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July 21, 2000

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Mr. Philip Ting
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11545 Rockville Pike
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Rockville MD 80852

Subject: Groundwater Modeling Report for the Groundwater Corrective Action Program
Ambrosia Lake Facility
License No.: SUA-1473; Docket No.: 40-8905

Dear Mr. Ting:

Quivira Mining Co. (QMC) is submitting a groundwater modeling report following the submittal of the surety estimate and documents in a letter dated June 30, 2000 to NRC. The modeling report is attached to this letter, and it is titled *"Groundwater Modeling and Feasibility Analysis for the Application of Alternate Concentration Limits, Quivira Mill Site, Ambrosia Lake, New Mexico"*. QMC believes that this modeling report will satisfy the request by NRC in a letter dated January 5, 2000 that requested additional groundwater modeling to justify the basis for the proposed 1999 surety.

If you have any questions, please call me at (405) 858-4807.

Sincerely,

William Paul Goranson, P.E.
Manager, Radiation Safety, Regulatory
Compliance and Licensing

Enclosures

CC: Marvin Freeman, QMC
Terry Fletcher, QMC
Peter Luthiger, QMC
Russell Jones, Kerr-McGee

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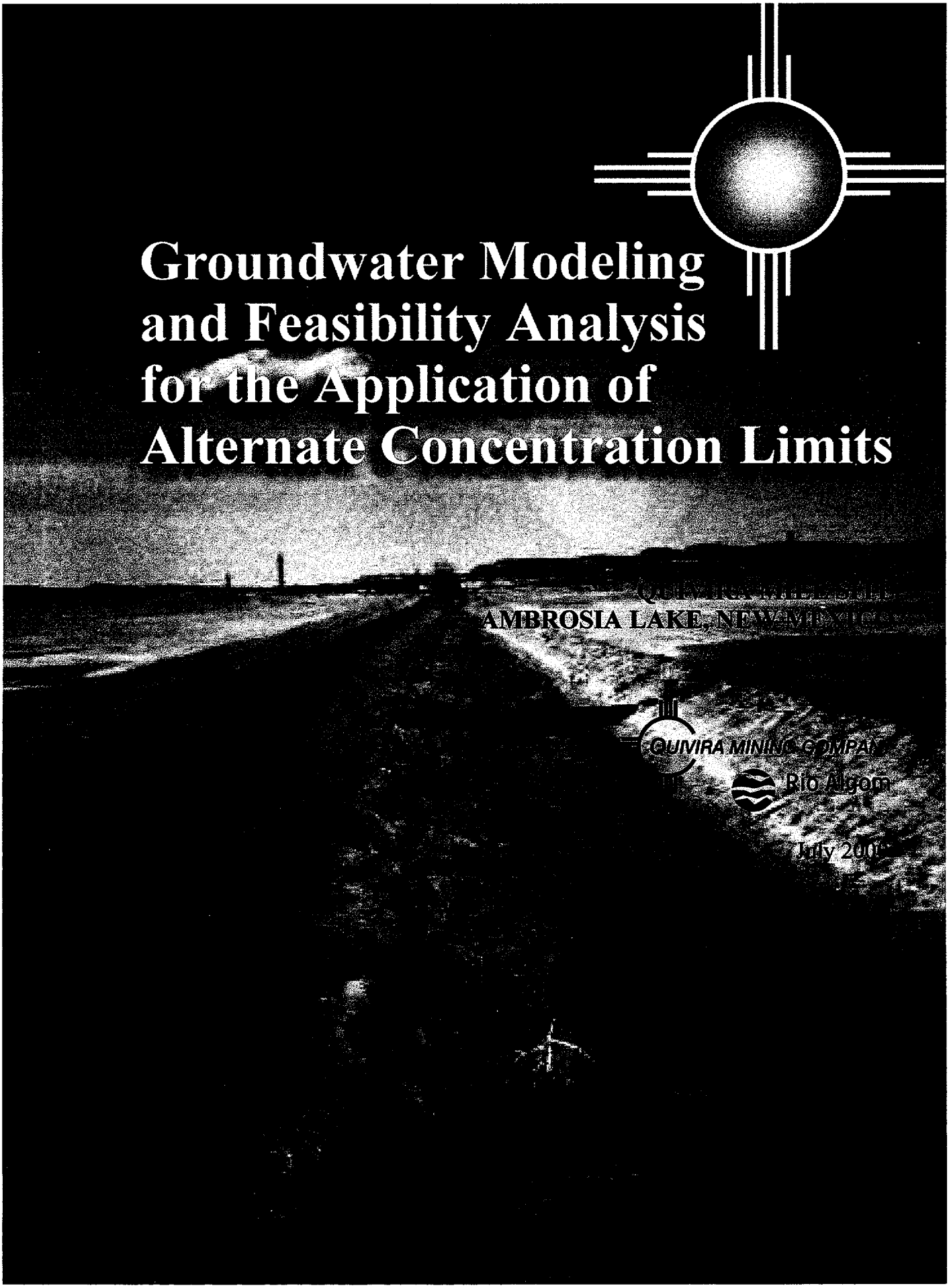
Groundwater Modeling and Feasibility Analysis for the Application of Alternate Concentration Limits



QUIVIRA MINING COMPANY

AMBROSIA LAKE, NEW MEXICO

QUIVIRA MINING COMPANY

Rio Algom

July 2001

Groundwater Modeling and Feasibility Analysis for the Application of Alternate Concentration Limits

QUIVIRA MILL SITE
AMBROSIA LAKE, NEW MEXICO

QUIVIRA MINING COMPANY

Rio Algom

July 2000

MAXIM

GROUNDWATER MODELING AND FEASIBILITY ANALYSIS FOR THE APPLICATION OF ALTERNATE CONCENTRATION LIMITS QUIVIRA MILL SITE AMBROSIA LAKE, NEW MEXICO

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GROUNDWATER MODELING AND FEASIBILITY ANALYSIS FOR THE APPLICATION OF ALTERNATE CONCENTRATION LIMITS QUIVIRA MILL SITE AMBROSIA LAKE, NEW MEXICO

1.0 INTRODUCTION

1.1 APPROACH

In order to address the request for proposal from Quivira Mining Corporation (QMC), dated February 29, 2000, Maxim Technologies, Inc.® (Maxim) developed a task-based approach to address project requirements, groundwater modeling and the feasibility of the application of alternate concentration limits (ACLs) to the alluvium unit at the Quivira Mill site, Ambrosia Lake, New Mexico (Figure 1.1). The objective of the work is to evaluate long-term fate of groundwater impacts in the alluvial system, which will allow QMC to develop a cost for the continuing groundwater corrective action program (CAP) and ensure proper surety is in place. Additionally, the groundwater modeling will act as a basis to determine the feasibility of preparing an acceptable petition to the Nuclear Regulatory Commission (NRC) for release of the groundwater program under an ACL.

The tasks followed by Maxim in the preparation of this report were:

- Task 1 – Model the CAP "as is" and with modifications to support ACLs,
- Task 2 – Tools and information to be used for groundwater modeling, and
- Task 3 – Process for determining the feasibility of an ACL

QMC provided the following guidance relative to Tasks 1 and 2: *Perform groundwater modeling to predict the time to complete the recovery of the tailings plume using the current CAP for the alluvium, including an evaluation of the current and predicted rate of seepage from the tailings pile. Additionally, the modeling should consider the fate and transport of the contaminant plume with no active remediation [i.e. without any pumping]).* Maxim was also instructed to address the following considerations:

- *Effects and estimated rates of continued seepage from the covered tailings.*
- *Sources of regional groundwater recharge that may impact the CAP.*
- *The 1,000-year time period for long-term stability (for modeling purposes).*

- *The disposal limitations of the current evaporation ponds. Any alternatives or modifications to the water treatment/disposal method should be detailed enough to allow a reasonable cost estimate to be developed.*

Guidance supplied relative to Task 3 included: *Perform a feasibility study of an application for ACLs using modeling information performed in the above item and utilizing the distant point of exposure (POE) approach. The feasibility study should include the proposed ACLs at the point of compliance (POC) and the method to achieve groundwater protection standards at the POE.* Maxim was also instructed to address the following considerations:

- *The use of institutional controls such as land acquisition for development of a distant POE.*
- *Preliminary risk assessment and exposure modeling necessary for key contaminants to determine the feasibility of the ACL approach using the distant POE. This work can be performed under the assumption that institutional controls can be implemented to restrict access to the affected groundwater between the POC and POE wells.*

Tasks 1 and 2 focused on gaining an understanding of the current site conceptual model, developing and calibrating a two-dimensional MODFLOW model, and performing various corrective action simulations. Concurrent with and building upon Task 1 and 2 results, Task 3 focused on the feasibility of developing an ACL application within the framework of the NRC guidance. Task 3 evaluated the feasibility of technical approaches to support the ACL including a preliminary hazard assessment (source and contaminant characterization, transport assessment and an exposure assessment) and a preliminary corrective action assessment (current CAP performance, feasibility of alternate corrective actions, corrective action costs and benefits, and an ALARA demonstration). These evaluations will follow the NRC's ACL format guidance so that formalizing the feasibility analysis into an actual ACL application will not be problematic. The feasibility analysis paralleled the previous work performed on the "bedrock" ACL application for the purpose of consistency.

1.2 METHODOLOGY TO MODELING AND FEASIBILITY ANALYSIS

1.2.1 Modeling

Maxim developed a two-dimensional groundwater flow model with coupled particle tracking to evaluate the effectiveness of the current CAP within the alluvial system and provide an estimate of the time when the CAP should be complete. The model was based on the existing site conceptual model. The development of the model was carried out using the MODFLOW code.

Maxim designed the model to achieve the objectives stated in the QMC request for proposal for the Quivira facility, which were:

- *Predict the time to complete the recovery of the tailings plume using the current CAP, and*
- *Simulate the fate of the contaminant plume with no active remediation (i.e. closing the trenches, cutting current infiltration, and cutting flow of treated water to the redirected stream).*

The groundwater flow model was developed using Groundwater Vistas (Environmental Simulations, Inc.), a computer-aided design system for groundwater models. Groundwater Vistas uses a graphical interface to design the model grid, boundary conditions, and aquifer properties. The design is stored in a model-independent format that can be converted to one of several model-specific forms. By using Groundwater Vistas, the model boundaries and configuration can be readily altered if the scope of the project changes. This would include adding layers to the MODFLOW model in cases where that might be required.

Advective transport was simulated to identify groundwater flow paths under steady state non-pumping conditions using MODPATH. Simulation of advective transport was accomplished through the computation of path-lines and the position of particles at specified points in time as well as the discharge point coordinates and total travel time for each particle. This technique is termed *particle tracking*.

In the event the NRC requests a more robust treatment of contaminant transport, then a solute transport model can be developed and coupled to the existing flow model. This can be accomplished using a solute transport code such as MT3D[96], which is fully compatible with MODFLOW, because the groundwater flow model is developed independently from the solute transport model. The flow field from MODFLOW can then be imported into the solute transport model to simulate advection, dispersion, sink/source mixing, and chemical reactions (such as sorption and first-order irreversible decay).

1.2.2 ACL Feasibility Analysis

Maxim utilized a task-based approach to evaluate the feasibility of the application of ACLs. The approach paralleled the *Standard ACL Application Format* presented in the Staff Technical

Position for Title II Uranium Mills, U.S. Nuclear Regulatory Commission, January 1996. Maxim believes that evaluating the data against the NRC requirements will enable QMC to identify potential data gaps within the ACL process, and to formally proceed with the ACL application once identified data gaps were filled.

Results of the modeling simulations and the analysis of existing groundwater quality data were weighed against the NRC-specified data requirements presented in the above referenced NRC guidance document. The primary focus of the feasibility determination was on the ACL hazard assessment data requirements and the ACL corrective action assessment data requirements as presented below:

- Hazard Assessment
  - Source and Contamination Characterization
  - Transport Assessment
  - Exposure Assessment

- Corrective Action Assessment
  - Results of Corrective Action Program
  - Feasibility of Alternate Corrective Actions
  - Corrective Action Costs
  - Corrective Action Benefits
  - ALARA Demonstration
  - Proposed Alternate Concentration Limits
  - Proposed Implementation Measures.

ACLs require reasonable assurance that the source of the constituents of concern has been abated and those remaining constituents of concern will not be a threat to human health and the environment at the point of exposure within a specified time frame. The Hazard and Corrective Action Assessments present the core argument in making the ACL application to the NRC.

2.0 PHYSICAL SETTING AND SITE BACKGROUND

2.1 LOCATION

The facility is located approximately 20 miles due north of Grants, New Mexico in the Ambrosia Lake uranium-mining district. Uranium mining and milling operations, which began in the area in the mid-1950s, have created significant changes in the groundwater system in the area.

Dewatering from several mines and discharges of mine water and disposal of mill tailings and effluents at several facilities in the area have combined to alter the quantity, quality and pattern of flow of groundwater in the region.

2.2 SITE HISTORY

Activities at the site started in 1957. A water storage reservoir was constructed to contain mine water for mill use and unlined evaporation Ponds 4, 5, and 6 were constructed for evaporative treatment of mine water and mill effluents (Figure 1.1). Tailings Impoundments 1 and 2 were built in late 1958 along with Pond 3 located at the eastern toe of Tailings Impoundment 1 for decant of the tailings impoundments. The tailings were first produced in November 1958. The solid portions of the process were disposed through a slurry transfer system to the tailings impoundments, while the liquid fraction was transferred to evaporation ponds. Evaporation pond residues from Ponds 4, 5, 6, 7, and 8 were placed in Tailings Impoundments 1 and 2 or Pond 3 prior to final reclamation.

Seepage from the tailings impoundments and from evaporation Ponds 3 through 6 and discharge of treated mine water from the facility and seepage and discharges at other uranium mining and milling operations in the vicinity have recharged the previously dry portions of the alluvium of the Arroyo del Puerto. Seepage from the tailings impoundments and from evaporation Ponds 7 and 8 have also recharged the shallow sedimentary bedrock units that outcrop at the facility, including the Tres Hermanos sandstones occurring within the Mancos Formation and the Dakota Sandstone, which underlies the Mancos Formation. These sedimentary rocks dip gently to the northeast. The bedrock units located stratigraphically below the Dakota Sandstone are the Brushy Basin and the Westwater Canyon members of the Morrison Formation, the latter being the uranium ore bearing unit in the Ambrosia Lake area. Figure 2.1 shows a generalized cross section through the Ambrosia Lake area. The Westwater Canyon member in the vicinity of the facility has been de-watered by historic and on going mine dewatering operations. Furthermore, the bedrock formations above the Westwater Canyon Member have been drained in the locations north and northeast of the facility by the numerous ventilation holes, mine shafts and fractures induced by subsidence into the underground mine workings.

Tailings Impoundments 1 and 2 and the unlined evaporation Ponds 7 and 8 overlie bedrock while unlined Ponds 3, 4, 5, and 6 were located within the alluvium of the Arroyo del Puerto. The unlined evaporation Ponds 4, 5, and 6 were not used during the years 1960 to 1975. Instead, the water was diverted to ponds atop Tailings Impoundments 1 and 2 and to the unlined evaporation Ponds 7 and 8 which were built in 1961. During this 15-year time span when unlined evaporation Ponds 4, 5, and 6 were not used, the channel and alluvium of Arroyo del Puerto continued to receive water from solutions seeping from Tailings Impoundments 1 and 2 and Pond 3 and from the continued discharge of treated mine water. The infiltration and percolation of this water created an area of saturation along the stream channel, slowly saturating the alluvium.

In 1976, the natural stream course of the Arroyo del Puerto, which carried National Pollution Discharge Elimination System (NPDES) permitted mine water discharge, was diverted from its natural course just east of Pond 3 to its current location along the northern and eastern restricted area boundary. This placed the Arroyo del Puerto channel to the north and east of the unlined Ponds 4, 5, and 6, and also east of the lined Ponds 9 and 10, which were constructed in 1976. Following the channel relocation, unlined Ponds 4, 5, and 6 were placed back into service to hold and evaporate excess process solutions.

