plan, subsequent submittals and, quarterly monitoring reports as well as results of published independent research.

Review of the discharge plan was conducted to determine if QMC's DP-264 satisfied the technical requirements of the WQCC regulations. To obtain an approved discharge plan, QMC must have sufficiently demonstrated that discharges will not result in ground-water contamination beyond standards specified in the regulations.

The purpose of Part 3 of the WQCC regulations, as defined in Section 3-101.A. is to ". . . protect all ground water of the state of New Mexico which has an existing concentration of 10,000 mg/l or less TDS, for present and potential future use as a domestic and agricultural water supply. . ." Section 3-103 of the regulations lists numerical standards which are the allowable pH range and the maximum allowable concentration in ground water for the contaminants specified, unless the existing condition exceeds the standard. These standards for human health, domestic water supply, and irrigation use are listed in Table 1. A discharge plan shall set forth in detail the methods or techniques the discharger proposes to use or processes expected to naturally occur which will ensure compliance with these regulations.

TABLE 1

NEW MEXICO GROUND WATER STANDARDS

A - Standards for Human Health

Constituent	Symbol	Allowed Concentration
Arsenic	As	0.1 mg/l
Barium	Ba	1.0 mg/l
Cadmium	Cd	0.01 mg/l
Chromium	Cr	0.05 mg/l
Cyanide	CN	0.2 mg/l
Fluoride	F	1.6 mg/l
Lead	Pb	0.05 mg/l
Mercury	Hg (total)	0.002 mg/l
Nitrate (as Nitrogen)	NO3 as N	10.0 mg/l
Selenium	Se	0.05 mg/l
Silver	Ag	0.05 mg/l
Uranium	U	5.0 mg/l
Radium	Ra-226 plus Ra-228	30.0 pCi/l
Benzene		0.01 mg/l
Polychlormated biphenyls	PCB's	0.001 mg/l
Toluene		15.0 mg/l
Carbon Tetrachloride		0.01 mg/l
1,2-dichloroethane	EDC	0.02 mg/l
1,1-dichloroethylene	1,1 DCE	0.005 mg/l
1,1,2,2-tetrachloroethylene	PCE	0.02 mg/l
1,1,2-trichloroethylene	TCE	0.1 mg/l

B - Other Standards for Domestic Water Supply

Constituent	Symbol	Allowed Concentration
Chloride	Cl	250 mg/l
Copper	Cu	1.0 mg/l
Iron	Fe	1.0 mg/l
Manganese	Mn	0.2 mg/l
Phenols		0.005 mg/l
Sulfate	SO4	600 mg/l
Total Dissolved Solids	TDS	1000 mg/l
Zinc	Zn	10 mg/l
pH	pH	between 6 and 9

C - Standards for Irrigation

Constituent	Symbol	Allowed Concentration
Aluminum	Al	5.0 mg/l
Boron	B	0.75 mg/l
Cobalt	Co	.05 mg/l
Molybdenum	Mo	1.0 mg/l
Nickel	Ni	0.2 mg/l

Provided that the other requirements of the WQCC regulations are met, the Director shall approve a proposed discharge plan if the discharge will not result in WQCC ground water standards being violated or a toxic pollutant (as defined in Section 1-101.UU of the WQCC regulations) being present at a place of use in the present or reasonably foreseeable future.

2.2 GENERAL DESCRIPTION OF MINING AND BACKFILLING PROCESSES

QMC utilizes the room and pillar method of underground mining. Thomson and Heggen (1983) describe this method of mining in some detail. The following discussion is a summary of mining procedures described by Thomson and Heggen.

In the room and pillar method, vertical shafts are sunk to the ore level. Horizontal drifts are then mined out in a checker board pattern within and around the ore body (Fig. 2). Pillars of ore are left in place to provide roof support. Once the drifts are completed some of the areas between them (pillars) are removed. This practice creates large open areas termed stopes.

Haulage drifts in the mine are constructed with a one to two percent slope toward the mine shaft and sump. This provides for greater ease of movement of loaded ore cars and provides for more efficient mine drainage.

Sand backfilling is currently practiced at QMC's mines in Sections 35 and 36, T14N, R9W, McKinley County, New Mexico. The primary purpose for backfilling stopes is to prevent roof collapse in mined out areas. Several benefits gained from this practice are:

1. Prevention of roof fracturing which may result in increased hydrologic connection between the ore zone and overlying aquifers.

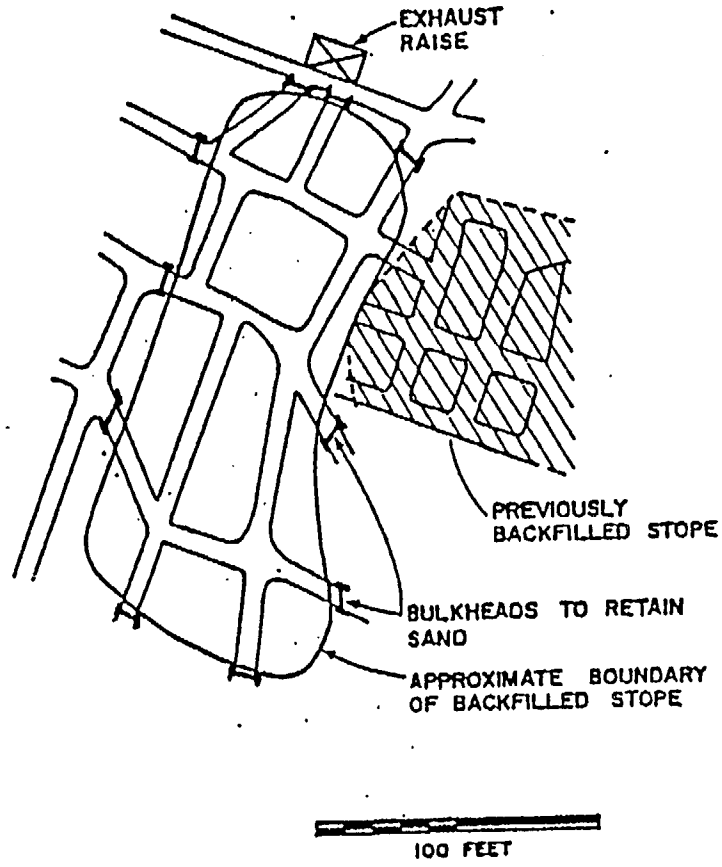


FIGURE 2. Mine layout showing location of bulkheads and mined-out stope to be backfilled.

From Thomson and Heggen (1983)

Hydrologic connection would increase mine dewatering requirements and operation costs, and allow ground water of poorer quality to enter the ore zone.

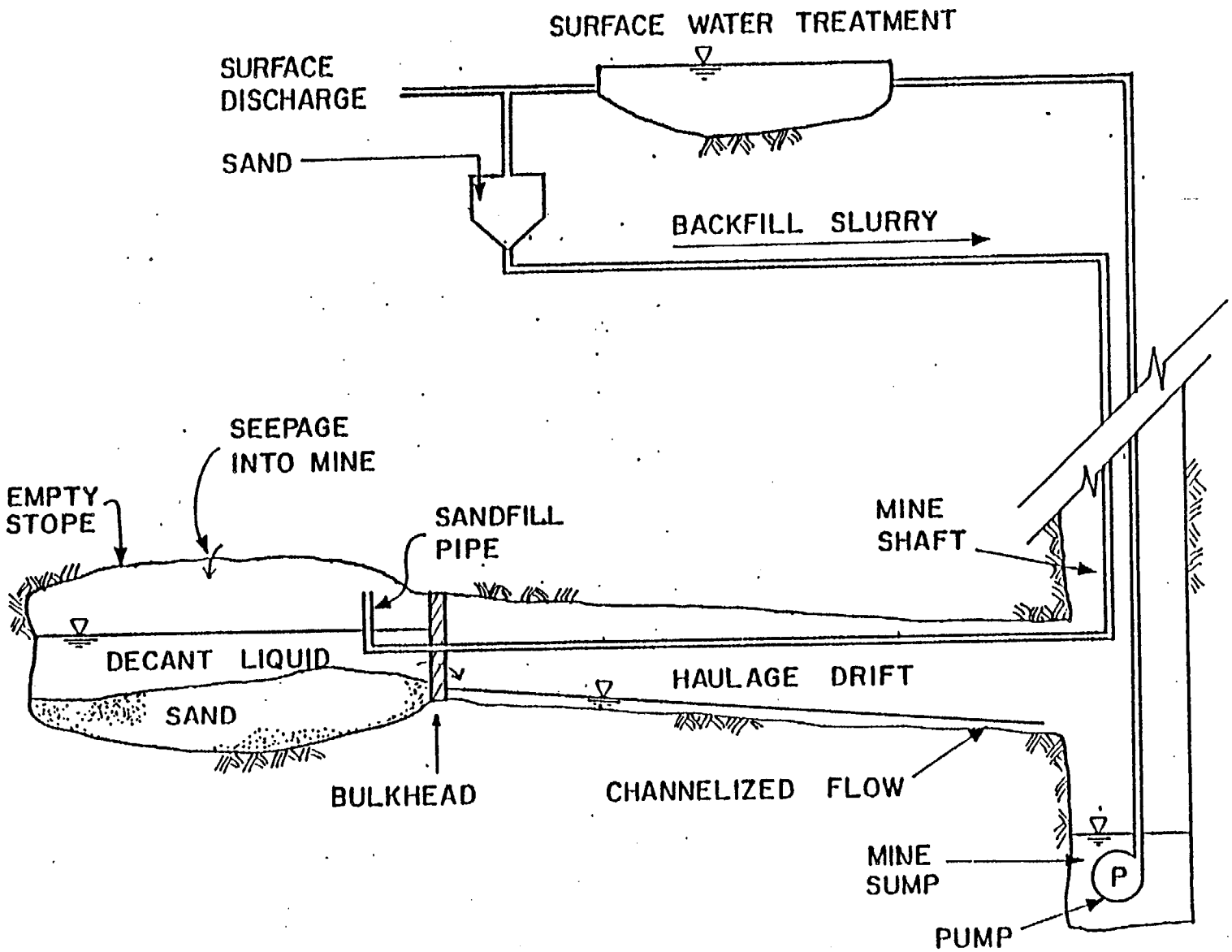
2. Providing support so that additional ore can be mined.