In 1983, QMC entered into an assurance of discontinuance (AOD) with the State of New Mexico to minimize the future impact of mill tailings solutions seeping into the alluvium. The approved AOD remedial action plan required the construction and maintenance of an Interceptor Trench (IT-1 and discontinuing the use of all unlined evaporation ponds, including Ponds 4, 5, 6, 7 and 8). These ponds were permanently taken out of service in 1983 with all solutions removed.

The purpose of interceptor trench IT-1 was to prevent tailings seepage from entering the alluvium and to create a local hydrologic gradient towards the trench. This gradient caused the solutions in the alluvium located to the east of the interceptor trench, to flow towards the trench for recovery and removal from the unit. Construction of the trench was initiated in 1984. Alluvium material was removed down to the underlying Mancos shale or sandstone contact. The completed trench extends approximately 6,200 feet on the down dip gradient side of Tailings Impoundment 1 along the northern, eastern, and southern toe of the pile.

Completed to a maximum excavation depth of 36 feet, the trench has effectively captured seepage from the tailings impoundment and thereby preventing further migration of seepage to the alluvium. Due to the depth of excavation, the hydrologic gradient in the area east of the interceptor trench, has been reversed from its normal easterly direction to a westerly gradient. This reversed gradient created by the interceptor trench combined with the recharge of the fresh water from the re-aligned channel of the Arroyo del Puerto has been effective in flushing the alluvium in the vicinity of the former Ponds 4, 5 and 6.

2.3 GROUNDWATER PROTECTION PROGRAM

On June 1, 1986, the State of New Mexico relinquished its licensing authority over uranium milling activities. The NRC reasserted its regulatory jurisdiction over New Mexico uranium processing facilities. As a result of the new regulatory jurisdiction, QMC submitted a detection monitoring plan to the NRC on January 29, 1988 for the hydrogeologic units that could potentially be impacted by processing of uranium ore and disposal of by-product material at the facility. The hydrogeologic units addressed by the groundwater protection program were the Tres Hermanos A Sandstone Unit (TRA), the Tres Hermanos B Sandstone Unit (TRB), the Dakota Sandstone Unit (Dakota) and the alluvium of the Arroyo del Puerto (alluvium). The Detection Monitoring Plan was submitted pursuant to the NRC's newly adopted 10 CFR 40, Appendix A, Criteria 7 regulations that had became effective on December 14, 1987. Upon plan approval, the NRC established its groundwater protection program for the facility.

Following the review of data from the groundwater detection monitoring program sampling events, the NRC established groundwater protection standards (GPSs) for hazardous constituents in groundwater at the POC wells for the TRA, TRB, Dakota and the alluvium. The GPS for all hazardous constituents, except combined radium were set at "background" concentrations determined from sampling events in October 1988 from one background well in each of the aquifers.

2.3.1 Alluvium Groundwater Corrective Action Program

Prior to mining, the alluvium within the Ambrosia Lake valley was dry. With the commencement of mining activities in the area during the 1950s, dewatering of the mines

resulted in two actions: 1) development of a cone of depression within the underlying geologic units (Tres Hermanos, Dakota and Westwater); and 2) recharge into the alluvium. Corrective actions that QMC initiated to mitigate water migration were: 1) re-alignment of the Arroyo del Puerto in 1976 to divert surface water flows around the evaporation ponds; 2) discontinued use and removal of ponded solutions from all unlined evaporation ponds; 3) construction of an intercept trench adjacent to Tailings Impoundment 1. As a result of the intercept trench forming a reverse hydraulic gradient within the alluvium, the NPDES discharge water infiltrates and flushes the alluvium from the NPDES creek towards the intercept trench; resulting in improved water quality within the impacted alluvium.

During the period of July 1998 through June 1999, in excess of 82 million gallons of water consisting of impacted water and the groundwater sweep program were recovered and removed from the alluvium via the intercept trench and disposed within lined evaporation ponds. This volume also included storm water runoff that accumulated within the trench.

In addition to the flushing action, geochemical processes also act upon the water present within the alluvium (explained fully in Section 6.4). This results in neutralization of the water and reduced solubility of parameters. The corrective actions described above for the alluvium are currently in operation.

2.4 SURROUNDING LAND AND WATER USE

Utilization of groundwater in the Ambrosia Lake area can be divided into two categories: 1) irrigation and 2) domestic/stock watering. Neither irrigation nor domestic/stock watering wells in the vicinity of the tailings impoundments are completed in the alluvium. The alluvium is not capable of providing sufficient water for use because it is not saturated anywhere except within the vicinity of the QMC facility and the US Department of Energy (DOE) tailings impoundment. Groundwater corrective action compliance and license termination was obtained by the DOE at their facility through the application of Supplemental Standards, demonstrating that the alluvium is not, and never was, an aquifer because of limited yield.

A listing provided by the US Geological Survey (USGS 1998) shows approximately 65 groundwater wells within a 25-mile radius of the facility. The closest groundwater supply well is

completed in the Westwater Canyon Sandstone Member of the Morrison formation at a location approximately 1.5 miles west of the tailings impoundment.

There has been a large reduction in water use and groundwater withdrawals in the area over the past 10 to 15 years because of poor economic conditions associated with the decline of the uranium industry. The current economic base in the Ambrosia Lake area is reclamation at the Facility and ranching. The area is very sparsely populated and the population is declining. Projecting into the future, with facility reclamation nearing completion, any increased use of groundwater in the Ambrosia Lake area in the vicinity of the tailings impoundment is highly unlikely.

3.0 GEOLOGY

3.1 REGIONAL GEOLOGY

QMC's Quivira 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 subject of this evaluation), the Mancos shale and Tres Hermanos sandstones, the Dakota Sandstone, the Brushy Basin and the Westwater Canyon members of the Morrison Formation. The ore-bearing unit in the vicinity is the Westwater Canyon. The bedrock formations above the Westwater Canyon Member of the Morrison Formation have essentially been dewatered by ventilation holes and mine shafts located to the north and east of QMC's mill and tailings facility. The units that have been affected by milling activities are the alluvium, Tres Hermanos B sandstone, and the Dakota sandstone.

3.2 LOCAL GEOLOGY

The mill site and Tailings Impoundments 1 and 2 are located on the weathered Mancos Formation (saprolite) or on alluvium overlying the Mancos section. The alluvium consists of clay and clayey sand derived from reworked Mancos Formation. The bedrock units that have been impacted by tailings seepage include the Dakota Sandstone which outcrops at Pond 7 and 8,

and the TRB which underlies the saprolite throughout most of the location of Tailings Impoundments 1 and 2. Most of the seepage from Tailings Impoundments 1 and 2 migrates laterally through the alluvium and shallow saprolite in the direction of the surface slope to the alluvium of Arroyo del Puerto where it enters the interception trench. The seepage that enters the unweathered bedrock beneath Tailings Impoundment 1 and 2 slowly migrates through the TRB to the north and northeast of the Facility in the general direction of the dip. The dewatering trench located between Pond 7 and Pond 2 has minimized any tailings seepage to the TRA, which underlies the saprolite and alluvium in the general vicinity of Pond 7.

4.0 HYDROGEOLOGY

This section presents the background hydrogeologic information and a conceptual model of the physical flow system. Included are discussions of surface water and groundwater flow within bedrock and alluvial hydrostratigraphic units, with emphasis on the alluvial system. Figure 2.1 is a west to east cross-section through the study area showing key components of the conceptual model of near surface groundwater flow system.

4.1 BEDROCK UNITS

Principal near-surface bedrock hydrogeologic units beneath the site include the TRA, TRB and the Dakota Sandstones. Mancos shale serves as aquitards that separate these water-bearing units. Hydrogeologic characteristics of near-surface bedrock units are described in detail in AVM (2000) and are summarized below.

4.1.1 Groundwater Flow

Groundwater flow within bedrock units is generally down-dip, toward the north-northeast. One exception to this is a small portion of TRB in the southwest portion of the study area. Interception trenches IT-2 and IT-3 (Figure 1.1) intercept water flowing in the TRB to the east from beneath Tailings Impoundment 1.

A regional cone of depression has formed within bedrock units beneath the site resulting from the dewatering of mines through vent holes and mine shafts the dewatering of mines (Quivira 1986). Bedrock units are recharged where they crop out or where they are covered by alluvium.

4.1.2 Aquifer Characteristics

AVM (2000) reports transmissivity values for TRB and Dakota of 4.7 square feet per day (ft^2/d) and 13 ft^2/d, respectively

4.2 ALLUVIAL SYSTEM

This section discusses the hydrogeology of the alluvial flow system. Figure 4.1 is a water table map for the alluvial system based on average second half 1999 groundwater elevations measured in representative water table wells. Prior to mining activity, the alluvial system in the area was unsaturated (Quivira 1986). Recharge to the alluvium related to mining activity has resulted in an unconfined saturated near-surface groundwater flow system.

4.2.1 Groundwater Flow

Current groundwater flow in the alluvial system is generally to the southeast with a gradient of approximately 0.006. A groundwater mound has formed in the northern portion of the study area, caused by infiltration from the Arroyo del Puerto bypass channel. North of this mound, groundwater flows north toward mine shafts and vent holes located in Section 30. South of the mound groundwater flows toward the northern half of trench IT-1, creating the "groundwater sweep". Groundwater seeping from Tailings Impoundment 1 flows east toward trench IT-1. At the southern end of IT-1, groundwater flows from Tailings Impoundment 1.

4.2.2 Aquifer Properties

Estimates of hydraulic conductivity for the alluvium range from 0.6 feet per day (ft/d) based on pumping tests performed in wells AW-1 and AW-2 (Quivira 1986), to 20 ft/d based on lithologic descriptions in monitoring well logs. Based on the lithology of the alluvium, porosity is estimated to range from 0.15 to 0.25 (Fetter 1989). Specific yield estimates range from 0.10 to 0.20.

4.2.3 Recharge and Discharge

Prior to mining in the area, natural sources of recharge to the alluvial system were insufficient to establish saturated conditions within the alluvium. Therefore natural sources of recharge such as infiltrating overland flow and drainage are insignificant. Two principal sources of recharge to the system are currently maintaining the saturated condition:

- Infiltration of water from the Arroyo del Puerto bypass channel
- Leakage from Tailings Impoundment 1

Groundwater exits the alluvial system at the northern and eastern margins of the study area where vent holes and mine shafts intersect the water table. Alluvial groundwater also exits the southern end of study area as underflow beneath the Arroyo del Puerto through a narrow gap in bedrock.

Hydraulic gradients between the alluvial system and subcropping Tres Hermanos units are generally downward indicating some groundwater is probably moving from the alluvial system into subjacent sandstone units. This concept is supported by the water budget analysis discussed below.

4.3 SURFACE WATER

Prior to mining activity, the Arroyo del Puerto was an ephemeral drainage. Flow in the creek occurred only in response to large rainfall or snowmelt events.

Currently, the creek is dry until it reaches the B-3 discharge point (Figure 1.1). During 1999 an average of 337,000 ft^3/d of treated mine water was discharged to the Arroyo del Puerto channel at the B-3 discharge. Some water was diverted then from the creek for mine injection. Since January 2000 an average of 125,000 ft^3/d of treated mine water has been released to the Arroyo del Puerto channel at the B-3 discharge and no water has been used for mine injection. Between the B-3 discharge point and the Puertocito Creek weir water leaks from the creek. This leakage is the primary source of recharge to the alluvial groundwater system in the site.

5.0 NUMERICAL MODELING

In order to meet the project objectives, a numerical model of groundwater flow was developed based on the information and conceptual model presented in Section 4.0. This section describes methods used to design and calibrate the groundwater flow model and results of particle tracking.

5.1 MODEL DESIGN

This section describes design elements needed to simulate groundwater flow using MODFLOW including the development of a finite-difference grid, boundary conditions, and initial aquifer parameters assigned to the model.

5.1.1 Model Area and Grid

The model area selected includes roughly the saturated extent of alluvium excluding the area beneath Tailings Impoundment 1 (Figure 5.1). A small portion of TRB adjacent to the southeast corner of Tailings Impoundment 1 was included because groundwater collected by trench IT-4 and portions of IT-2 and IT-3 come from saturated TRB in that area. Groundwater flow directions in that area suggest that this wedge of TRB is in direct communication with the alluvial system.

A finite difference grid was fit to the area of interest (Figure 5.2). The grid has 120 rows and 61 columns with a uniform grid-spacing of 100 feet. The model has one layer that is MODFLOW Type-1 (unconfined)

5.1.2 Water Budget

In order to estimate model inputs, a water budget was estimated for the alluvial groundwater system based on current conditions. This water budget is summarized below.

Current inflows and outflows to the alluvial system were estimated using 1999 data. Infiltration from Arroyo del Puerto was estimated based on documented water losses from the creek. The influx from Tailings Impoundment 1 was estimated based on modeling results presented in Quivira (1986) and using Darcy's Law. Underflow through the southern end of the model area and drainage to mine shafts vents and was estimated using Darcy's Law. Fluxes removed from

trenches IT-1 through IT-4 were based on 1998 and 1999 monthly data. Differences between inflows and outflows were assumed to represent drainage to TRA and TRB. Flux estimates are summarized below.

	Low (ft^3/d)	High (ft^3/d)	Estimated Flux(ft^3/d)
IN			
Arroyo and Infiltration	81,620	163,423	119,850
Influx from Tailings Impoundment 1	3,000	12,000	8,000
Total In:	**84,620**	**175,423**	**127,850**
OUT			
Underflow to South	350	14,000	12,000
Trench IT-1	12,512	77,000	14,000
Trench IT-2	96	231	149
Trench IT-3	1,020	2,312	1,328
Trench IT-4	424	2349	543
Infiltration to mineshafts & vents	20,000	60,000	48,000
Total Out:	**34,402**	**155,891**	**76,020**
Infiltration to Bedrock Units:			**51,830**

5.1.3 Boundary Conditions

Figure 5.2 shows finite difference grid and various MODFLOW boundary conditions. Infiltration is simulated using Recharge cells. Influxes from the Arroyo del Puerto and Tailings Impoundment 1 are simulated as constant flux boundaries using Well Package cells. Underflow to the south, drainage to the mine vents and TRA and TRB and water removed from the infiltration trenches were simulated with Drain Package cells.

5.1.4 Initial Parameter Assignments

Hydraulic conductivity values were assigned to the alluvial cells uniformly using values in the middle of the estimated range (5 ft/d). TRB cells were given values of 1 ft/d. Initial fluxes for the Arroyo del Puerto and tailing impoundment 1 and recharge from infiltration were average or representative values from the table above. Conductance for drains were estimated based on a

hydraulic estimates. For transient runs, porosity and specific yield were estimated at 0.2 and 0.14, respectively.

5.2 CALIBRATION

This section describes methods used to calibrate the numerical model and results of the calibrations. The model was calibrated to "steady state" conditions based on 1999 data. This made calibration somewhat problematic, since the water table has been dropping in many portions of the site for several years and the alluvial groundwater flow is not in equilibrium.

5.2.1 Calibration Methods

We used both qualitative and quantitative methods to judge calibration results of the numerical model. The qualitative method involved visual comparison between contour maps of measured and simulated heads. Quantitative methods used to evaluate model calibration included comparison of simulated heads to measured heads at target locations and comparison of simulated groundwater fluxes to measured and estimated fluxes.

Average second half 1999 head values were contoured in accordance with the conceptual model (Figure 4.1) and the resulting potentiometric surface is the qualitative calibration target. Quantitative calibration targets for head are water table elevations measured in alluvial wells with screens across the water table during second half 1999. Error associated with these targets is estimated to be at least ± 2.5 feet. Sources of error include measurement error, interpolation error and scaling effects.

The following calibration objectives were established for our numerical model:

- The model must produce simulated potentiometric contours that generally resemble measured head contours, and
- The model should produce simulated heads and fluxes that generally fall within calibration target ranges.

Model parameters were subsequently adjusted using trial-and-error procedures in an attempt to accomplish the above objectives. Hydraulic conductivity values, recharge rates, and conductance of drains were systematically adjusted to produce simulated potentiometric surfaces

that resembled potentiometric maps drawn using field-measured heads. After each calibration run, we calculated the residual at each target node. Residual is the difference between the measured heads and simulated heads at target nodes. Residual statistics were used as one criterion to judge the degree to which calibration of the model improved through successive runs.

While calibrating the flow model, parameters with a higher degree of uncertainty (estimates having no field measurements to back them up, e.g. conductance of TRB) were adjusted before adjusting parameters with a lower degree of uncertainty (estimates based on field measured values, leakage from Arroyo del Puerto).

5.2.2 Preliminary Calibration Results

Figure 5.3 shows preliminary model calibration results. Contours show simulated head elevations. Residual at each target location is also posted on the map. Comparison of Figure 5.3 to Figure 4.1 shows that qualitatively, simulated heads generally match field-measured heads. The following is a comparison of estimated fluxes to calibrated flux values.

	Estimated Flux (ft^3/d)	Calibrated Flux (ft^3/d)
IN		
Arroyo infiltration	119,850	115,089
Influx from Tailings Impoundment 1	8,000	8,237
Total In:	127,850	123,326
OUT		
Underflow to South	12,000	12,331
Trench IT-1	14,000	16,119
Trench IT-2	149	220
Trench IT-3	1,328	675
Trench IT-4	543	459
Infiltration to mineshafts & vents	48,000	47,726
Infiltration to Bedrock Units	51,830	45,798
Total Out:	127,850	123,328

5.3 PARTICLE TRACKING AND TRANSIENT MODELING

This section presents the results of transport analyses using particle tracking methods. It includes transient modeling to assess CAP effectiveness and long-term transport at the site.

5.3.1 Steady State Transport

Based on preliminary calibrated model parameters, the average linear groundwater velocity at the site is approximately 0.5 feet per day. Figure 5.4 shows particle traces from MODPATH depicting transport directions for the alluvial system under steady state flow conditions. This figure shows that most particles originating in Tailings Impoundment 1 are captured by trench IT-1. Particles from the south end of Tailings Impoundment 1 are transported past the southern end of IT-1 but many of these particles are captured by trench IT-3 and TRB drain cells. Particles north of the Arroyo del Puerto end up in drains representing mine vents and shafts to the north. Particles south of the west end of the Arroyo del Puerto bypass channel end up in trench IT-1. Particles south of the first 90-degree bend in the bypass channel end up infiltrating to TRB. Particles originating in the southern half of the model that do not infiltrate to TRA or TRB are transported out of the southern model boundary.

5.3.2 Transient Flow Modeling

In order to assess the effectiveness of the CAP and to estimate the time required to capture contaminant plumes, the calibrated flow model was run in transient mode under two scenarios. The first scenario maintained the fluxes used in the steady state calibration for the Arroyo del Puerto. Decreasing flux from Tailings Impoundment 1 was simulated by estimating the volume of water remaining in the impoundment and decreasing fluxes logarithmically over 100 years so that the cumulative flux over that period equaled the estimated volume remaining in the pile. The actual time required for Tailings Impoundment 1 to drain is unknown and 100 years was assumed to be a conservative estimate. The model was then run over 10 stress periods (10 time steps each, with a 1.2 time step multiplier) for a period of 1,000 years.

A second scenario was simulated to assess the affects of discontinuing the current CAP. Under this scenario, constant flux boundaries representing the Arroyo del Puerto infiltration and drain cell boundaries representing interception trenches were removed from the model. Declining flux from Tailings Impoundment 1 were simulated as described in the paragraph above. The model was then run over 10 stress periods 1,000 years.

Preliminary results of the 1,000 year transient run simulating operation of the current CAP results in a water table that looks very similar to Figure 5.3 with the exception that water table elevations southeast of Tailings Impoundment 1 are slightly lower.

Figure 5.5 shows preliminary results of the discontinued CAP transient scenario after 65 years. Figure 5.5 indicates that after 65 years most of the alluvial system is dewatered. At 65 years, only four feet of saturation remains at the southern model boundary and relatively little water is discharging as underflow in the alluvium.

5.3.3 Transient Particle Tracking

The 1984 chloride plume was selected as being representative of the extent of alluvial groundwater affected by mill activities. To estimate the time required for plume capture under the current CAP, particles were input to the model in the area encompassed by the greater than 200 mg/L line on the 1984 chloride plume map (See *Section 6*). Particles representing mass in groundwater from Tailings Impoundment 1 were input along the flux boundary representing the impoundment at time = 0 days and at the end of each stress period in which water drained from the impoundment. Particles were tracked over a 1,000-year period.

To estimate the time required to capture the plume under the discontinued CAP scenario, particles were input to the system as described above and particles were also tracked for 1,000 years.

Transient pathlines for the current CAP scenario are presented in Figure 5.6. MODPATH output indicates that approximately 44 years were required for all the particles representing the current plume in the alluvial system to be captured or removed from the system. More than 100 years were required to capture particles within the TRB included in the southwest portion of the model domain. More than 200 years could be required to capture all contaminants coming from Tailings Impoundment 1. This assumes advective transport velocities, which would be representative of the least retarded species (chloride). Other more retarded species would require more time. In addition, due to heterogeneities and preferential flow paths present in real systems, practical experience indicates that approximately 4 to10 pore volumes would be required to remove 100 percent of contaminant mass from the system.

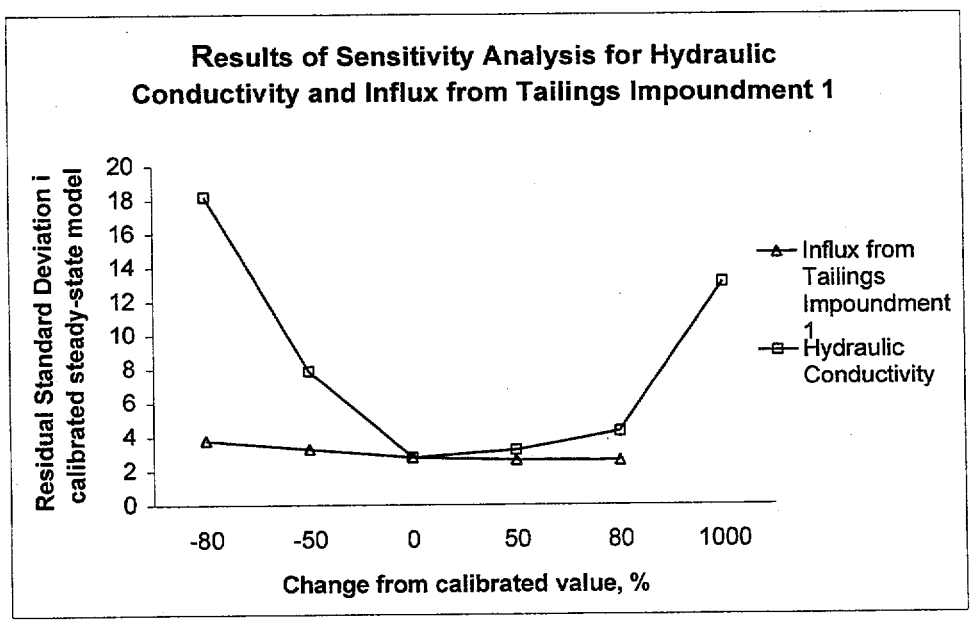
Transient pathlines for the discontinued CAP scenario are presented in Figure 5.7. It is difficult to assess the time required for complete capture of particles under the discontinued CAP scenario due to numerical issues after 200 years as model cells go dry. MODPATH results show that particles remain in TRB portion of the model domain after 1,000 years. However, this water is stagnant and trapped by dry cells within the model.

5.4 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to identify which parameters most influence model results. The sensitivity analysis also helps to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of model parameters. The parameters included in the sensitivity analysis included hydraulic conductivity, influx from Tailings Impoundment 1, and the porosity of the alluvium.

Calibrated values of hydraulic conductivity and the influx from Tailings Impoundment 1 were increased and decreased by constant multiples and input to the steady state flow model. The resulting standard deviation of head residual, also known as the root mean squared error (RMSE) was noted for each model run. The graph below summarizes the results of this analysis.

Results of the sensitivity analysis show that the model is most sensitive to changes in hydraulic conductivity. Most notably, decreases in hydraulic conductivity values. Varying influx from the Tailings Impoundment 1 had relatively little effect on the calibration of the model.



Porosity values for the alluvium were varied to demonstrate how porosity effects model results for travel time through the model area. The following is a summary of the results of this analysis.

Porosity	Approximate time required for total particle capture from entire model domain
0.10	42 years
0.20 (calibrated value)	111 years
0.30	182 years

Changes in porosity values showed a direct influence on travel times of particles through the system. This is expected because travel time is directly proportional to porosity (Fetter, 1989).

5.5 MODEL LIMITATIONS

The numerical groundwater model described in this report was developed to serve as an interpretive and predictive tool. The model was generally able to simulate a pre-established set of hydraulic and solute transport conditions, which indicates the calibrated model is reliable.

Limited site-specific data were available regarding aquifer parameters. Attempts to calibrate the model using hydraulic conductivity values from pumping tests performed on alluvial wells were unsuccessful.

Inherent in any modeling effort is a degree of uncertainty. In developing the groundwater model, we used simplifying assumptions such as:

- Groundwater flow is horizontal and isotopic,
- Hydraulic conductivity of alluvium is uniform, and
- Natural recharge from precipitation is negligible.

This work was performed in accordance with the generally accepted practices of other consultants undertaking similar studies at this time. In completing this project, Maxim observed the degree of care and skill generally exercised by other consultants operating under similar circumstances and conditions. Maxim's findings and conclusions must be considered not as scientific certainties, but as opinions based on our professional judgement concerning the

significance of the data gathered during the course of the evaluation. Other than this, no warranty is implied or intended.

6.0 GEOCHEMISTRY

The purpose of this section is to delineate the areas where site related constituents exist, document the individual chemical constituents that contribute to constituent mass, and estimate the constituent mass that exists in groundwater as a result of uranium processing at the Quivira site. This information is used in the development of a conceptual model of the groundwater in the alluvial material at Quivira.

6.1 BACKGROUND GROUNDWATER QUALITY

Background water quality is defined as the quality of groundwater that would exist if uranium-milling activities had not occurred at the QMC mill. Information on background groundwater quality is limited to one monitor well in each geologic unit at the site. According to NRC Materials License SUA-1473 alluvial background groundwater is recognized at monitor well 5-03. This well was likely chosen as background because it had the lowest concentrations of mill derived constituents.

Spatial variability in groundwater quality is commonly much greater than temporal variability seen in groundwater taken from one monitor well. Therefore, it is unlikely that one background monitor well in the Alluvium adequately represents the true variability of groundwater at the Quivira site. Concentrations of constituents in monitor well 5-03 do not reflect all of the sources of constituents in the vicinity of Ambrosia Lake (Figure 6.1) that are unrelated to QMC milling impacts including the following:

- Mine pumping and discharge
- Seepage from the nearby UMTRA Title I tailings site
- Runoff and erosion from mine spoils and ore piles.

The influence of these and any other sources of constituents must be quantitatively evaluated to determine more realistic cleanup standards. The current groundwater cleanup standards, based on water quality from a single monitor well completed in the alluvium, are impractical. Cleanup to these standards would not be achievable due to high ambient concentrations of constituents at the

site. The wide variety of constituent sources and processes that are known to have operated in the Ambrosia Lake Valley result in high levels of uranium ore related constituents in groundwater that are not attributable to the QMC mill site.

6.1.1 Mine Pumping and Discharge

The alluvial materials were unsaturated before mining began in the Ambrosia Lake Valley and mine-dewatering discharges from underlying geologic units created saturated conditions during the development of numerous mines in the vicinity (Bostick 1985). The quality of mine discharge water is dependant on mine conditions and mining processes. Mine discharge is not regulated by the NRC and is unrelated to regulated milling activities.

Current discharge water typically exceeds alluvial Groundwater Protection Standards for uranium, molybdenum, and selenium (Table 6-1). It is important to note that while mine discharge water is the primary source of groundwater in monitor well 5-03, low concentrations of constituents in groundwater at that location are likely due to the natural attenuation capacity of the alluvial materials as mine water infiltrates and travels through the alluvium. The natural attenuation capacity of the alluvial materials removes constituents from groundwater along its flowpath.

6.1.2 Seepage from the UMTRA Title I Tailings Site

Seepage from the Nearby Title I Tailings Site (Figure 6.1) is unrelated to milling activity at the Quivira site, however it does contribute to saturation and constituent mass in the Alluvium. The effect of seepage from the Title I site can be clearly identified in analyses of groundwater from monitor wells on the eastern side of the Quivira site (Figure 6.2).

Flow directions in the Alluvium are toward and along a paleochannel incised into older bedrock units. The axis of the paleochannel is roughly parallel to the current axis of the Arroyo del Puerto (Figure 6.1) but located to the east of that feature, near the current location of Highway 509. Flow from the Quivira site is first east to the area of the paleo low and then south along the axis of the paleochannel. Flow from the Title I site is west toward the paleo low, where it joins with flow from mine drainage and the Quivira site as that flow moves south.

Figure 6.2 shows contours of TDS/chloride ratios in groundwater from monitor wells completed in the alluvium between Tailings Impoundment 1 and the Title I tailings pile. The TDS/chloride ratio found in seepage from a uranium mill tailings pile is related to the milling process. The milling at the Quivira site was an acid leach process while milling at the Title I site was an alkaline leach process (DOE 1995). Near source groundwater at the Quivira site has a TDS/chloride ratio near 4 (Figure 6.2).

As seepage from Tailings Impoundment 1 moves along its flowpath, the natural geochemical attenuation capacity of alluvial materials removes various constituents from solution, thus lowering the TDS of resulting groundwater. Chloride is a conservative constituent and does not react with alluvial material. Therefore, its concentration in groundwater would be expected to remain constant along a flowpath.

If groundwater TDS/chloride ratios in the Alluvial material were only affected by seepage from Tailings Impoundment 1 the ratio could be expected to decrease from 4 as groundwater moves away from the pile. This is because the numerator (TDS) would be constantly getting smaller through natural geochemical processes, while the denominator (chloride) remains the same. Mine discharge water would have little effect on the ratio because it has both low TDS and low chloride relative to tailings seepage. TDS/chloride ratios in Figure 6.2 *increase* dramatically to the east away from Tailings Impoundment 1 indicating another source for TDS/chloride ratios in the eastern portion of the site. These TDS/chloride ratios are consistent with alkaline leach milling processes such as those employed at the Title I site (DOE 1985).

6.1.3 Runoff and Erosion from Mine Spoils and Ore Piles

Figure 6.1 shows at least three mines in locations that drain to Arroyo del Puerto in the Ambrosia Lake Valley. Quivira has documented one incident in 1997 when an extreme storm mobilized stockpiled uranium ore and spoils at an abandoned mine shown directly south of the site on Figure 6.1 (Quivira 1997). Storm runoff transported this material to the vicinity of stock ponds north of the Quivira NPDES Outfall, causing a discharge at the NPDES Outfall.

While this is the only known documented incident, it is unlikely that it is the only time that mining related sediments have been transported to Arroyo del Puerto. This source undoubtedly

contributes constituents to surface water during storm events and to groundwater when surface water seeps into soils. There is a potential to concentrate mining related constituents by evaporation of standing water in the wake of storm events. These residual ponds would be an extended source of seepage to soils.