3. Control of land surface subsidence.

4. Disposal of mill tailings.

5. Improved worker safety.

The backfill process begins with separation of the sand fraction (greater than 200 mesh) from the balance of mill tailings (slimes) at the QMC mill. Slimes are excluded from backfill because fine-grained particles inhibit the backfilled material from draining and result in unstable mud backfill. Sand is then stockpiled near the mill in Section 31 for future use. Upon decision to backfill, sand is hauled to the mine site by truck where it is slurried with mine water. This slurry contains 50 to 70 percent sand by weight. After mixture, the slurry is piped through the shaft to prepared stopes at approximately 135 gallons per minute (gpm)(Figure 3). Stope preparation consists of constructing bulkheads covered with burlap to retain sand in the stope (Figure 4). This operation is repeated to build the sand level to 80-90 percent of the available stope volume. Water that drains from the backfilled stope (decant fluid) mixes with mine water and drains to the mine sump (Figure 3). Water from the sump is pumped to the surface at approximately 1289 and 1567 gpm respectively from the Section 35 and 36 mines (QMC, 10-30-84) to be treated and discharged, or recycled.



Schematic of the backfill process

From Longmire (1985)

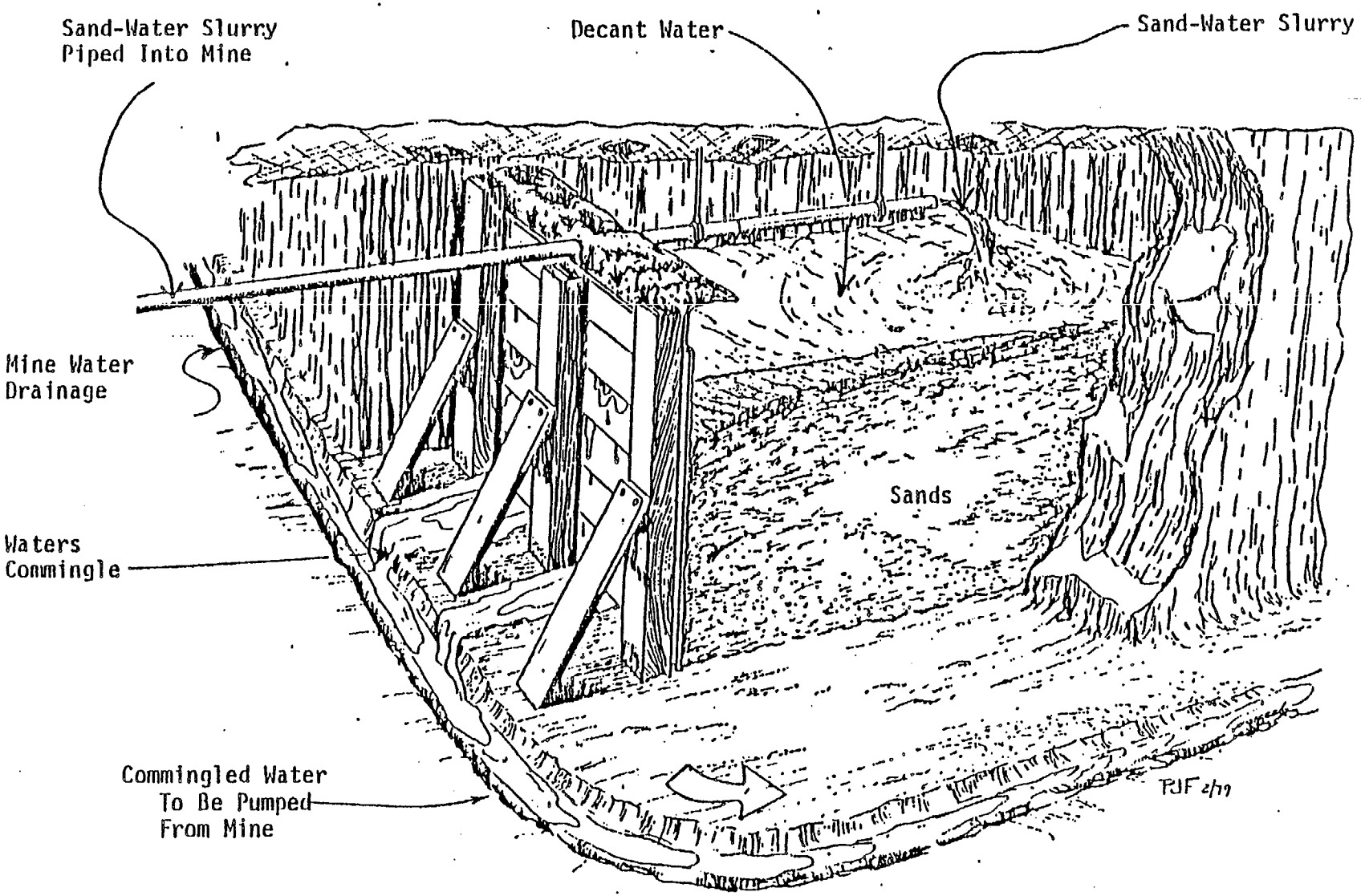


FIGURE 4 -- GENERALIZED DIAGRAM OF
TAILINGS BACKFILL IN MINES

ADAPTED FROM UNITED NUCLEAR CORPORTION BACKFILLING DISCHARGE PLAN

2.3 POTENTIAL POINTS OF DISCHARGE AND IMPACTS ON GROUND WATER

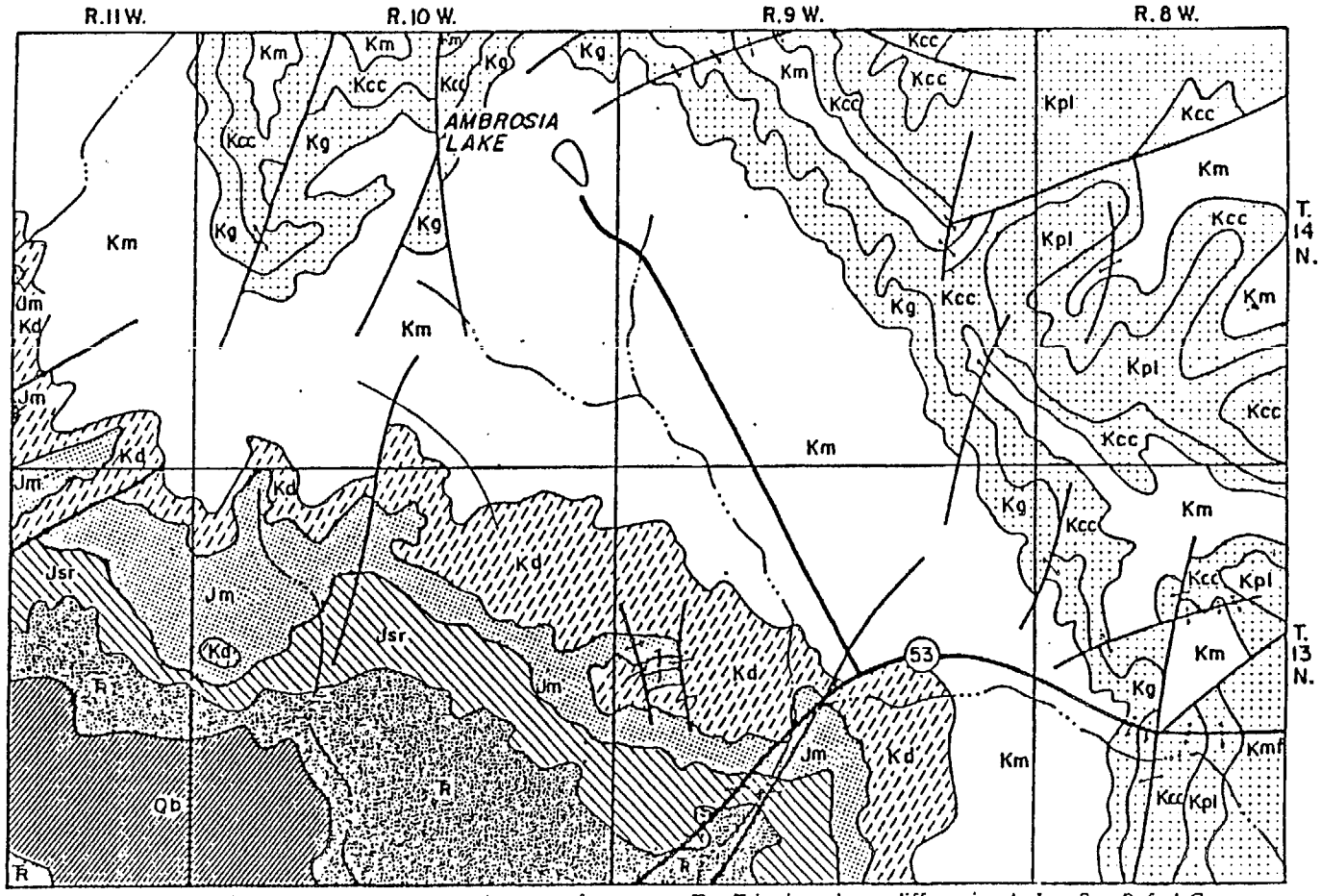
Discharge plan 264 for sand backfilling at the Section 35 and 36 mines addresses one potential point of discharge. This is the release of mine water and tailings liquor, which adheres to backfill material, into the Westwater Canyon Member of the Morrison Formation.

Discharges and potential ground-water quality effects from other QMC facilities such as the mill, tailings pile, and evaporation ponds are discussed in DP-169 and DP-71.