6.2 URANIUM PROCESSING AND PROCESS SOLUTIONS

Merritt (1971) indicates that acid leaching of sandstone uranium ores contributed sulfuric acid (H_2SO_4) to the tailings piles, and, thus, to the groundwater at the Quivira site. Sodium chlorate ($NaClO_3$), was added to the acid process as an oxidizer to bring the solution to an Eh of between 0.400 and 0.425 volts. Additionally, ammonia gas (NH_3) was used as a neutralizer and sodium chloride (NaCl) was used in the stripping process. Thus, major indicators of contamination expected in downgradient wells are the sulfate (SO_4^{2-}), and chloride (Cl^-) ions. Secondary indicators of contamination are ammonium (NH_4^+), and nitrate (NO_3^-) (mostly from oxidation of ammonium). Constituents that can be expected in association with the uranium ores themselves are iron, lead, molybdenum, nickel, radium, selenium, thorium, and uranium (DeVoto, 1978).

6.3 EXTENT AND MAGNITUDE OF GROUNDWATER CONTAMINATION

Figure 6.3 shows chloride concentration contours from the most recent sampling round at the site (April, 1999). Chloride is the primary indicator of site related constituents in groundwater because levels of this constituent were high in milling processes and relatively low in mine discharge water. Figure 6.3 shows locally high concentrations of chloride just downgradient of Tailings Impoundment 1, and adjacent to a series of unlined evaporation ponds that have since undergone remediation. Local chloride highs confirm the intuitive assumption that Tailings Impoundment 1, and unlined evaporation ponds are the primary sources of constituents in this part of the alluvium. Locally elevated chloride near monitor well 32-57 is suggestive of the Title I seepage to the east.

TDS/chloride ratios in groundwater from monitor wells completed in the alluvium (Figure 6.2) define the extent of groundwater that has been impacted by seepage from Tailings Impoundment 1 and former evaporation ponds. TDS/chloride ratios in excess of 20 indicate alkaline leach processes (DOE, 1985). Therefore, a very conservative estimate of the Quivira related seepage

in the Alluvium can be taken as the 20 TDS/chloride isopleth in Figure 6.2. Ratios higher than 20 indicate pure alkaline leach solutions. Due to mixing of constituents from the Title I and Quivira sources, constituent impacts from the Title I source likely extend considerably to the west of the 20 TDS/chloride isopleth.

Quivira Tailings Impoundment 1 has now been covered to minimize infiltration, thereby restricting future recharge from that source. Evaporation pond residues from Ponds 3, 4, 5, 6, 7, and 8 were placed in Tailings Impoundments 1 and 2 prior to final reclamation. By these actions Quivira has removed the primary sources of mill related constituents in groundwater and constituent mass in groundwater can be expected to diminish with time and natural attenuation.

6.4 CONTAMINANT FATE AND TRANSPORT

The constituents listed in the groundwater protection standards were evaluated for possible attenuation. Contaminants are transported at the site by groundwater flow in the alluvium. Mobility and/or potential for attenuation depend on the species of ions in the aqueous environment. The types of ion species and complexes depend on anion and cation availability and on pH and Eh conditions. There are no data available to evaluate Eh conditions in the alluvium which may be either oxidizing or reducing. If conditions are oxidizing, attenuation of metallic constituents will be primarily by adsorption. However if reducing conditions are present many metallic constituents may be removed from solution by precipitation as metallic sulfides. The pH conditions in monitor well 5-03 are in the range of 6.5 to 9.4, but are much lower near the sources of contamination (in some cases near 3.5).

6.4.1 Lead-210

Lead^{210} is a product of the uranium^{238} decay chain, but once it is in solution its behavior is the same as any other isotope of lead. Lead^{210} concentrations have been as high as 98 pCi/L in near-source monitor well 32-60 (October 1989). However, the lead^{210} concentrations in this well have shown a strong downward trend since that time. Lead^{210} concentrations during the most recent sampling round were 8.1 pCi/L (April 1999). Figure 6.4 shows that lead^{210} concentrations have not moved far from source areas, and appear to be naturally attenuated at the Quivira site.

6.4.2 Molybdenum

Under oxidizing conditions, the dominant molybdenum species above a pH of 5 is molybdate ion (MoO_4^{2-}). Many of the metallic elements have molybdates of low solubility. Under reducing conditions the sulfide mineral molybdenite forms, also with a low solubility. Currently, molybdenum is primarily present in the alluvium in monitor wells that are adjacent to the creek carrying mine discharge water (Figure 6.5). Consistent with the low solubility of molybdenum there has been minimal transport of molybdenum from sources.

6.4.3 Nickel

Dissolved nickel is present in oxidizing, acidic, near-source environments as the cation Ni^{2+}. This species is mobile under acidic, oxidizing conditions. However, it is strongly adsorbed by Fe/Mn oxides and hydroxides (Rai 1984) that are likely present in abundance in near-source environments at the Quivira site. Figure 6.6 shows the current distribution of nickel in the alluvium and Table 6-1 shows the historical high concentration of nickel in samples from near source monitor well 31-63 and current concentrations. Monitor well 31-63 typically has the highest concentrations at the site of most constituents, yet concentrations of nickel in this well have decreased by at least two orders of magnitude since 1986. Nickel concentrations are predicted to be naturally attenuated in the vicinity of the Quivira site.

6.4.4 Selenium

Selenium occurs in solution as selenate or selenite species under oxidizing Eh conditions. These anionic species should be adsorbed under acid conditions and desorb as conditions become more neutral. As conditions become reducing, selenides become more stable and selenium precipitates as ferroselite or substitutes for sulfur in pyrite. Currently selenium is primarily present in the alluvium in monitor wells that are adjacent to the creek carrying mine discharge water (Figure 6.7). Table 6-1 shows that mine discharge water has historically had selenium concentrations as high as 0.36 mg/L, and yet current concentrations in the alluvium are all at least an order of magnitude lower. This is evidence that selenium is being naturally attenuated in the alluvium.

6.4.5 Radium$^{226+228}$

Radium^{226} and radium^{228} are products of the uranium^{238} and thorium^{232} decay chains, respectively. However, once in solution, these isotopes display the same geochemical behavior as all other radium ions. Radium is present in solution almost exclusively as Ra^{2+} ion. Radium is soluble only under acid conditions and is generally immobile in natural waters due to the extreme insolubility of radium sulfate (Brookins 1988). Radium^{226} typically comprises more than 90 percent of total radium and Figure 6.8 shows the Radium^{226} distribution in the alluvium. Radium is present above 5 pCi/L in three localized areas in the alluvium. Two areas in the northern portion of the site are directly adjacent to sources. The third, at the southern end of the site is completely isolated from the other two. This isolation and the very low solubility of radium sulfate suggest a local source that is unrelated to other sources at the Quivira site. Radium has been naturally attenuated in the alluvium.

6.4.6 Thorium^{230}

Thorium^{230} is part of the uranium^{238} decay chain but is geochemically identical to other isotopes of thorium in aqueous solution. Thorium is soluble only at low pH values, and, at pH values above about 3 precipitates as thorium oxide (Brookins 1988). Figure 6.9 shows the thorium^{230} distribution in the alluvium and it appears to be somewhat mobile. However, note that the distribution of thorium closely mimics the distribution of uranium (Figure 6.10). Thorium^{230} is a product of the uranium^{238} decay chain and is produced continuously wherever natural uranium is present. When uranium is removed from a region thorium^{230} typically falls to low levels (Brookins, 1984).

6.4.7 Uranium

Uranium is mobile in oxidized water, primarily as uranyl sulfate and carbonate complexes. Under reducing conditions uranium is removed from solution as a uranium oxide. The current uranium distribution in the alluvium (Figure 6.10) shows that highest concentrations are adjacent to the creek carrying mine discharge water. Mine discharge water has consistently had uranium concentrations in the 1-2 mg/L range. Despite these levels of uranium and despite the high volume of mine discharge water relative to tailings and pond seepage, most monitor wells

currently show uranium concentrations lower than 0.5 mg/L. This is evidence of natural attenuation of uranium in the alluvium.

6.4.8 Gross Alpha

Gross alpha has also been identified as a possible constituent of concern. However, it was reported in the ACL petition for the uppermost bedrock units that the laboratory performing the groundwater analyses, stated that the gross alpha concentration results includes alpha activity from U-nat and all other alpha emitters. Normally, alpha activity from uranium will contribute most of the gross alpha activity in neutralized groundwater impacted with uranium mill tailings liquids from sulfuric acid leach process. Figure 6.11 shows that the distribution of gross alpha closely mimics the distribution of uranium.

7.0 HUMAN HEALTH AND ECOLOGICAL RISK SUMMARY

7.1 COMPLETE EXPOSURE PATHWAYS

The potential pathways for human exposure to hazardous constituents in groundwater obtained from the alluvium in the vicinity of the facility are as follows:

- Consumption of drinking water from impacted groundwater sources, and
- Eating beef from cattle consuming impacted groundwater and forage irrigated with impacted groundwater.

Groundwater is not used as a potable source nor is it expected to be used as one in the foreseeable future. The groundwater in the alluvium is not used as a potable source for the following reasons (1) there are few people living in the area of the Facility, no residents within five miles have wells in this aquifer, and data indicate the population in the area is declining; and (2) ambient background quality of the water has been demonstrated to be poor, making this groundwater unattractive as a potable source. However, consistent with the ACL petition for the uppermost bedrock units, it was assumed that groundwater could be used as a drinking water source for purposes of developing health risk-based concentrations. Beef cattle do exist in the vicinity of the Facility and groundwater may be used for watering of these cattle. No dairy cattle live or graze in the area so human ingestion of milk was not considered a complete exposure

pathway. The mine discharge water is currently used to irrigate alfalfa but this will cease once the dewatering operations end.

The potential for contamination of naturally occurring surface water is negligible because groundwater does not naturally discharge to surface water within 10 miles of the tailings area. The only surface water that exists in the vicinity of the Facility is water that is pumped out of the mines to the land surface during dewatering of the mines. This water source will disappear when dewatering ceases. Without discharge to surface water, there are no exposure point concentrations and exposure to surface water is considered an incomplete pathway.

7.2 CONSTITUENTS OF CONCERN IN GROUNDWATER

The hazardous constituents of concern include the following:

- Molybdenum
- Nickel
- Selenium
- $Lead^{210}$
- Natural uranium
- $Thorium^{230}$
- $Radium^{226}$
- $Radium^{228}$

Gross alpha has also been identified as a possible constituent of concern. However, it was reported in the ACL petition for the uppermost bedrock units that the laboratory performing the groundwater analyses, stated that the gross alpha concentration results includes alpha activity from U-nat and all other alpha emitters. Normally, alpha activity from uranium will contribute most of the gross alpha activity in neutralized groundwater impacted with uranium mill tailings liquids from sulfuric acid leach process. Proposed health risk-based concentrations will be developed for all the potential alpha emitters (U-nat, Th^{230}, Ra^{226}, and Po^{210} a decay product of Pb^{210}) in neutralized groundwater impacted with uranium mill tailings liquids. Therefore, development of a health risk-based concentration or an ACL for gross alpha was deemed unnecessary.

7.2.1 Health Risk-based Concentrations

Proposed health risk-based concentrations for the constituents of potential concern in groundwater will be MCLs, when available and applicable, or calculated values assuming a 1 x 10^{-4} (1 in 10,000) target risk. MCLs protective of humans using water as a drinking source have been established by the USEPA for nickel and selenium. MCLs are generally health-based concentrations that may have been adjusted to account for technological limitations. The MCLs for nickel and selenium are 0.1 mg/L and 0.05 mg/L, respectively. While there is no enforceable MCL for molybdenum, USEPA has identified 0.18 mg/L in drinking water as a health protective concentration. While the conservative nature inherent in the development of MCLs is recognized, these values are proposed as the health risk-based concentrations for molybdenum, nickel, and selenium in groundwater.

Health risk-based concentrations that will limit the lifetime risk to 1 x 10^{-4} assuming groundwater consumption at the POE location are necessary for $Lead^{210}$, Natural uranium, $Thorium^{230}$, $Radium^{226}$, and $Radium^{228}$. Review of the potential groundwater exposures that might be associated with the alluvium indicate that the health risk-based concentrations calculated for these constituents in the ACL petition developed for the uppermost bedrock units are also applicable to the alluvium.

The USEPA has identified 5 pCi/L as the MCL for $Ra^{226/228}$. However, because it is highly unlikely the alluvium groundwater will be used as a drinking water source, and the radiological characteristics of Ra^{226} and Ra^{228} indicate that a combined value for the two isotopes is not the best approach to developing a protective value, the MCL is not proposed as the health risk-based concentration. The health risk-based concentrations for Ra^{226} and Ra^{228} in groundwater were calculated to be 44 pCi/L and 12 pCi/L, respectively. Separate health risk-based concentrations were developed to account for the different radiological characteristics; specifically, Ra^{226} is an alpha emitter while Ra^{228} is a beta-emitter.

Evaluation of the groundwater data collected from the source area for the alluvium indicate that the radium composition is 99 percent Ra^{226} and only 1 percent Ra^{228}. These data are consistent with that reported in the ACL petition for the uppermost bedrock units. Toxicological data indicate that Ra^{228} presents a higher cancer risk per unit intake than Ra^{226}. As was done in the

ACL petition for the uppermost bedrock units, it was conservatively assumed that the average Ra^{228} was 3 percent. Using these data, the combined Ra^{226} and Ra^{228} health risk-based concentration that limits the lifetime risk to 10^{-4} was calculated to be 41 pCi/L. A health risk-based concentration of 164 pCi/L was developed for natural uranium. The Pb^{210} and Th^{230} health risk-based concentrations that each limit lifetime risk to 10^{-4} assuming ingestion of water as a potable source are 13 pCi/L and 139 pCi/L, respectively.

In summary, the health risk-based concentrations applicable at the POE for the constituents of potential concern are as follows:

- Molybdenum: 0.18 mg/L
- Nickel: 0.1 mg/L
- Selenium: 0.05 mg/L
- $Lead^{210}$: 13 pCi/L
- Natural Uranium: 164 pCi/L (0.24 mg/L)
- $Thorium^{230}$: 139 pCi/L
- $Radium^{226}$ and $Radium^{228}$ combined: 41 pCi/L

These concentrations appear to be protective of human health.

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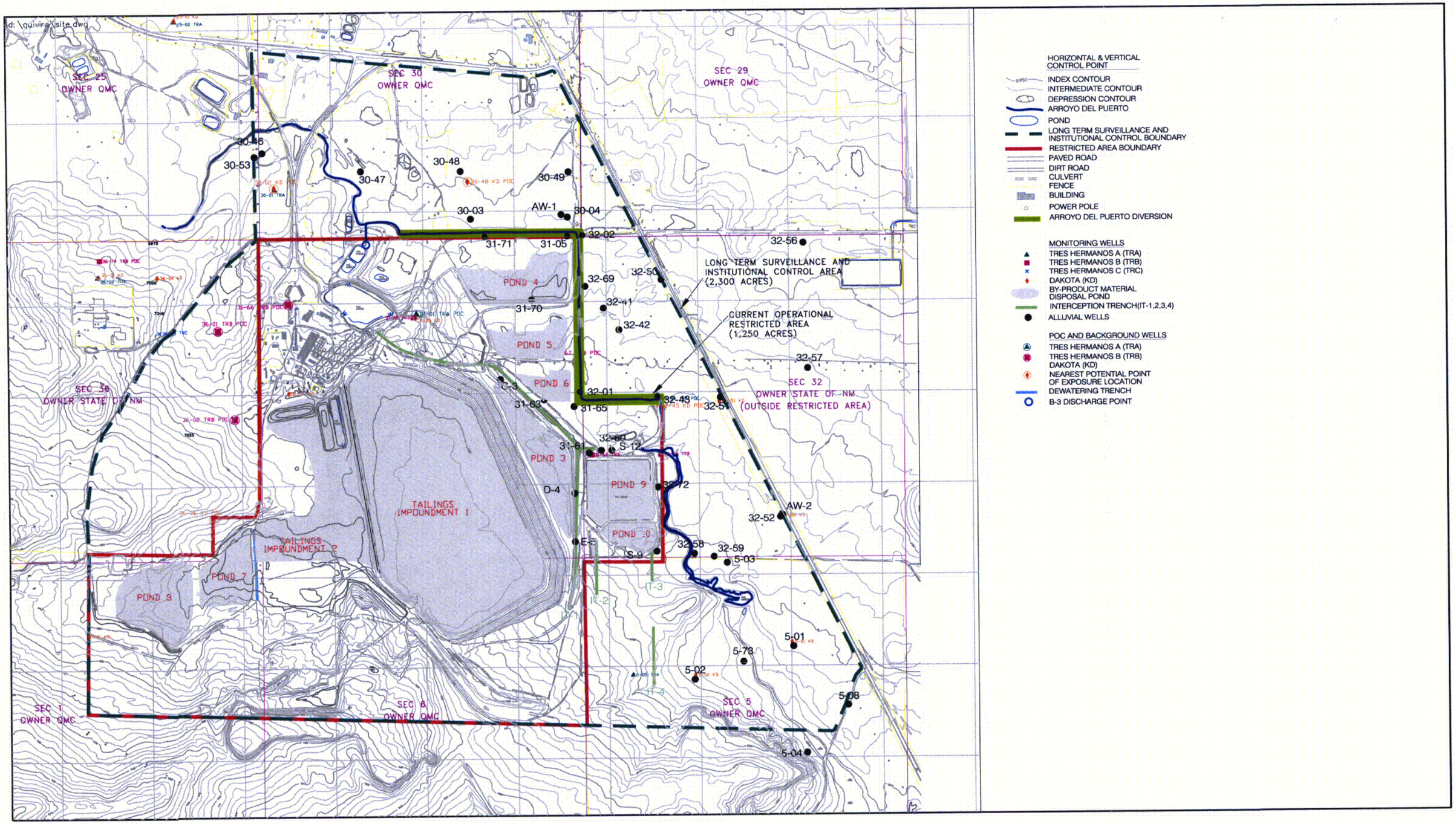
TABLE

	Process Liquids	Tailings Liquids (1987)	MW 31-63 (Highest)	MW 31-63 (Current)	Mine Water (Highest)
pH (s.u.)	1.1	3.95	(3.7)	5.4	-
Chloride (mg/L)	1,540	2,300	5800	3130	810
Molybdenum (mg/L)	14	0.46	1.07	0.004	0.62
Nickel (mg/L)	1.0	1.0	2.66	0.009	<0.01
Lead-210 (pCi/L)	-	4.5	58	58	6.4
Radium-226+228 (pCi/L)	336	62	35.91	2.8	3.9
Selenium (mg/L)	6	< 1.2	0.32	0.026	0.360
Sulfate (mg/L)	34,600	16,000	44300	9380	1380
TDS (mg/L)	40,800	28,090	76200	17400	3460
Thorium-230 (pCi/L)	-	11	12.9	6.2	2.1
Natural Uranium (mg/L)	11.2	8.4	13.8	0.282	1.52

Comparison of Concentrations of Constituents in Water from Tailings and Mine Discharge
Ambrosia Lake Facility
Near Grants, New Mexico
TABLE 6.1

FIGURES



N

0 Feet 1500

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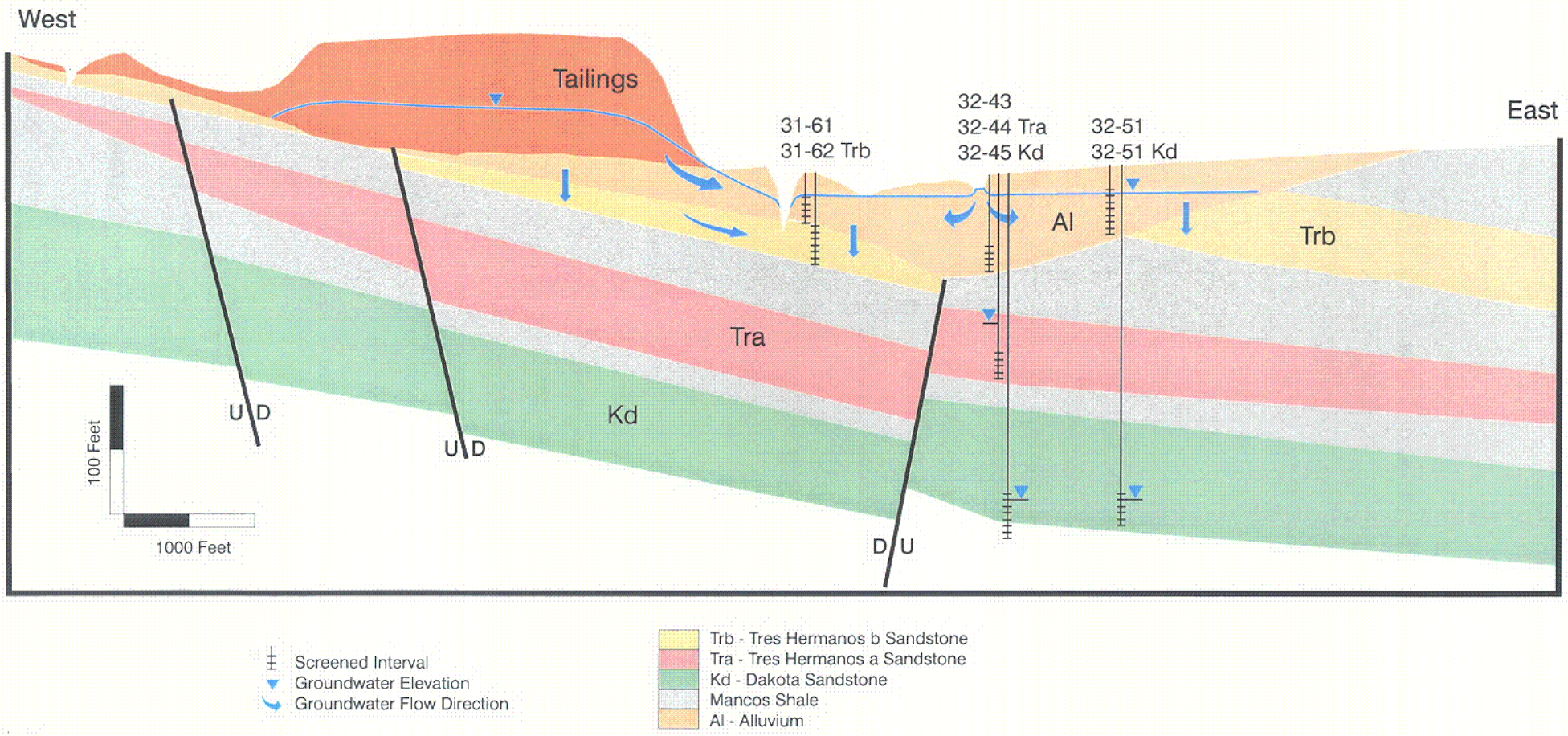
C1

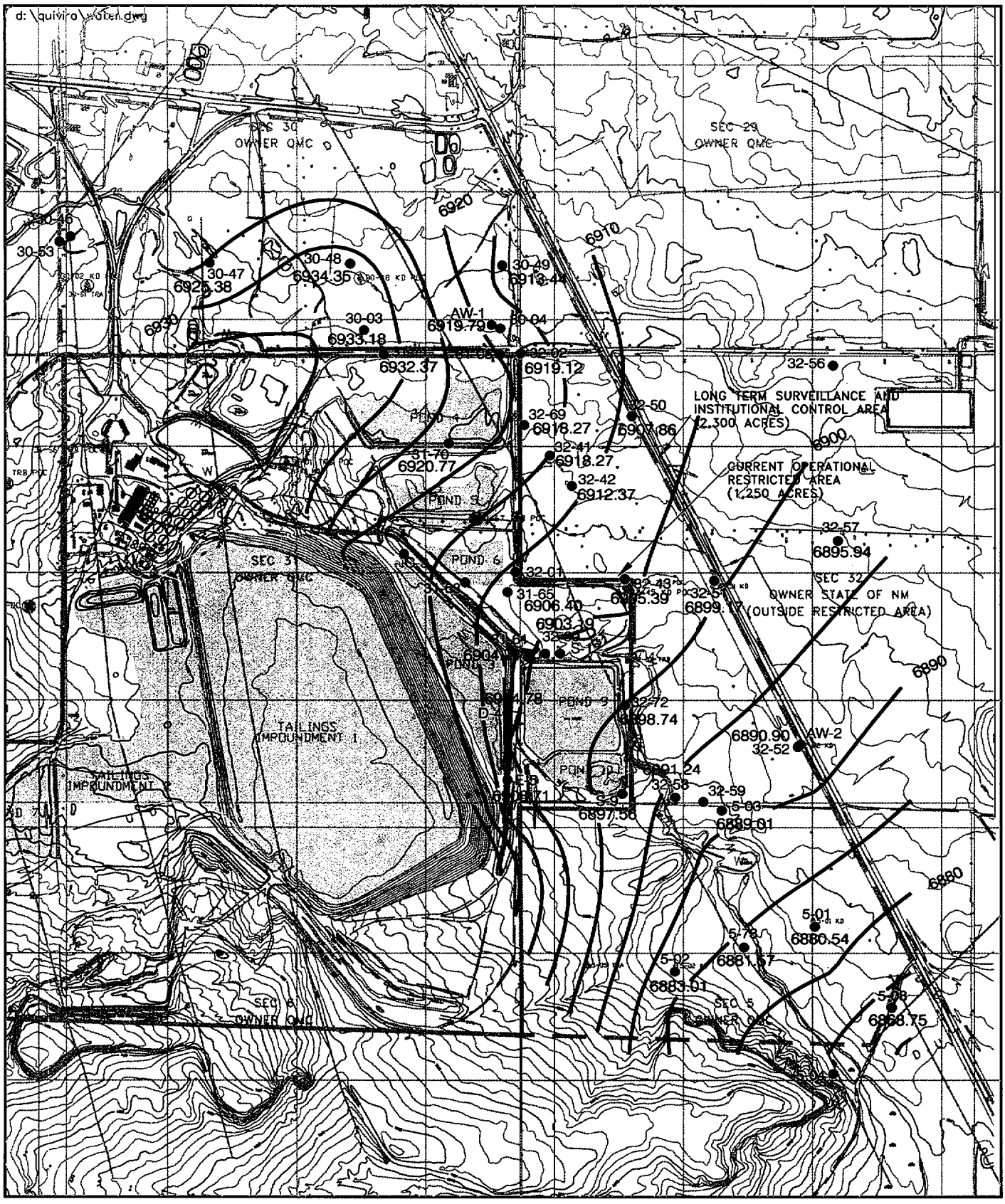
Site Map
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 1.1



Generalized Hydrogeologic Cross Section
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 2.1

MAXIM

C2



N

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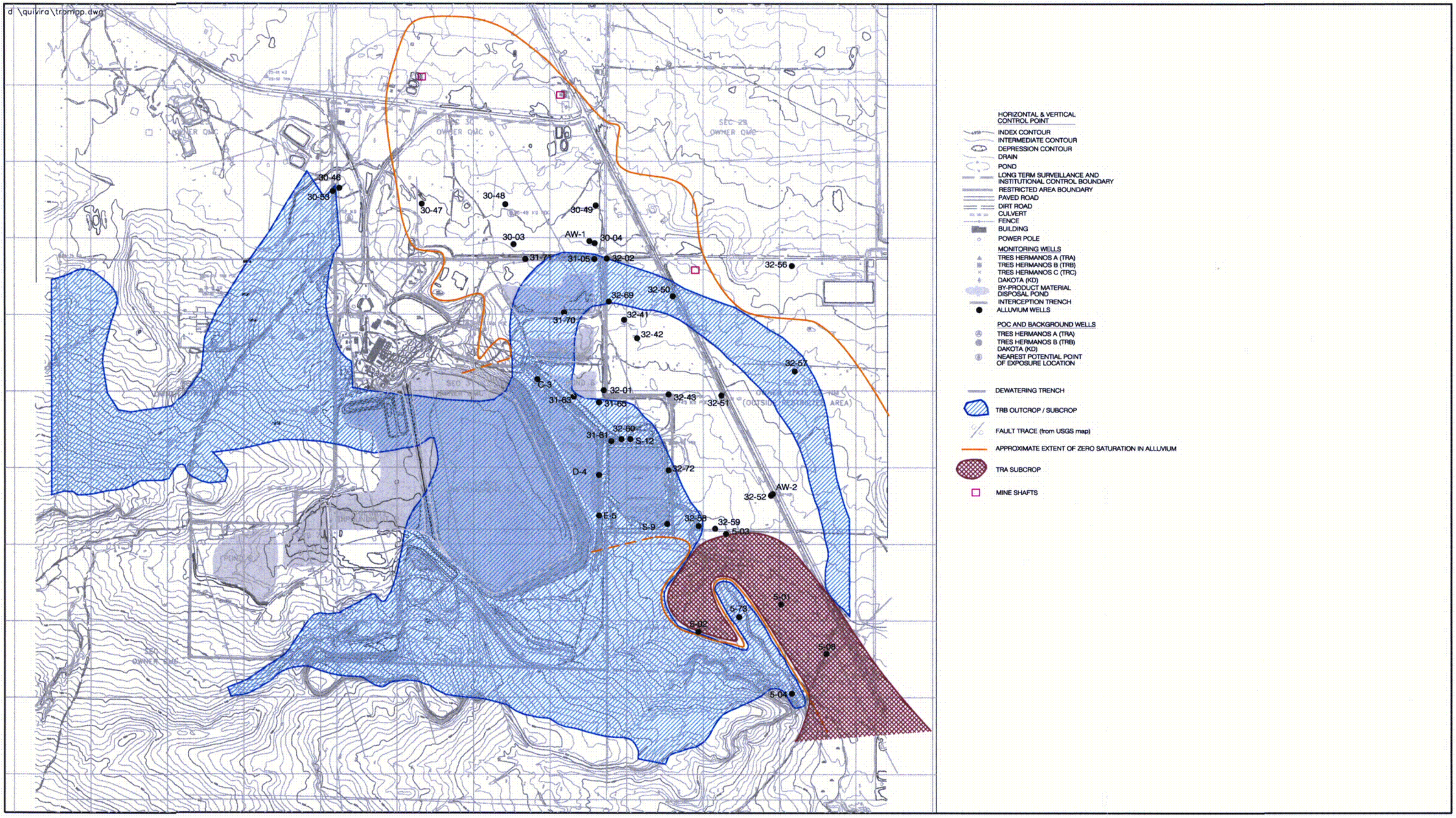
Equipotential Line

6868.75 Groundwater Elevation (feet)

Water Table Map for the Alluvial System - Second Half 1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 4.1