2.4 SUMMARY OF THE HYDROGEOLOGIC SETTING

QMC's Section 35 and 36 mines are located on the Chaco Slope on the southern margin of the San Juan Basin. The basin is a circular structural depression which occupies much of the Colorado Plateau. The basin attained its structural configuration by Late Cretaceous-Early Tertiary time, with minor Late-Cenozoic deformation (Wells and Smith, 1983). The region of the basin in which QMC's mines are located is underlain by alluvium, and Mesozoic sedimentary units which strike N68^{o}W and dip two degress northeast, into the Central Basin (Santos and Thadden, 1966). Two sets of faults are present near the mines. Directly adjacent to the Section 35 and 36 mines a set of faults trends N to N30^{o}E. Approximately 5 miles north of the mines another set of faults trends N75^{o}E (Figure 5).

Two sets of vertical fractures are present in the overlying formations. These fractures strike N-S, and E-W (Santos and Thadden, 1966).



PRE-QUATERNARY GEOLOGY IN THE AMBROSIA LAKE AREA; Tr—Triassic rocks, undifferentiated, Jsr—San Rafael Group (Jurassic), Jm—Morrison Formation (Jurassic), Kd—Dakota Sandstone (Cretaceous), Km—Mancos Shale (Cretaceous); Cretaceous Mesaverde Group: Kg—Gallup Sandstone, Kcc—Crevasse Canyon Formation, Kpl—Point Lookout Sandstone, Kmf—Menefee Formation; Qb—Quaternary basalt (figure after Dane and Bachman, 1965).

Figure 5.

From Kelly (1981)

Sedimentary units of concern to DP-264 are, in decending order: alluvium (Qa); Mancos Shale (Km) and Tres Hermanos sandstones; Dakota Sandstone (Kd) and; Brushy Basin Member (Jmb), Westwater Canyon Member (Jmw), and Recapture Member (Jmr) of the Morrison Formation. Geologic and hydrologic descriptions of these and other stratigraphic units in the Ambrosia Lake area are presented in Figure 6.

Of the units underlying the mine sites only the Tres Hermanos sandstones, Dakota Sandstone, and Westwater Canyon Member yield significant quantities of water to wells. Figure 7 presents a generalized northeast-southwest geologic cross section of the area showing recharge zones of aquifers and zones of saturation.

Sand backfilling occurs within the Westwater Canyon Member of the Morrison Formation. This unit contains the principal ore zone in the Ambrosia Lake District and is an important aquifer. The Westwater Canyon Aquifer is 200 feet thick in this area and confined under natural conditions with a storage coefficient of 4 x 10-4. Premining potentiometric levels of the Westwater Canyon Aquifer in the area were approximately 6600 feet above mean sea level (Kelly and others, 1980). Mine dewatering activity in the Ambrosia Lake area has created a cone of potentiometric depression in the Westwater Canyon Aquifer which locally exceeds 400 feet in depth and has a radius of influence of over 48 km (30 miles) into the basin (QMC, 5-5-83) (Figure 8).

In the Ambrosia Lake area, the Westwater Canyon Aquifer contains ground water of generally good quality (Table 2), while the Tres Hermanos and Dakota

Figure 6. Stratigraphic column of the Ambrosia Lake Mining District.

AGE	GROUP	FORMATION	MEMBER	THICKNESS (Feet)	CHARACTER
Upper Cretaceous	Mesa-verde	Point Lookout Sandstone	Main Body	60-160	Light gray and reddish brown, medium- to fine-grained massive sandstone
			Satan Tongue (Mancos)	0-140	Dark gray sandy shale, some interbedded pale yellowish-brown fine-grained silty sandstone and siltstone
			Hosta Tongue	100-140	Light gray, medium- to fine-grained sandstone
		Crevass Canyon Formation	Gibson Coal Member	160-300	Light gray lenticular sandstone interbedded with gray siltstone, carbonaceous shale and coal
			Cotton Ss Member	60-150	Light gray, fine- to medium-grained sandstone
			Mulatto Tongue (Mancos)	220-400	Pale yellowish-brown, sandy shale, dark gray shale
			Barrego Pass Lentil	0-40	Gray, fine- medium- and coarse-grained sandstone
			Dilco Coal Member	80-180	Yellowish-gray, pale-orange sandstone, siltstone, carbonaceous shale, coal
		Gallup Sandstone	Main Body	0-120	Pale reddish-brown and light gray, fine- and medium-grained sandstone
			Pescado Tongue (Mancos)	140-160	Dark gray, silty shale
			Lower Part	10-40	Gray, fossiliferous, fine- and coarse-grained sandstone
		Mancos Shale	Main Body	600-650	Dark gray to black fissile silty shale with minor light brown sandstone
			Twowells Ss Tongue (Dakota)	95-150	Yellowish-brown to buff, medium- to fine-grained sandstone
			Whitewater Arroyo Sh Tongue		Gray, black shale
		Dakota Sandstone	Paguate Ss Tongue	50-90	Gray, very fine-grained sandstone
			Clay Mesa Sh Tongue		Dark gray shale (Mancos)
			Cubero Ss		
			Oak Canyon Member	85-160	Gray, very fine-grained sandstone
Upper Jurassic		Morrison Formation	Brushy Basin		Upper part—Light gray and greenish-tan, carbonaceous, very fine-grained sandstone and siltstone. Lower part—Pale yellowish brown, orange, white, fine- and medium-grained sandstone
			Westwater Canyon	40-220	Greenish-gray mudstone with minor lenticular, light gray and yellowish-gray, fine- and medium-grained sandstone
			Recapture	90-290	Light yellowish- and reddish-gray, medium grained sandstone, with greenish-gray, lenticular mudstone
				70-250	Interbedded variegated mudstone claystone, siltstone and sandstone
	San Rafael	Bluff Sandstone		235-370	White, light gray, grayish-yellow, pale orange, and reddish-brown fine-grained, massive crossbedded sandstone
		Summerville Formation		160-270	Interbedded variegated mudstone and siltstone, fine- to very-fine-grained sandstone
		Todilto Limestone		25-35	Pale olive-gray, dark olive-gray, and pale yellow, thick-bedded limestone
		Entrada Sandstone	Upper Sandstone	150-185	Moderate brown, fine-grained, massive crossbedded sandstone
			Moenkopi Siltstone	40-60	Grayish-red-brown calcareous siltstone
			Navajo	60-115	Moderate brown to moderate reddish-orange, medium-grained, crossbedded sandstone
Upper Triassic		Chinle Formation	Owl Rock	1100-1600	Greenish purple claystone and siltstone interbedded with pale blue to greenish-gray and dark limestone and silty limestone
			Correo Ss		
			Petrified Forest (Upper)		Moderate grayish red to pale reddish-brown and purple mudstone, siltstone, and sandy siltstone
			Sonsela Ss Bed		White, light gray to yellowish-gray and brown very-fine-grained to conglomeratic sandstone interbedded with reddish-brown claystone
			Petrified Forest (Lower)		Blue to gray and reddish-purple mudstone and siltstone
			Monitor Butte		Grayish-red claystone and sandy siltstone, fine- to medium-grained sandstone, brownish-gray conglomerate
Permian		San Andres Limestone		95-115	Dense gray and yellowish-brown to red limestone with interbedded tan fine- to medium-grained, crossbedded sandstone, upper surface karst

SOURCE: DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE

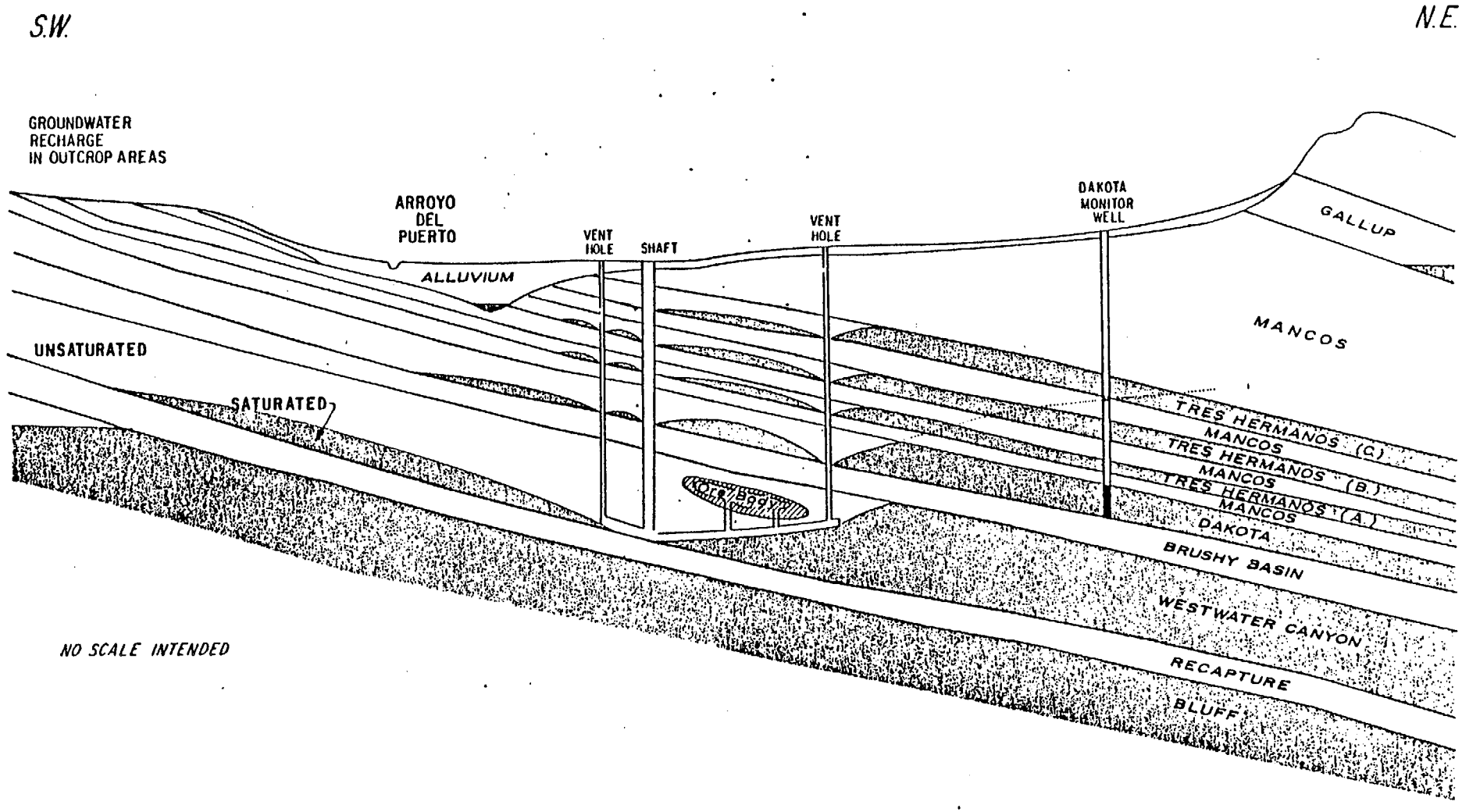


FIGURE 7.