MAXIM 2005075



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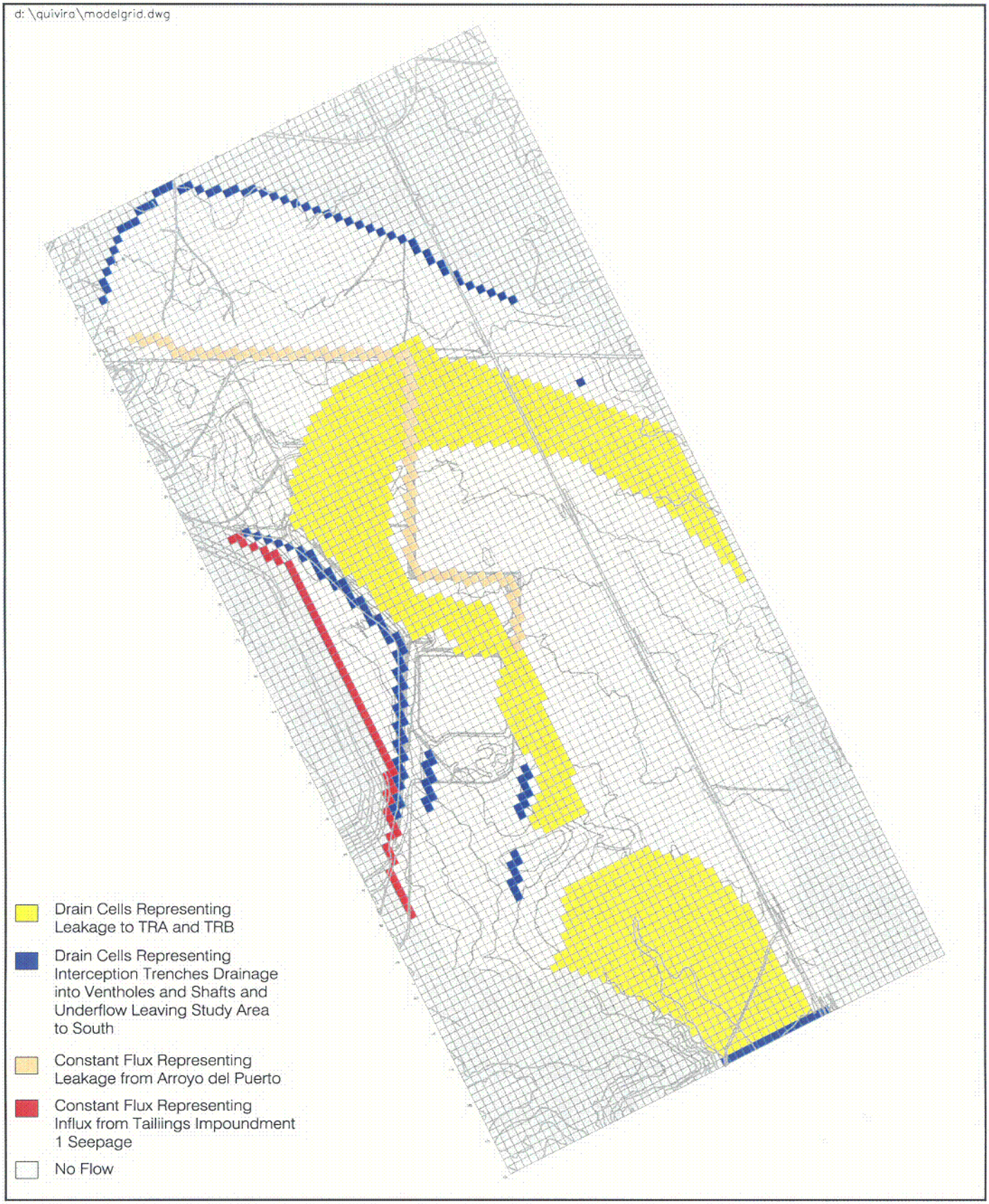
MAXIM 2005075

C3

Map Showing Sandstone Unit Subcrops and
Approximate Extent of Alluvial Saturation
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.1



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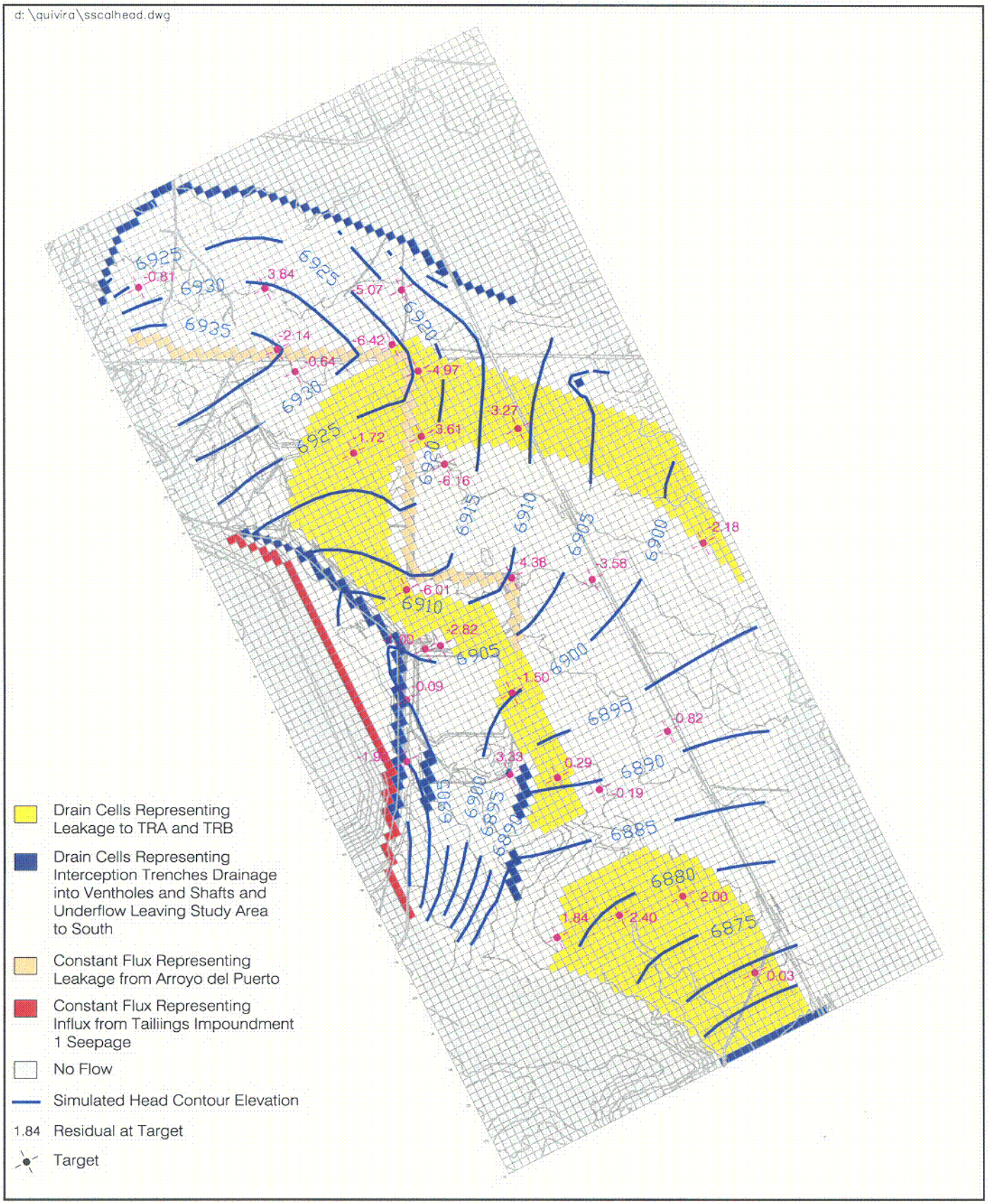
MAXIM 2005075

C4

Model Grid and Boundries
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.2



N

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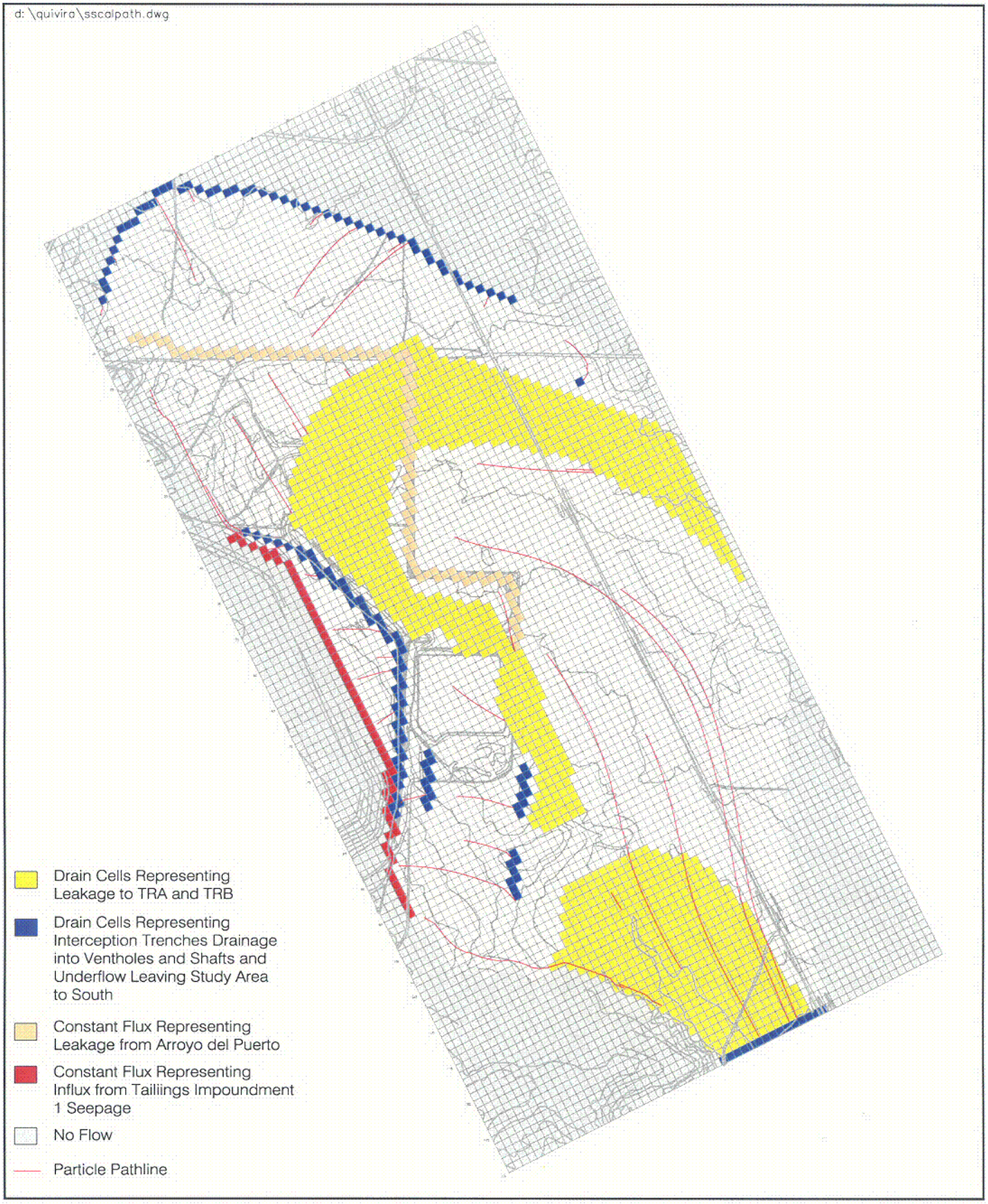
MAXIM 2005075

C5

Preliminary Calibration Results
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.3



N

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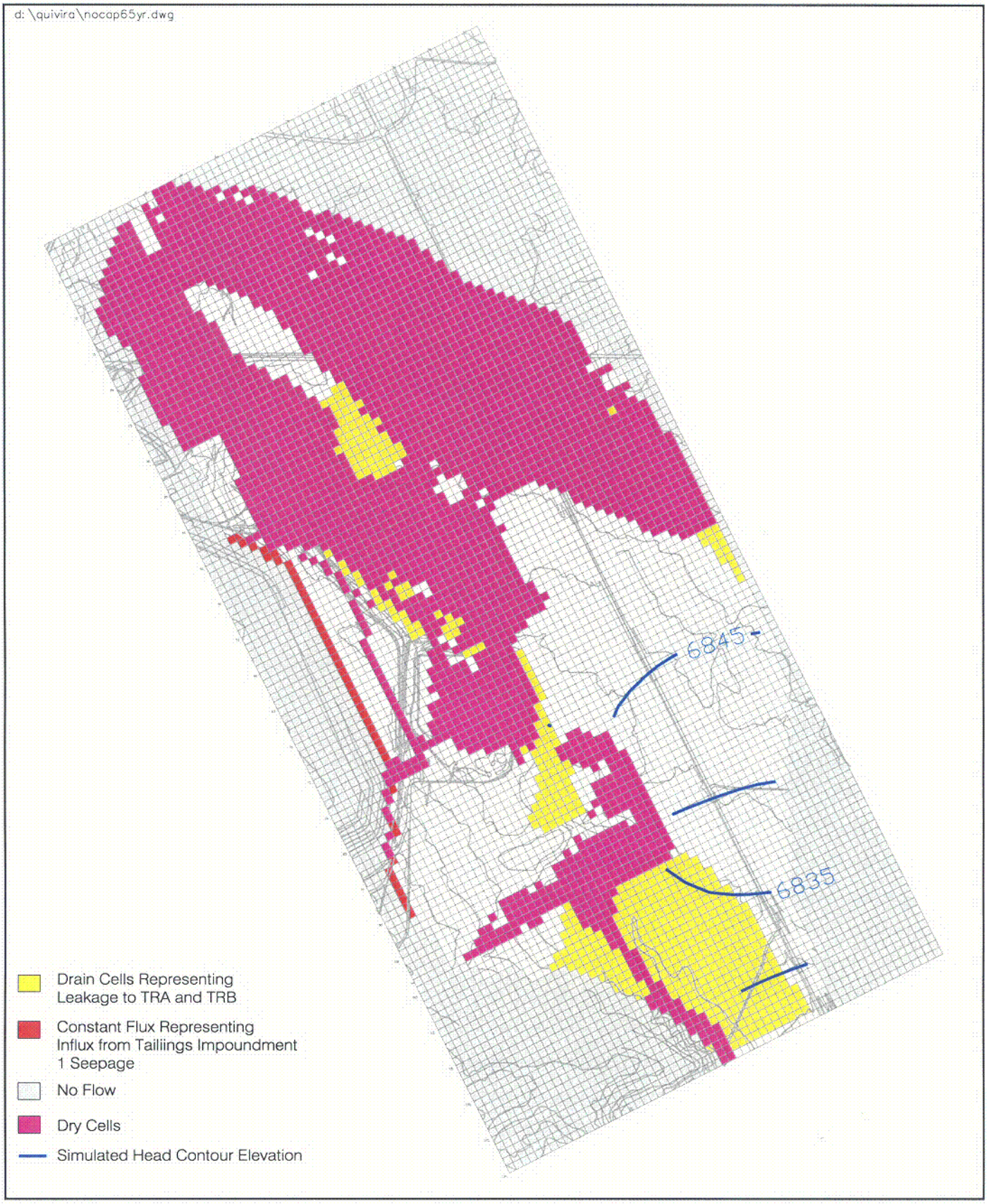
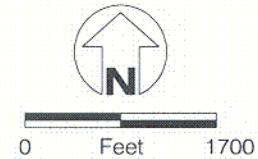
MAXIM 2005075

C6

Steady State Particle Pathlines
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.4





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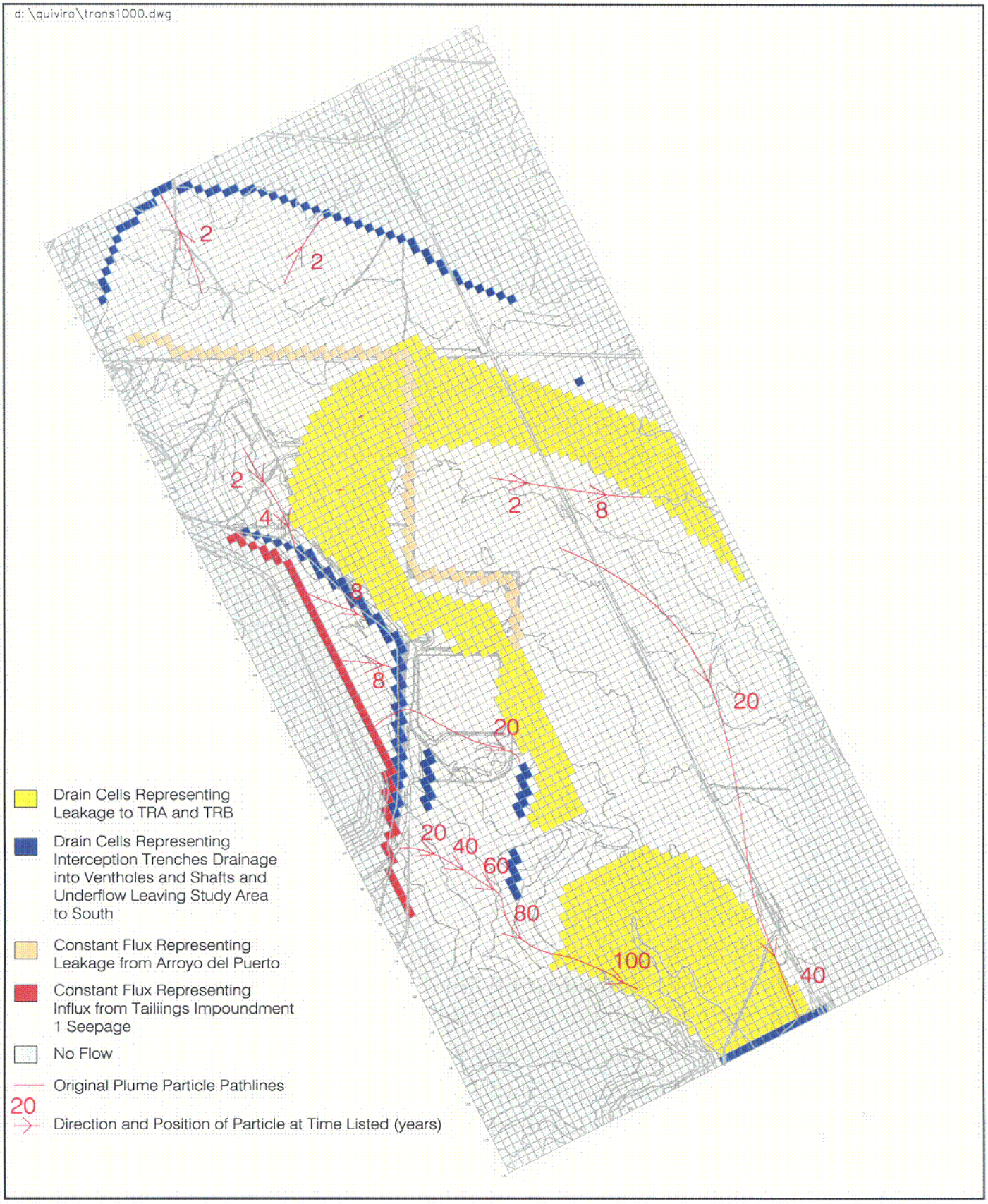
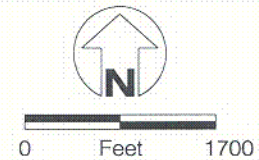
C7

Water Table Elevation After 65 Years
for Discontinued CAP Scenario
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.5

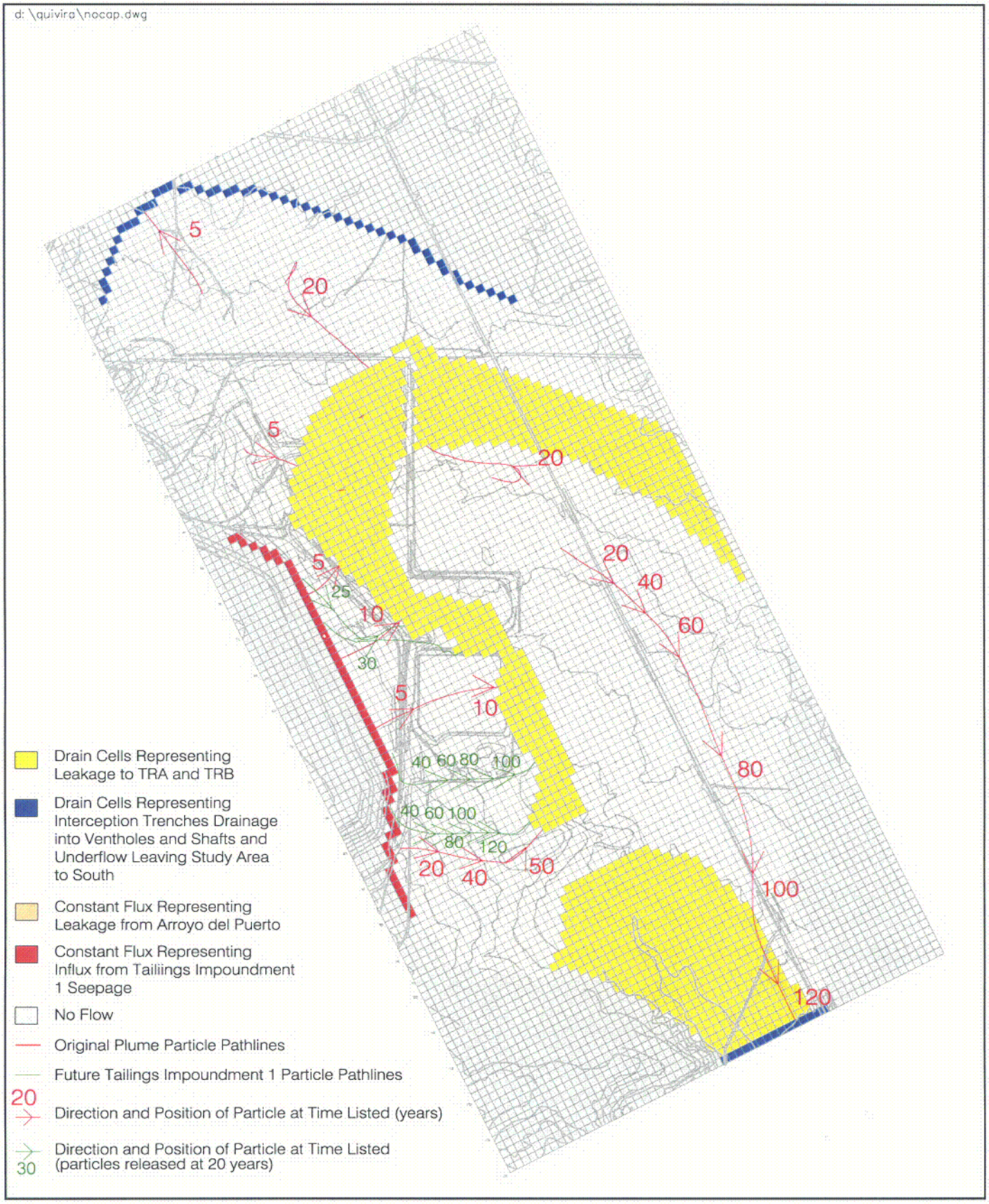


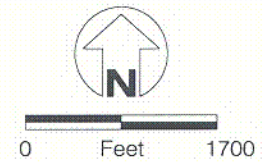


MAXIM 2005075

C8

Transient Pathlines for Existing CAP Scenario
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.6





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C9

Transient Pathlines for Discontinued CAP Scenario
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 5.7

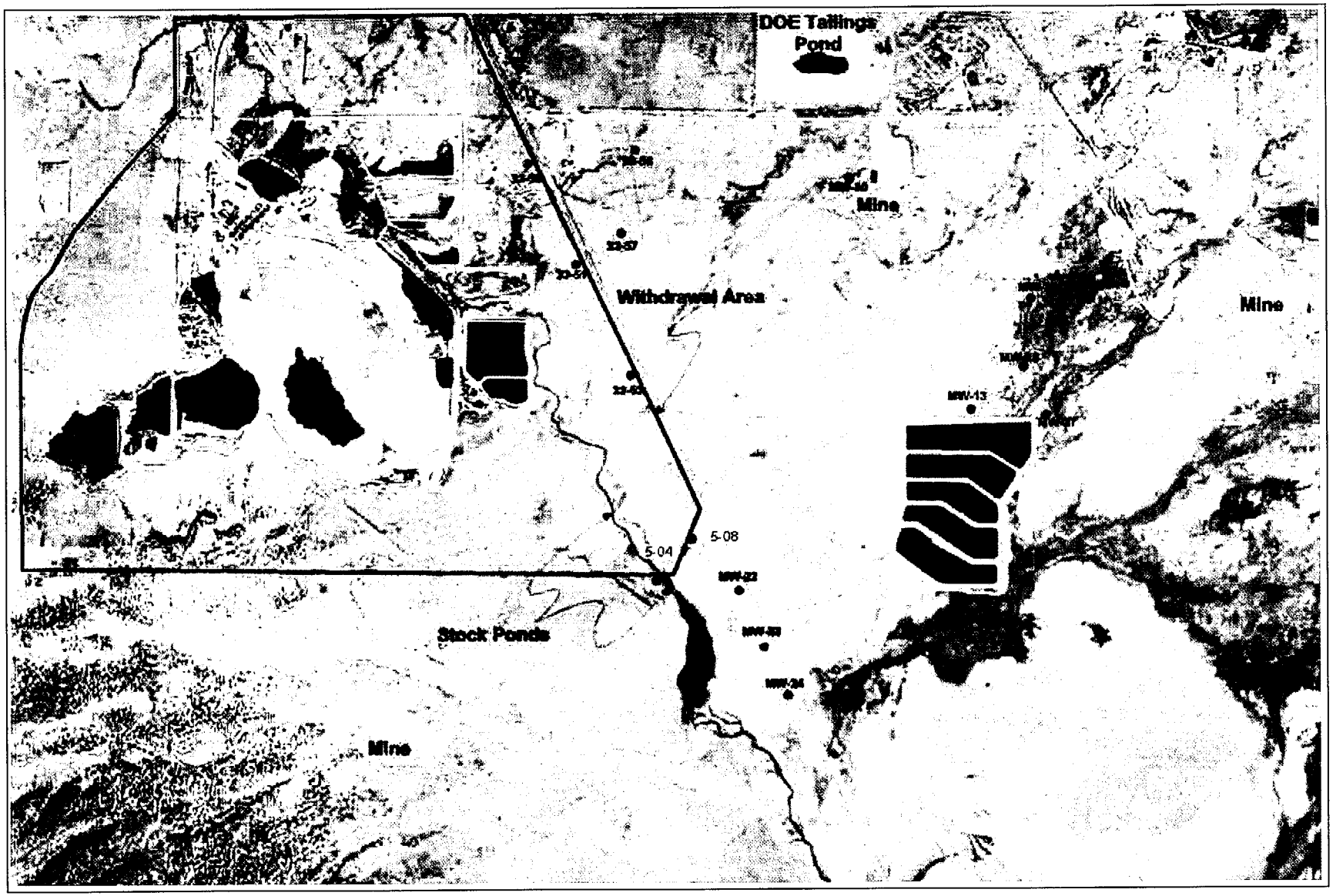
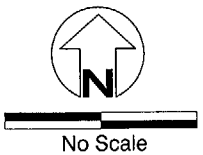


Photo 1977



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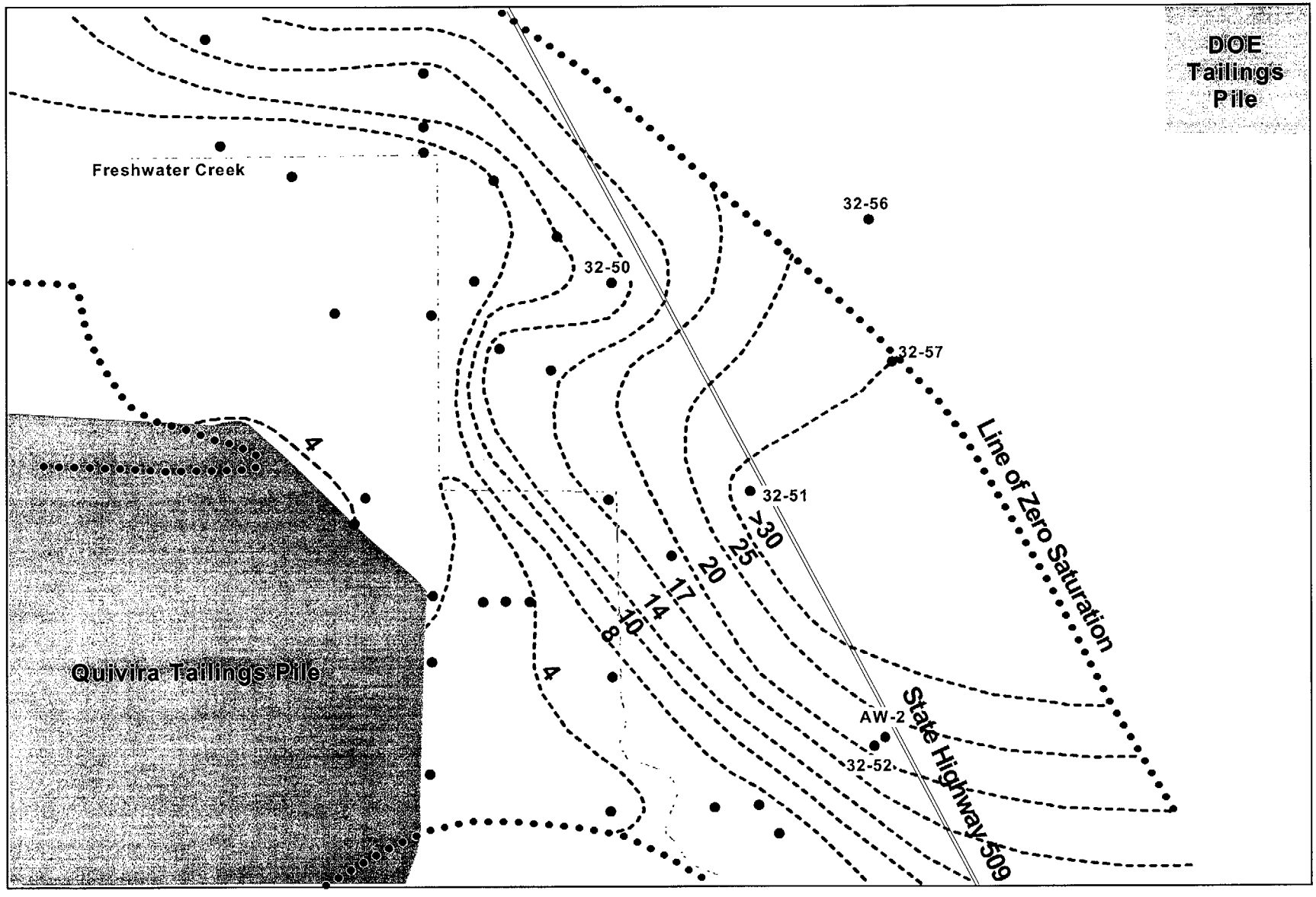
Sources of constituents
in the vicinity of Ambrosia Lake
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.1



N

No Scale

Line of Equal TDS/Cl^-

Contours of Total Dissolved Solids (TDS)/chloride ratios
in groundwater from monitor wells
completed in the alluvium
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.2