NE-SW CROSS-SECTION THROUGH AMBROSIA LAKE AREA - GENERALIZED MINING CONDITIONS

KERR-McGEE NUCLEAR CORPORATION Dec. 1980

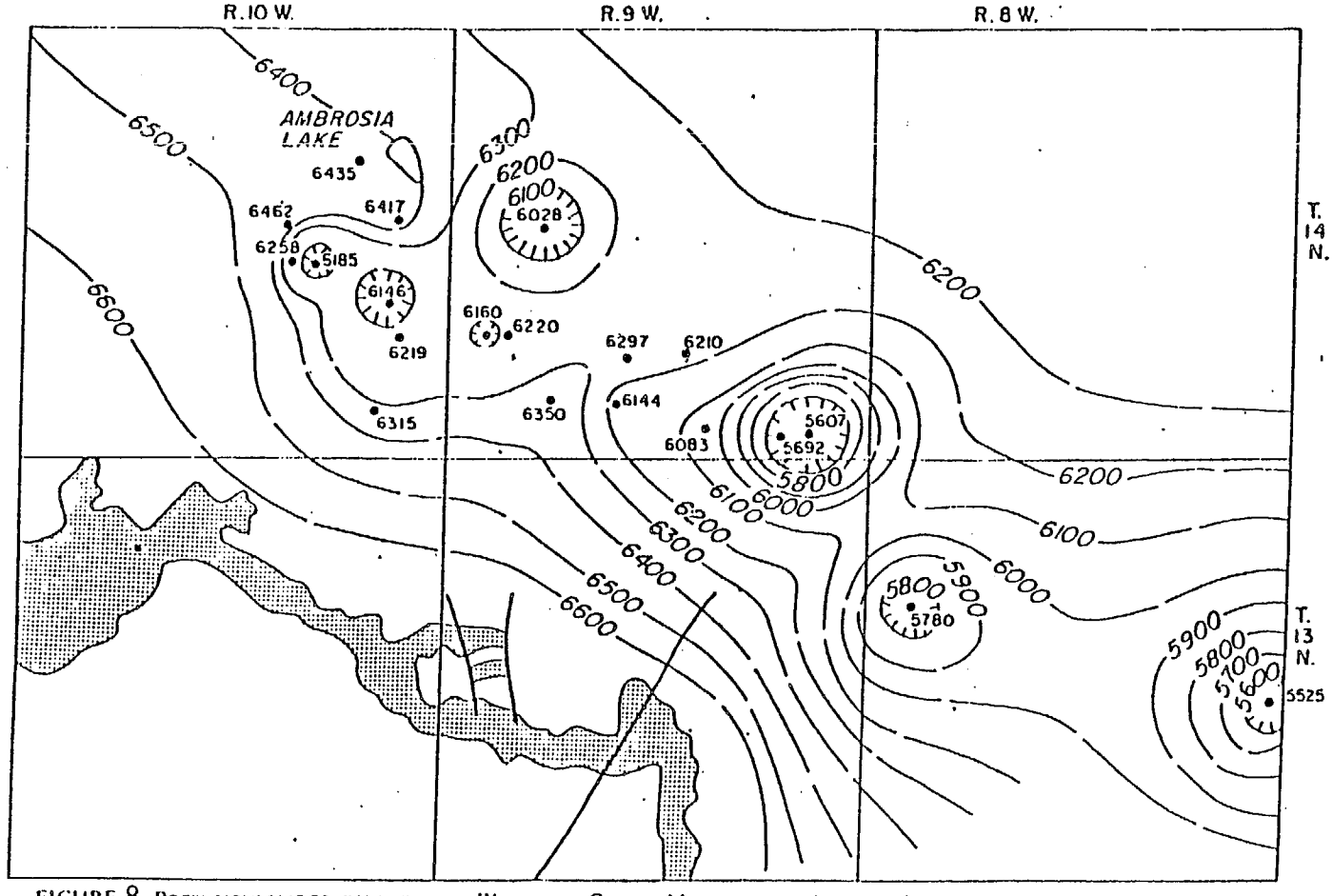


FIGURE 8 POTENTIOMETRIC CONTOURS FOR THE WESTWATER CANYON MEMBER IN THE AMBROSIA LAKE AREA, 1979; contour interval, 100 ft; stippled area represents the outcrop of the Morrison Formation.

From Kelly (1981)

TABLE 2

CHEMICAL ANALYSIS OF DISSOLVED CONSTITUENTS IN WESTWATER CANYON AQUIFER FLUIDS FROM QMC'S SECTION 30W MINE, 1-5 LEVEL

	mg/l		*ug/ml		*ug/ml
Ca	48.0	Al	0.10	Mg	18.0
Mg	24.1	Ba	0.10	Mn	0.05
Na	177	Be	0.10	No	0.10
K	7.41	B	0.23	Ni	0.10
HCO_3	275	Cd	0.10	Si	5.4
Cl	11.3	Ca	44.0	Ag	0.10
SO_4	282	Cr	0.10	Sr	1.80
TDS	728	Co	0.10	Sn	0.10
		Cu	0.10	V	0.10
		Fe	0.10	Y	0.10
		Pb	0.10	Zn	0.10

Samples February 5, 1985 by EID personnel
EID Sample number 8502051213
*ICAP Analysis

sandstones yield ground water of slightly poorer quality. The Tres Hermanos and Dakota have also been substantially dewatered by mining activity (Figure 7).

Backfilling has little or no effect on these aquifers and, therefore, they will not be discussed in detail in this report. Bostick (1985) examines these two units in detail as they relate to other QMC facilities.

3.0 GROUND-WATER QUALITY

Previous and projected backfilling activities at QMC mines will result in a total of 2.318 million tons of backfill material being placed in the Westwater Canyon Member of the Morrison Formation at the Section 22, 30, 30W, 35 and 36 mines. Backfill material includes tailing sand, tailings, alluvial sand, mine water, and tailing liquid which adheres to tailings.

At the time of this analysis, 1,044,000 tons of tailing sand, 289,000 tons of tailings, and 785,000 tons of alluvial sand have been placed in the Section 22, 30, 30W, 35 and 36 mines. An additional 200,000 tons of tailing sand is estimated to be placed in future mining operations.

As indicated in Figure 3, sand is slurried with treated mine water to facilitate backfilling. After placement in stopes, sand settles out of the mixture and the transporting fluid, termed decant liquid, drains through bulkheads into drifts and mixes with mine water to form "commingled water". Chemical analyses of mine water, slurry mixture, decant fluid, commingled water and mine discharge (treated mine water) are presented in Table 3. Although several chemical parameters exceed the WQCC numerical ground water standards, comparison between analyses of mine water upstream of backfill locations in stopes and commingled water indicated that contaminant levels in

TABLE 3

AVERAGE CHEMICAL ANALYSES OF MINE WATER, SLURRY FLUID, DECANT FLUID, COMMINGLED WATER AND MINE DISCHARGE

All units mg/l unless noted

CONSTITUENT	MINE WATER	SLURRY FLUID	DECANT FLUID	*COMMINGLED WATER	MINE DISCHARGE
pH	7.3	7.3	6.6	7.5	8.2
TDS	3,055	3,560	3,805	3,185	1,270
As	0.047	0.023	0.022	0.015	0.021
Ca	536	388	333	743	302
Mo	45.1	6.0	8.6	30.7	0.86
Na	337	353	333	311	257
Se	2.4	0.91	1.7	2.8	0.17
SO_4	1,660	2,120	2,400	2,053	555
V	0.79	0.27	0.47	0.55	0.075
238-U	105	19.5	68.7	62.6	1.1
226 Ra pCi/l	1,870	70	586	471	1.09
#Samples Averaged	10	2	9	8	2

Source: Thomson and Heggen, 1983, Pg. 53

*AVERAGE DATA COLLECTED FROM THOMSON & HEGGEN, 1983, Pg. 99

Samples collected 9-18-81 from Section 36 Mine Stope 6507 (Fig. 2).

commingled water are not significantly elevated by the practice of backfilling. A comparison of concentrations of selected ground-water constituents between these fluids and water is presented in Table 4.

Typical ground-water inflow rates to the Section 35 and 36 mines are 1289 and 1567 gpm, respectively (QMC, 10-30-84). Sand backfill is placed in mines at a rate of 135 gpm for six hours per day during backfill operations. Decant fluid from backfill can, therefore, constitute a maximum of 1.2 percent of daily mine discharge for the two mines combined. This represents a negligable impact on the water quality of mine discharge and ground water.

SHORT-TERM GROUND WATER QUALITY EFFECTS

Observations of backfilled stope seepage indicate that total seepage rates fall to rates indistinguishable from natural inflow rates within several hours after cessation of backfilling and that backfill drainage is essentially complete within 1-2 weeks after a stope is filled (Thomson and Heggen, 1983).

Infiltration of slurry and decant fluids within the mines are not likely to be a source of ground-water contamination. Mines in the region are connnected to the ground surface by shafts and vents and, therefore, are under nearly atmospheric pressure while ground water in surrounding formations is under somewhat greater hydrostatic pressure. For this reason, fluids flow from bedrock formations into mines rather than from the mine into bedrock. Decant fluid and commingled water drain via haulage ways to mine sumps within tens of minutes to a few hours after release from filled stopes and are then pumped to the surface and treated (Thomson & Heggen, 1983).

TABLE 4

ANALYSIS OF CHANGE IN CHEMICAL CONSTITUENTS BETWEEN MINE WATER AND SLURRY FLUID, DECANT FLUID AND COMMINGLED WATER

Constituent	Mine Water	Slurry Fluid	Decant Fluid	Commingled Water
pH	7.3	0	+ 9.5%	+ 3%
TDS	3,055	+16%	+24%	+ 4%
AS	0.047	-51%	-53%	-68%
Ca	536.	-27%	-38%	+39%
Mo	45.1	-86%	-81%	-32%
Na	377	- 6%	-12%	-17%
Se	2.4	-62%	-29%	+16%
SO4	1,660	+27%	+44%	+23%
V	0.79	-65%	-40%	-30%
238-U	105.	-81%	-34%	-40%
226-Ra	1,870	-96%	-69%	-75%

Comparisons based on data contained in Table 3.

Continuation of ground-water inflow through backfilled stopes is desirable as the inflow may leach and dilute contaminants that are retained in backfill after gravity drainage. These leached contaminants are contained in mine water and pumped to the surface for treatment and discharge. Figure 9 presents results of leachability tests conducted by QMC. These tests were conducted to determine the rate at which Al, Mo, Se, and SO_4 species are leached from backfill sands. These species were chosen to be chemically representative of the leachability of other cations and anions in backfill material. Uranium, Ra, Cd, Zn, V, and As are expected to wash out at rates similar to Al, Mo, and Se. Chloride should wash out at a rate similar to SO_4. The tests indicate that approximately 10 bed volumes of leach water will be required to produce a 10-fold decrease in contaminant concentrations for Al, Mo, and Se, and 20 volumes will be required to reduce SO_4 10-fold.

3.2 LONG-TERM GROUND WATER QUALITY EFFECTS

Thomson and Heggen (1983), as well as others, have performed computer simulations of the Westwater Canyon Aquifer in the Ambrosia Lake area. These simulations indicate the presence of a pressure release or cone of depression of 500 feet over an area of 80 square miles around the Ambrosia Lake area and 100 feet over approximately 1000 square miles (Figure 8). Recovery simulations indicate that hundreds of years will be required before any of the major mining centers will fully recover, even if all other pumping has stopped.

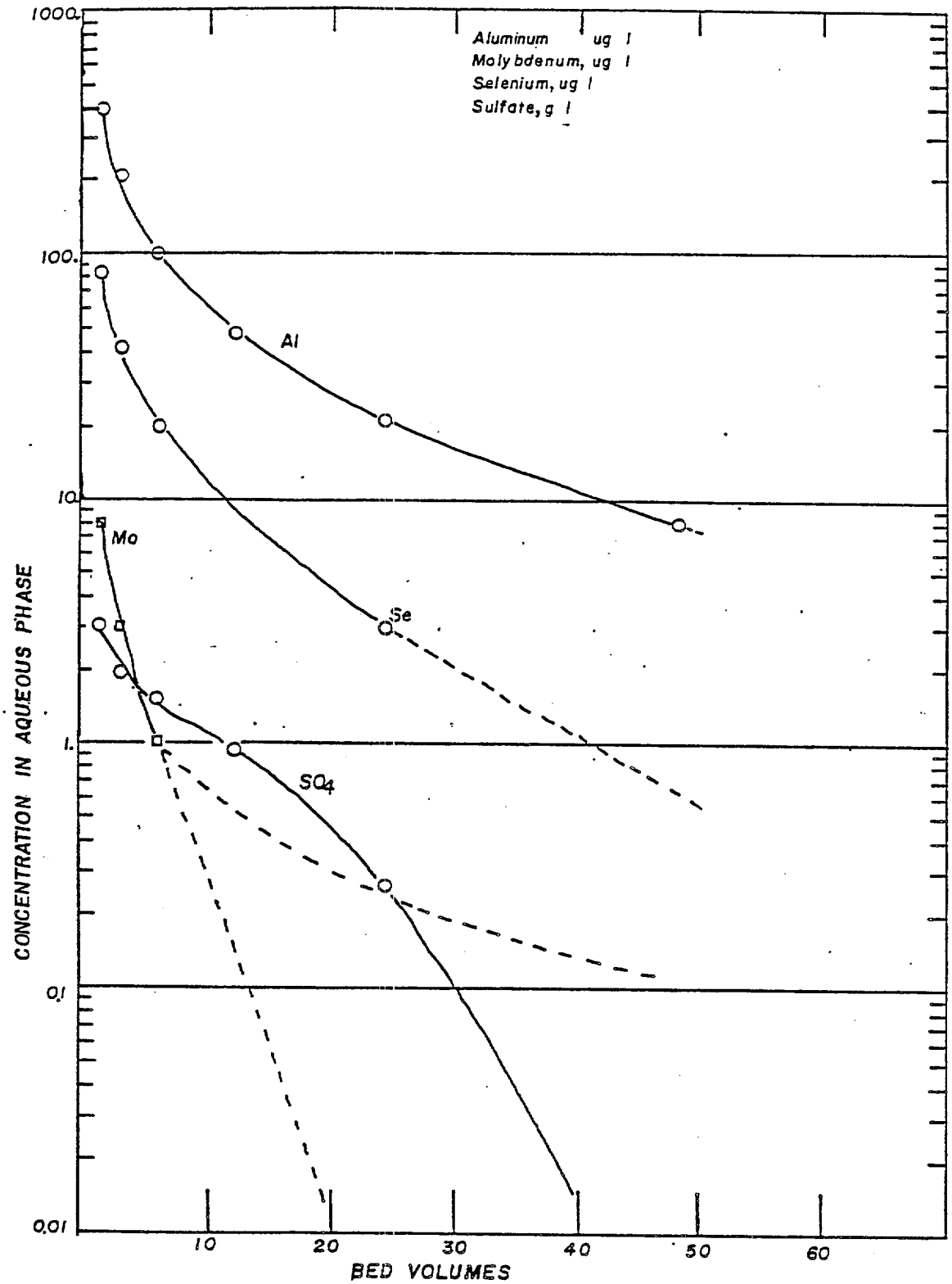


Figure 9. Results of leachability experiments on QMC backfill sand

Until full recovery for a pumping center is reached, a poteniometric gradient directed into the mined area will prevail, which will not allow outward flow for a long period of time (Bostick, 1985). Full recovery of the area will involve some 416,222 acre-ft (1.81×10^{10} cubic feet) of water. QMC estimates a volume of 368,000 acre-feet (1.6×10^{10}) cubic feet) of water is needed to restore the Westwater Canyon Member aquifer to premining-potentiometric levels.

In lieu of post operational monitoring and a contingency plan, QMC elected to present "worst case" calculations as to the amount of dilution of ground-water contaminants which will occur as the backfilled mines refill with water. The following discussion presents a summary of QMC's worst case calculations.

These calculations include estimated future tailings placement in refilled mines but do not include volume of ore to be mined. For conservatism, no allowance has been made for water refilling the potentiometric cone of depression or mines in Sections 24, 17, 19 and 33. Also the calculations are conservative in that they do not consider leaching of contaminants prior to mine flooding, drainage of contaminants in decant fluid, or geochemical removal of contaminants.

1. Total volume of backfilled material. A total of 1,333,000 tons of tailings sand has been placed in QMC mines at Ambrosia Lake. 200,000 tons are predicted to be placed in future operations. This yields a total of 1,533,000 tons of tailings material from past and future operations. 785,000 tons of alluvial sand has been placed in the Section 35 and 36 mines.

2. Ratio of fluids to solids. After gravity drainage, tailing sands measure 7.2 percent liquid by weight.

3. Water quality of backfill slurry. Four chemical analyses of backfill slurry, presented by QMC, indicate average concentrations of TDS-3920 mg/l, SO_4-2,416 mg/l, Cl-196 mg/l, Mo-5.4 mg/l, and Se-0.87 mg/l in slurry fluid (QMC, 4-22-83). Average concentrations of these parameters submitted as monitoring data by QMC indicate that chemical concentrations are 35 to 80 percent less than the values used in these calculations (Table 5).

4. Volume of mined out shafts, stopes and drifts. The Section 22, 30, 30W, 35 and 36 mines have produced 16,856,000 tons of ore plus waste. Given specific volume of in-place rock of 15 cubic feet per ton, 252.8 X 10^6 cubic feet of material have been mined.

5. Volume of replacement water. When mine dewatering ceases, 202,853,000 cubic feet of water will be needed to fill the void space. This is calculated by the following equation; (volume removed in mining 252.8 x 10^6 cubic ft)-(volume of backfill 57.95 x 10^6 cubic ft)÷(20% void space in backfill 11.59 x 10^6 cubic ft)-(volume of liquid contained in backfill 3.587 x 10^6 cubic ft).