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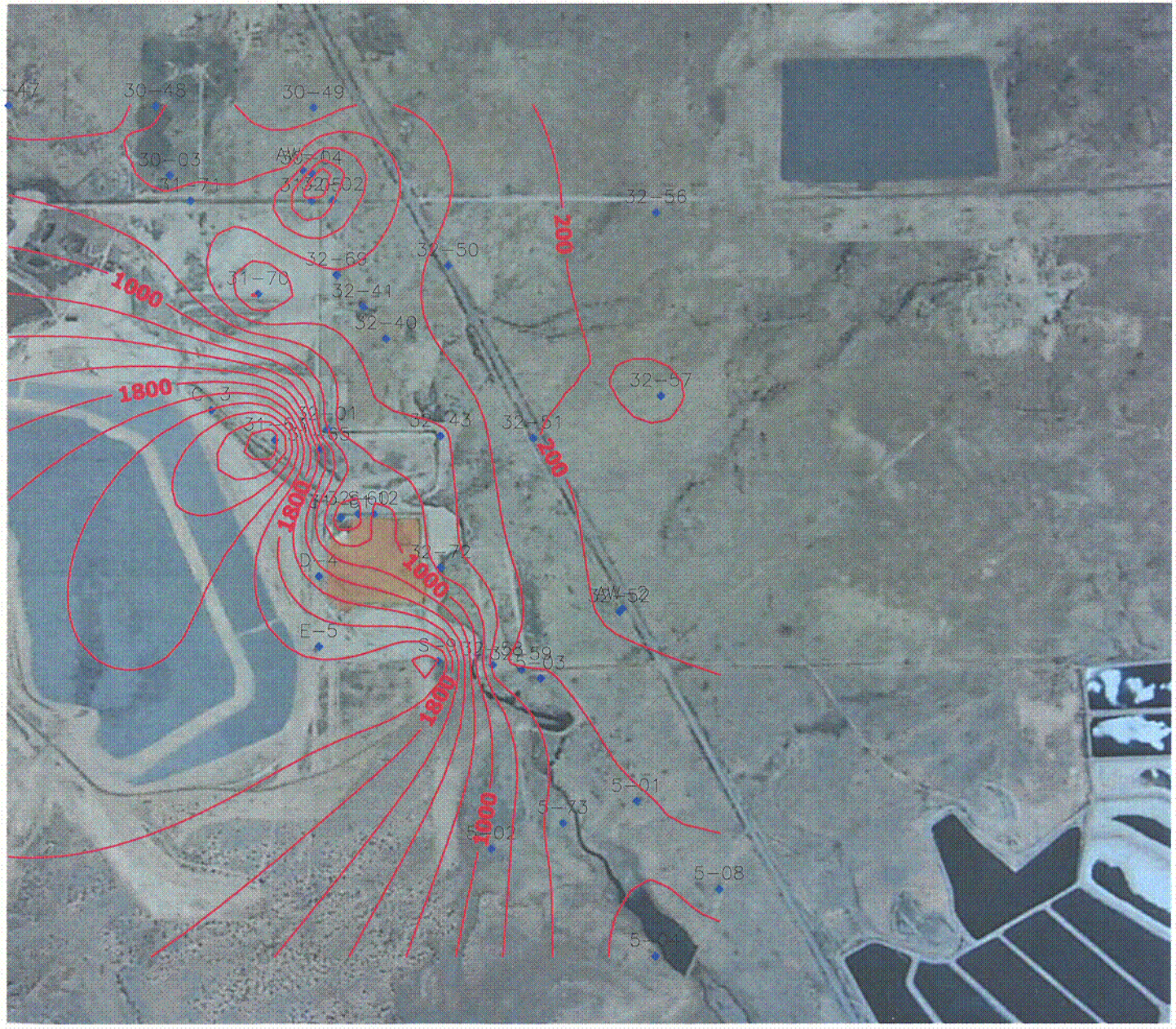
MAXIM 2005075



Contour Interval = 200 mg/L

No Scale

Photo 1997

Chloride concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.3

C10

MAXIM 2005075

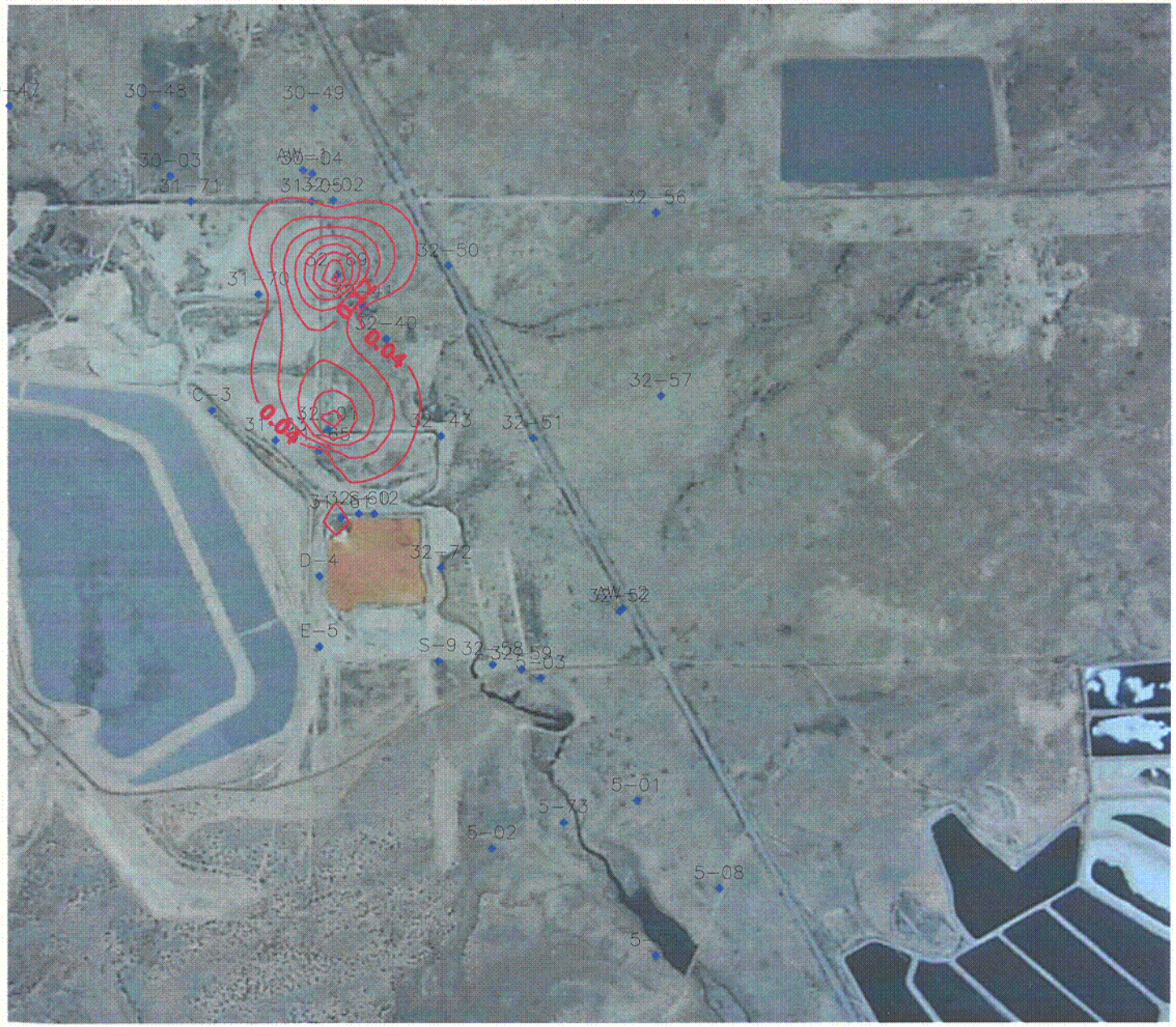
No Scale

Photo 1997

Alluvial Groundwater Protection Standard =4.9 pCi/L
Contour Interval = 5 pCi/L

Lead 210 concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.4

MAXIM 2005075



N

No Scale

Photo 1997

Alluvial Groundwater Protection Standard = 0.06 mg/L
Contour Interval = 0.04 mg/L

Molybdenum concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.5

C12

MAXIM 2005075

No Scale

Photo 1997

Alluvial Groundwater Protection Standard = 0.06 mg/L
Contour Interval = 0.002 mg/L

Nickel concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.6

C13

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Alluvial Groundwater Protection Standard =0.05 mg/L
Contour Interval = 0.02 mg/L

No Scale

Photo 1997

Selenium concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.7

C14

MAXIM 2005075

N

No Scale

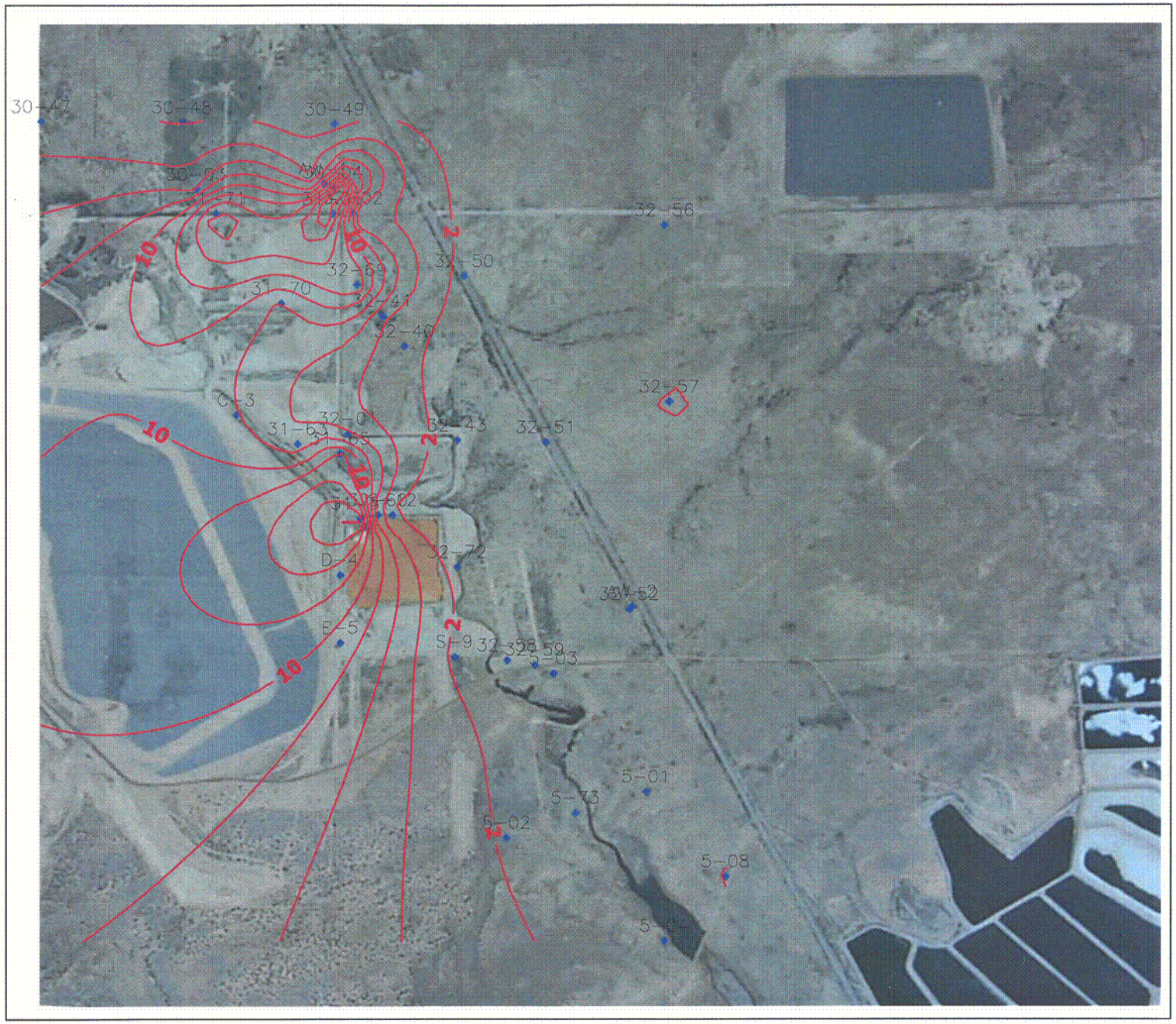
Photo 1997

Alluvial Groundwater Protection Standard = 5.0 pCi/L
Contour Interval = 5.0 pCi/L

Radium-226 concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.8

C15

MAXIM 2005075



N

No Scale

Photo 1997

Alluvial Groundwater Protection Standard = 3.1 pCi/L
Contour Interval = 2.0 pCi/L

Thorium-230 concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.9

MAXIM 2005075

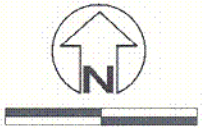


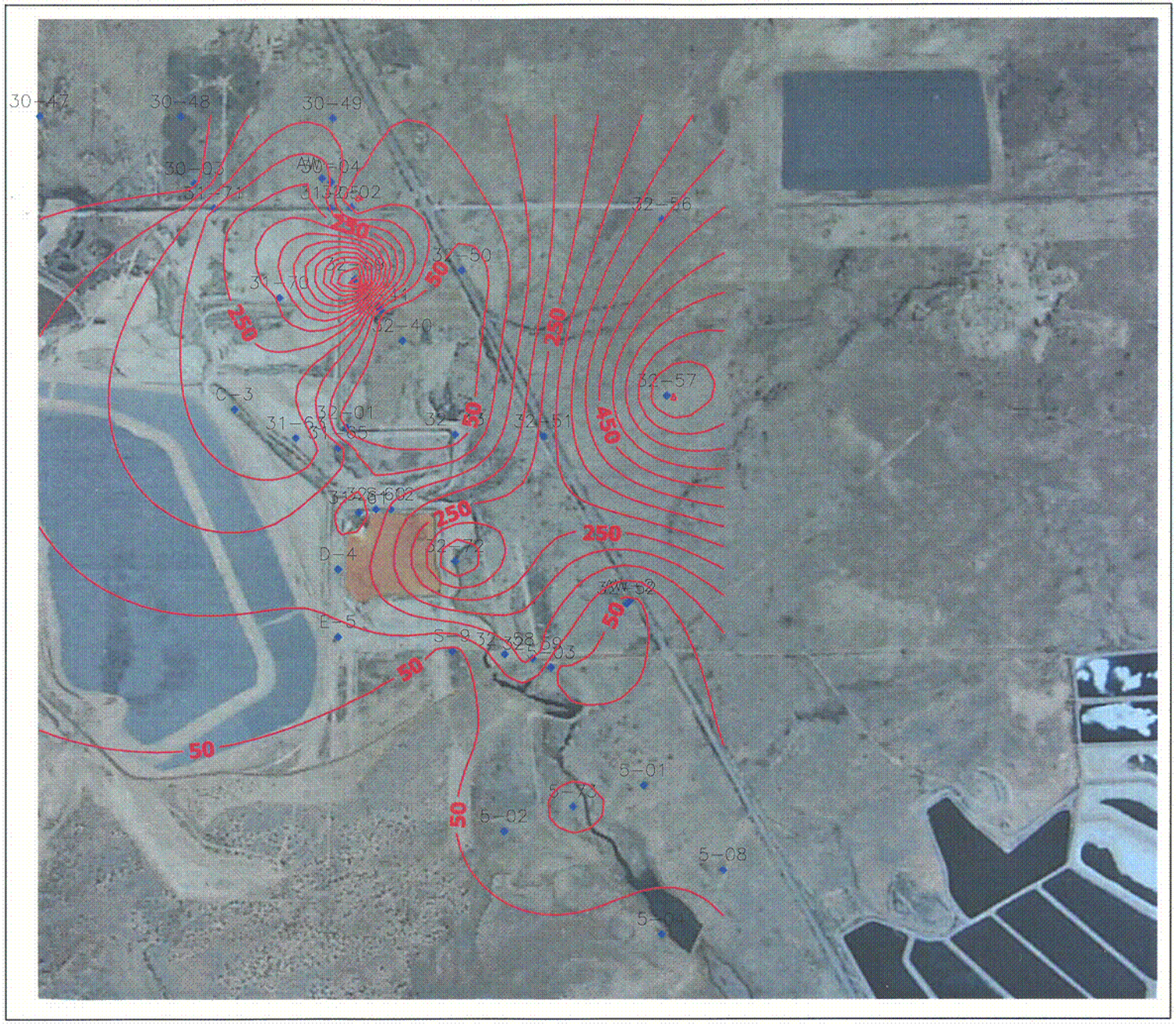
Photo 1997

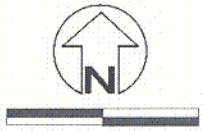
Alluvial Groundwater Protection Standard =0.06 mg/L
Contour Interval = 0.2 mg/L

Uranium concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.10

C17

MAXIM 2005075





No Scale

Photo 1997

Alluvial Groundwater Protection Standard = 57.0 pCi/L
Contour Interval = 50 pCi/L

Gross Alpha concentrations
1999
Ambrosia Lake Facility
Near Grants, New Mexico
FIGURE 6.11

C18

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