6. Water quality which will fill voids. Table 3 presents chemical analyses of water from the Westwater Canyon Aquifer which will refill mines. Averages of selected chemical constituents of 7 to 12

TABLE 5
WATER QUALITY MONITORING DATA FROM QMC BACKFILL SLURRY

DATE	5-11-83	5-12-83	8-31-83	9-83	12-14-83	AVE.
PARAMETER						
As	0.28	0.28	0.20	0.09	0.11	0.19
Ca	620.	600.	570.	270.	100.	432.
Fe	0.29	0.16	0.058	0.047	0.024	0.12
K	9.6	8.1	7.7	6.1	5.0	7.3
Mg	77.	56.	36.	33.	23.	45.
Mo			1.0	0.82	1.0	1.08
Na	250.	240.	250.	240.	250.	246.
Pb	0.48	0.46	0.26	0.14	0.76	0.28
Se	0.91	0.64	0.51	0.33	0.14	0.49
U	2.7	3.4	2.2	0.82	1.5	1.63
Cl	140.	86.	43.	52.	22.	58.
CO2	<10.	<10.	<10.	<10.	<10.	<10.
HCO3	110.	170.	240.	130.	130.	156.
NO3	20.	1.	<1.	5.	<1	5.6
SO4	1950.	2040.	1870.	1200.	800.	1578.
226 Ra (pC/l)	135.0	140.	24.	63.	0.68	58.3
228 Ra (pC/l)	<3.3	<1.9	<3.51	<5.12	<4.4	<3.6

All units in mg/l unless otherwise noted

samples are: TDS-735 mg/l, SO_4-278 mg/l, Cl-9.4 mg/l, Mo-0.31 mg/l, and Se 0.0325 mg/l. These analyses, submitted by QMC are similar to analyses of water entering the Section 30W mine that were collected by EID and analyzed at the New Mexico Scientific Laboratory Division in Albuquerque (Table 2).

7. Analysis. Tailing sand, after emplacement, occupies 25 cubic feet per ton. Past and future backfill will, therefore, occupy 57,950,000 cubic feet. The net volume for water refill is 202.853 X 10^6 cubic feet. This volume will contain approximately 12.6 X 10^9 pounds of water using a density of water of 62.45 lbs/ cubic feet. To calculate water quality of mine refill the following equation is used: (Weight of liquid in backfill 0.2238 x 10^9 lbs) X (concentration of parameter in backfill) + (weight of refill water 12.538 X 10^9 lbs) X (concentration of parameter in refill water) = (total weight of water 12,762 x 10^9 lbs) X (concentration of parameter in mixed water). Table 6 contains calculations of selected chemical constituents using this equation.

The calculations show that WQCC ground water standards will not be exceeded after the dilution takes place. These calculation results are based on the use of concentrations of parameters in backfill, which are 35 to 80 percent greater than the actual backfill slurry, as indicated by monit oring data.

TABLE 6

CALCULATION OF MINE WATER DILUTION

Weight of liquid in backfill = WLb = 0.2238 x 109 (lbs)

Concentration of parameter in backfill + Cxb (mg/l)

Weight of refill water = WLr = 12.538 x 109 (lbs)

Concentration of parameter in refill = Cxr (mg/l)

Total Weight of water = WT = 12.762 x 109 (lbs)

Concentration of parameter in mixed water = Cxm (mg/l)

$$C \times m = \frac{(WLb) \times (Cxb) + (WLr) \times (Cxr)}{WT}$$

$$= \frac{(0.2238 \times 10\text{-}9 \text{ lbs}) \times (Cxb) + (12.538 \times 109 \text{ lbs}) \times @Cxr)}{12.762 \times 109 \text{ lbs}}$$

Parameter	Cxb	Cxr	Cxm
TDS	3920	735	791
SO4	2416	278	315
Cl	196	9.4	12.7
Mo	5.4	0.31	0.40
Se	0.87	0.0325	0.047

3.3 GEOCHEMICAL INTERACTIONS BETWEEN BACKFILL AND FORMATION FLUIDS

Longmire (1983, 1985), Longmire and others (1981), Brookins and others (1982), and Thomson and Heggen (1983), among others, have investigated the geochemical interactions among backfill material, native formation fluids and formation framework materials. The major alteration processes occurring in mine stope backfill include mixing of waters of different composition (tailings raffinate, surface water discharge, backfill decant, and ground water) oxidation and reduction equilibria, authigenesis, cementation, and compaction (Longmire, 1985). Their studies conclude that precipitation, coprecipitation, and adsorption reactions effectively remove many contaminants from backfill material. These studies present and interpret thermodynamic data to predict stability of chemical species present in backfill in addition to analysis of chemical composition of fluids and mineralogical studies. Longmire (1983) points out that "the applicability of Eh-pH diagrams for describing element transformations is valid only for equilibrium conditions between backfill and ground water." Longmire further explains that the following assumptions and limitations must also be recognized when Eh-pH diagrams are used to describe oxidation-reduction equilibria relative to uranium tailings disposal:

1. The diagrams depict phase relationships of both aqueous species, minerals, and solid compounds at 1 atm pressure and 25°C.

2. Phases existing in nature occur as "impure" substances. Thermochemical data are generally not available for mixed compositions.

3. Eh-pH diagrams are dependent on the accuracy of thermochemical data.

Figure 10 presents a generalized Eh-pH diagram for uranium tailings, surface waters, and water in the Westwater Canyon Aquifer. Brookins (1977) discussed the geochemistry of uranium deposits in the Grants Mineral Belt. He pointed out the requirement of strongly reducing conditions for uranium ore formation. It is predicted that reducing conditions will become reestablished as mines reflood while near neutral pH is maintained. Metals associated with uranium tailings backfill should precipitate from solution in the form of oxide, sulfide, sulfate, and carbonate species. Migration of these metals is expected to be minimal. Eh-pH diagrams for U, As, Mo, and Se are presented in Figures 11-14.

These and other metals are effectivly removed from solution by adsorption, precipitation, and coprecipitation. Table 7 lists the predicted and observed fate of several elements based on x-ray diffraction, and scanning electron microscopy studies and Eh-pH diagrams (Longmire, 1981). Also, Longmire and others (1981) predicted through Eh-pH diagrams and numerous chemical analyses that Fe, As, Mo, Pb, Co, Cr, U, V, Ca, and Mn are removed from solution by incorporation into sulfide, sulfate, oxide, carbonate, and possibly silicate phases. Therefore, leaching of these constituents into ground water after repressurization should not cause the WQCC numerical ground-water standards to be exceeded. For further discussion of the geochemical interactions among water contaminants and formation fluids readers are referred to Longmire and others (1981), Longmire (1983, 1985), and Thomson and Heggen (1983).

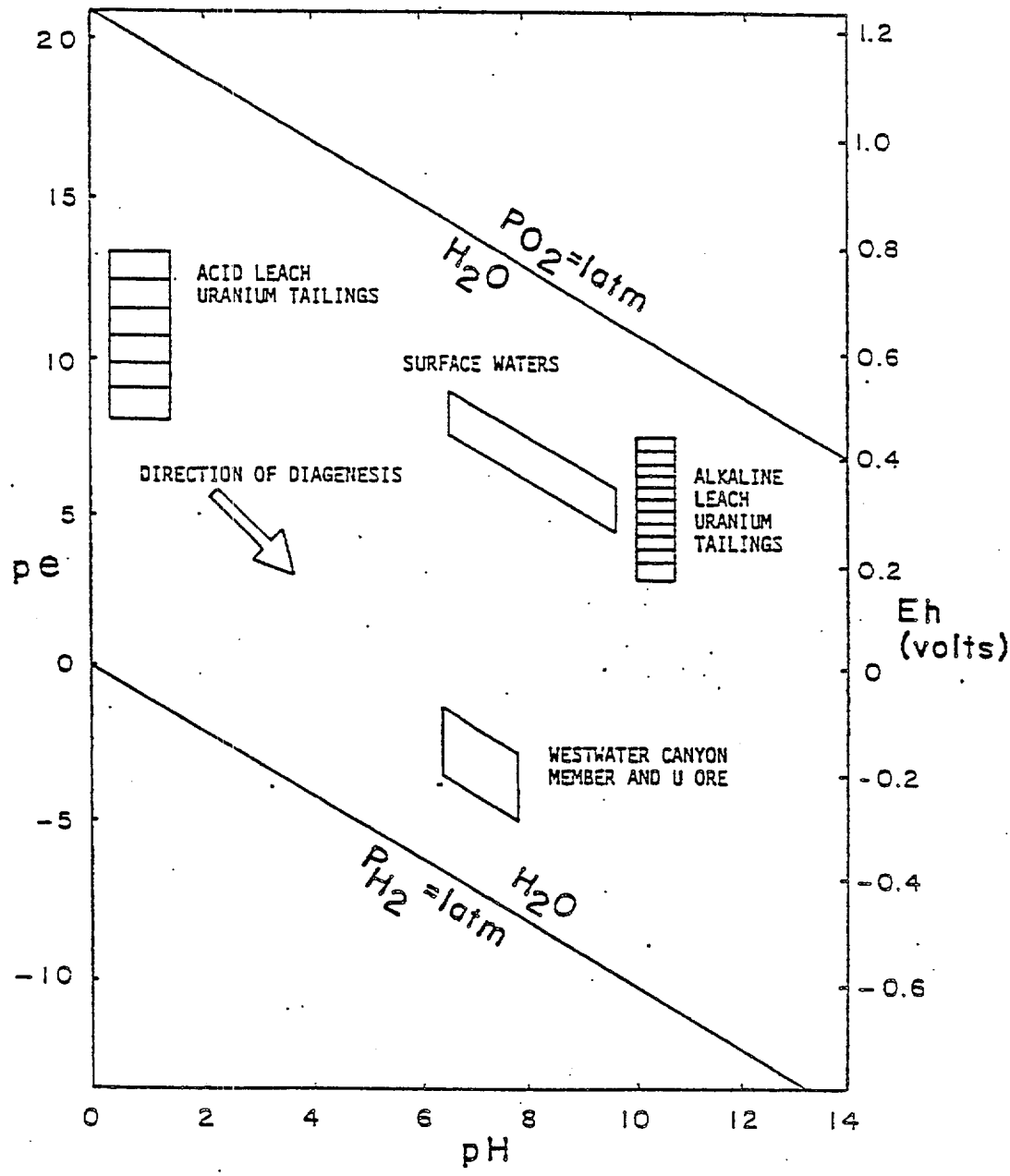


Figure 10. Eh-pH diagram showing typical areas for Westwater Canyon Member groundwater.

From Longmire (1983)

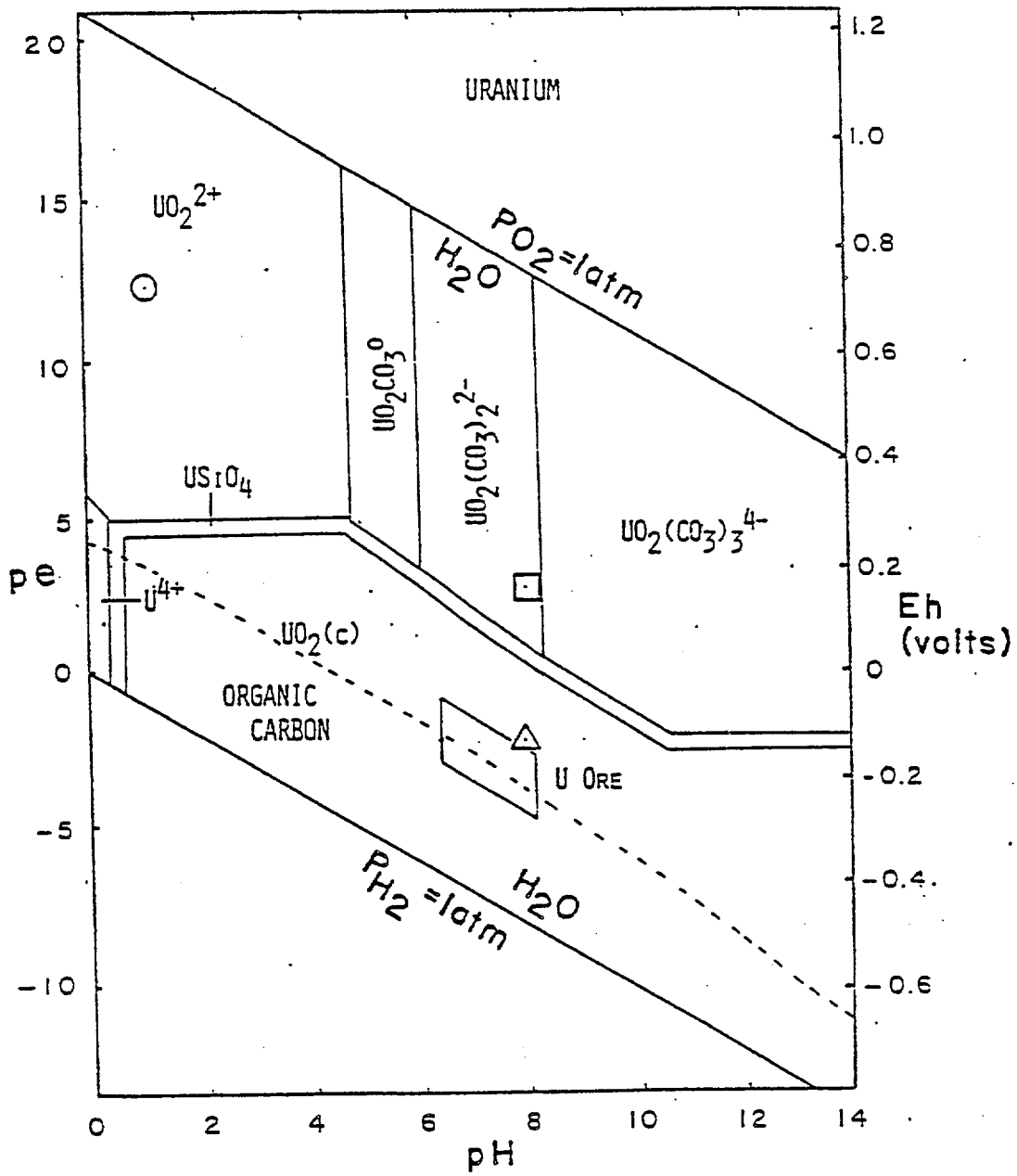


Figure 11. Eh-pH diagram for Uranium species.

From Longmire (1983)

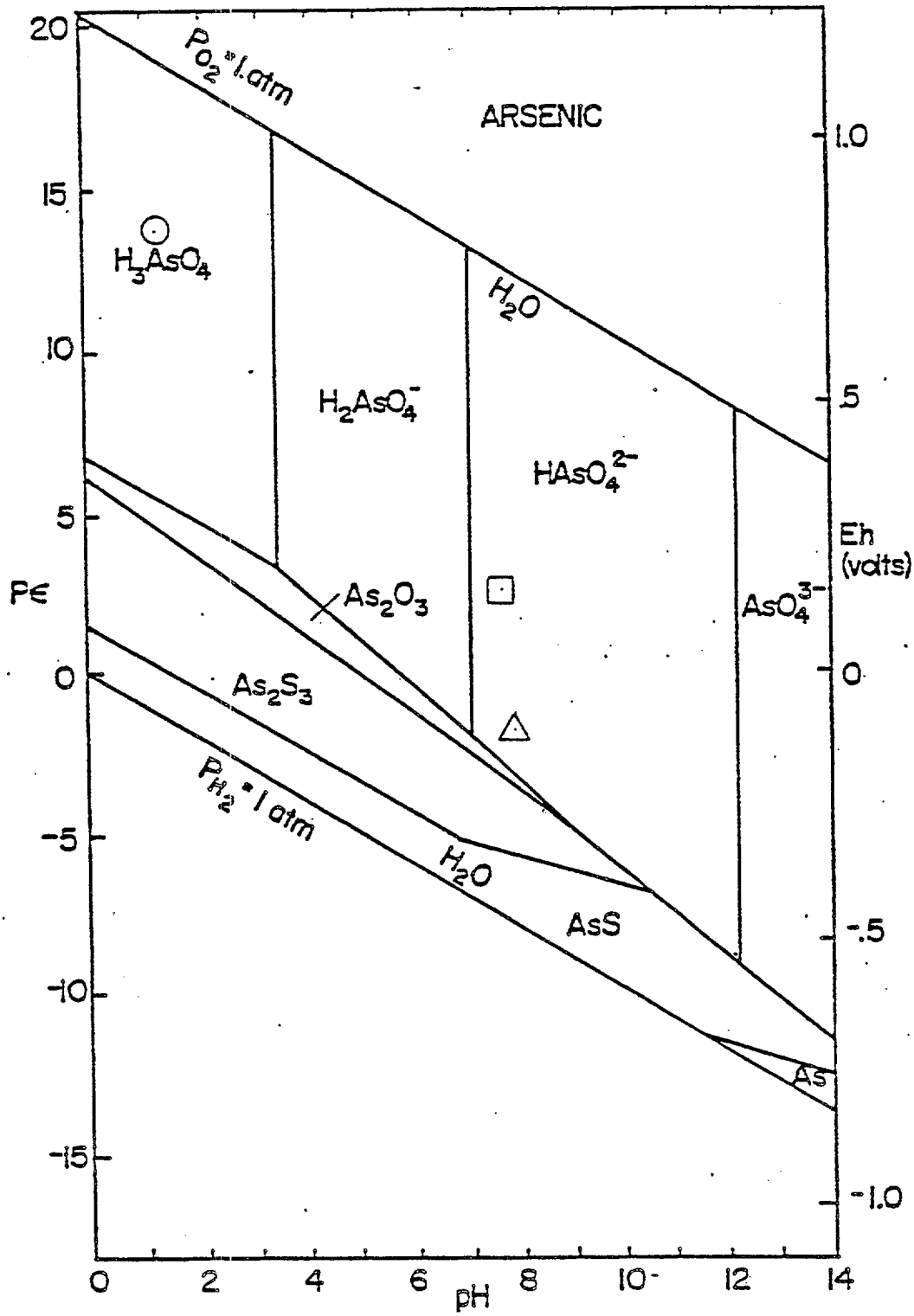


Figure 12. Eh-pH diagram for Arsenic.

From Longmire (1983)

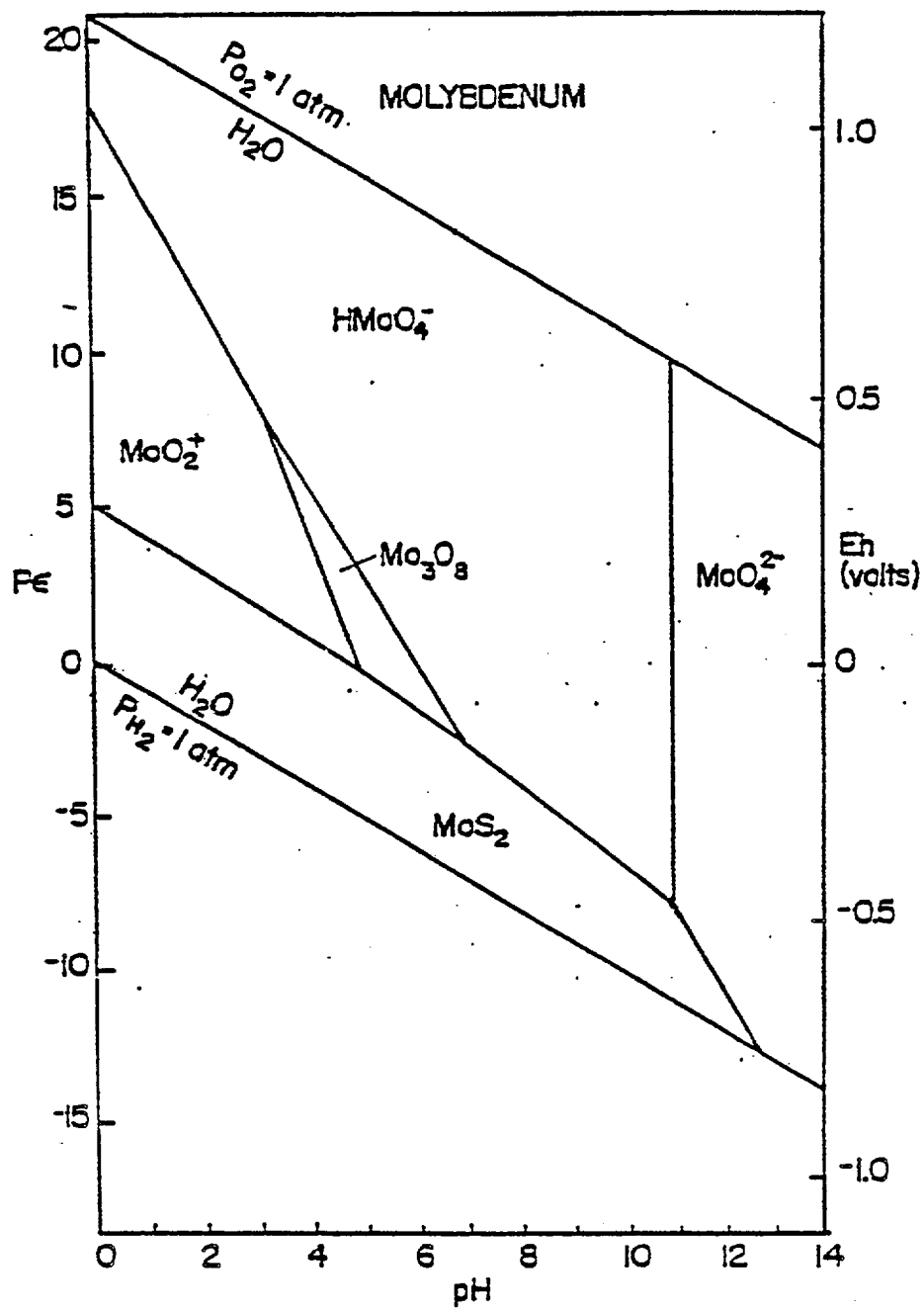


Figure 1 . pe-pH diagram for molybdenum species, total Mo = 10^{-6} M (prepared by P. A. Longmire, 1983).

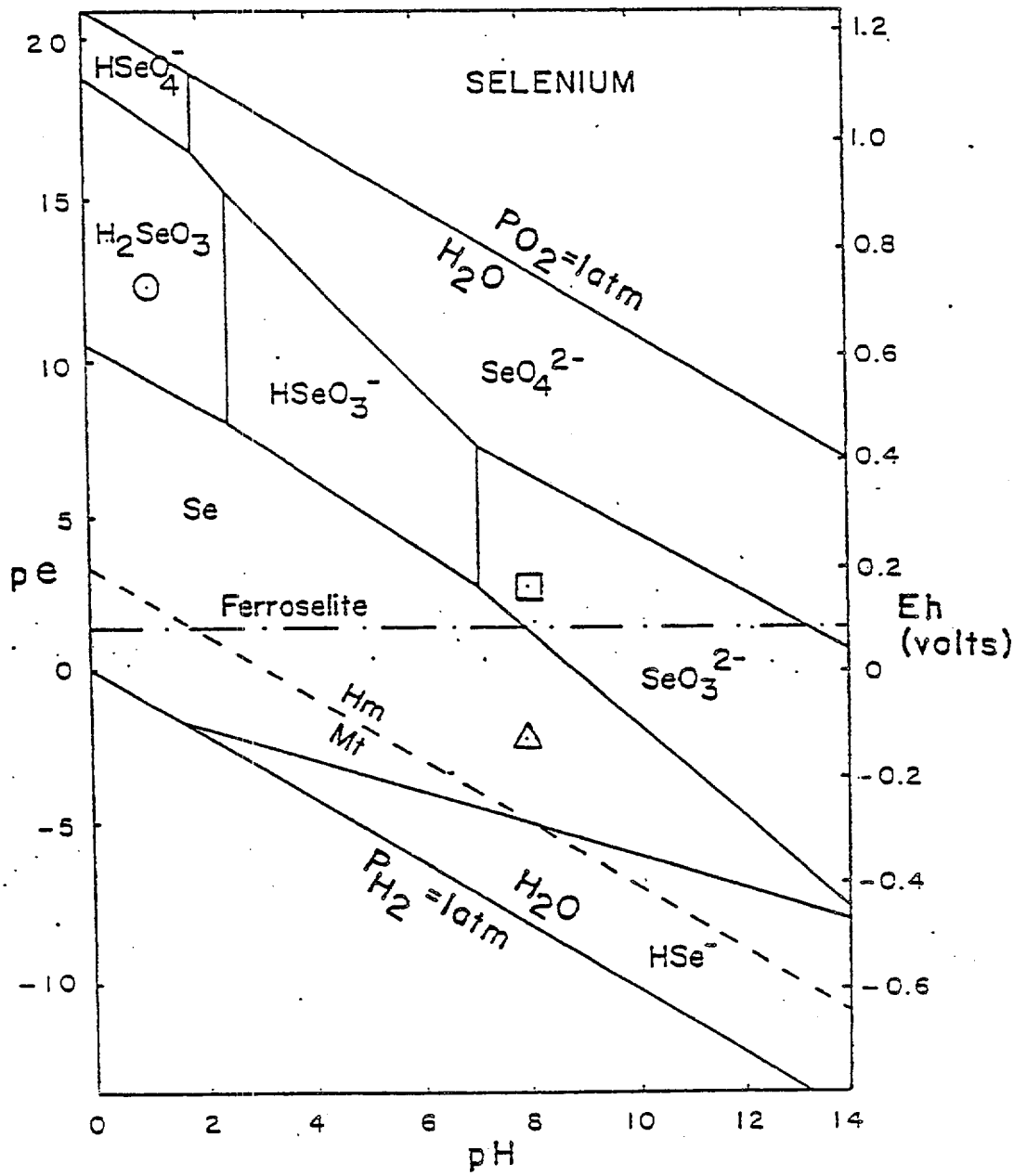


Figure 14. Eh-pH diagram for selenium.

From Longmire (1983)

*Table 7

Element	Prediction	Observation	Remarks
U	Retention	Retention/ Dilution	UO_2 and $(USiO_4)_{1-X}(OH)_{4X}$ are insoluble minerals.
U	Migration	Migration	UO_2^{2+} and uranyl carbonate complexes are soluble species in oxidized state.
S as SO_4^{2-}	Migration	Migration	SO_4^{2-} is a mobile species. However, retention expected in form of $CaSO_4 \cdot 2H_2O$ and Na_2SO_4.
Native S	Retention	Not observed	Not observed in GMB.
Fe	Retention	Retention/ Dilution	Possible precipitation as FeS_2, $FeCO_3$, $FeO(OH)$, $Fe(OH)_3$, and $K(FE)_3(SO_4)_2(OH)_6$.
	Migration	Migration	Fe^{2+} Fe^{3+}, and $FeSO_4^o$ complexes are mobile in acidic ground water.
Se	Migration	Migration	$H_2SeO_3^o$, $HSeO_3^-$, and SeO_4^{2-} are mobile in ground water. Sorption onto iron oxyhydroxide is possible.
	Retention	Retention/ Dilution	$FeSe_2$ and native Se are stable phases.
Mo	Retention	Retention/ Dilution	MoS_2 and Mo_3O_8 are stable phases.
As	Possible Retention	Possible Retention	Organo-As compounds may exist. Complex geochemistry is not completely understood.
Cr	Retention	Retention/ Dilution	Cr_2O_3 is stable phase in ground water.

*From Longmire (1983)

Table 7 (continued)

Element	Prediction	Observation	Remarks
Co	Retention	Retention/ Dilution	Co occurring as trace constituent in FeS_2.
Cu	Retention	Retention/ Dilution	CuS and Cu_2S are stable phases in anaerobic ground water.
	Retention	Retention/ Dilution	Incorporation in carbonate and sulfate cement and as trace constituent in PbS.
V	Retention	Retention/ Dilution	Occurs as trace element, which is effectively removed by milling process.
Mn	Migration	Migration	Occurs as Mn^{2+} below pH 9.6 at assumed activities.
	Retention	Retention/ Dilution	Stable as $MnCO_3$ above pH 9.6 at assumed activities. Sorption onto clay minerals and iron oxyhydroxides is possible.
Cd	Retention	Retention/ Dilution	Occurs as trace element in ground water. Sorption onto clay minerals, and iron oxyhydroxides is possible.
N	Mobile	Migration	Anions and neutral complexes are not significantly sorbed on substrates.
	Retention	Retention/ Dilution	NH_4^+ is strongly sorbed by clay minerals in anaerobic ground water.

4.0 FLOODING POTENTIAL

Backfill material is stockpiled near the mill facility and brought to the mines only when backfilling is proceeding. Backfill material at the mine sites is stored well above and away from flood zones. Therefore, surface flooding potential does not constitute a threat to backfill operations or ground-water quality at the mine site. Bostick (1985) discusses ground-water quality impacts from flooding at the mill site.

5.0 MONITORING REQUIREMENTS AND COMMITMENTS

QMC's current monitoring commitments for DP-264 are specified in the April 22, 1983 letter from W.J. Shelley (Kerr-McGee Vice President for Nuclear Licensing and Regulation) to Karl Souder (EID). These commitments are to report the following to EID on a quarterly basis: 1) Volumes and locations of backfill placed during the duration of DP-264. 2) A sample of slurry fluid to be taken every other month commencing in May 1983 and analyzed for Ca, K, Mg, Na, Pb, Se, As, Fe, Mo, Cl, NO_3, U, Ra-226, Ra-220, SO_4, CO_3, HCO_3. Should six consecutive analyses indicate that a constituent is not present in detectable quantities the analysis for the constituent will be discontinued in the future.

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