Attachment 1 Long Term Pit Lake and Groundwater Hydrology at the Highland Mine Site: Tetra Tech, May 2007

Long Term Pit Lake and Groundwater Hydrology at the Highland Mine Site

Final Report

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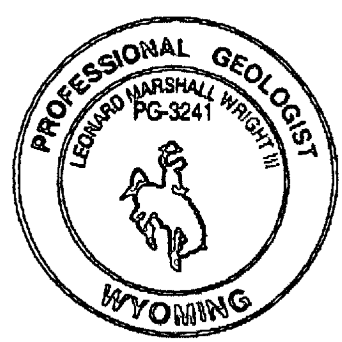

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

This report discusses the hydrologic model and the field investigation developed and performed by MFG, Inc. (MFG), formerly Shepherd Miller, Inc. (SMI), for the Pit Lake at the Highland Mine Site (Site). This report was initially prepared on behalf of ExxonMobil Corporation (ExxonMobil) by MFG. Blasland, Bouck, and Lee, Inc. (BBL), an ARCADIS Company, has incorporated third party comments from the final draft, prepared by MFG, into this version for final submittal.

1.1 Background

The Site is situated on Tertiary deposits of the Powder River Basin in Converse County, Wyoming. At this location, uranium and other heavy metals were precipitated as roll-front deposits after oxidized, metal-enriched waters encountered a redox interface in the host sandstones. A regional location map is presented on Figure 1.

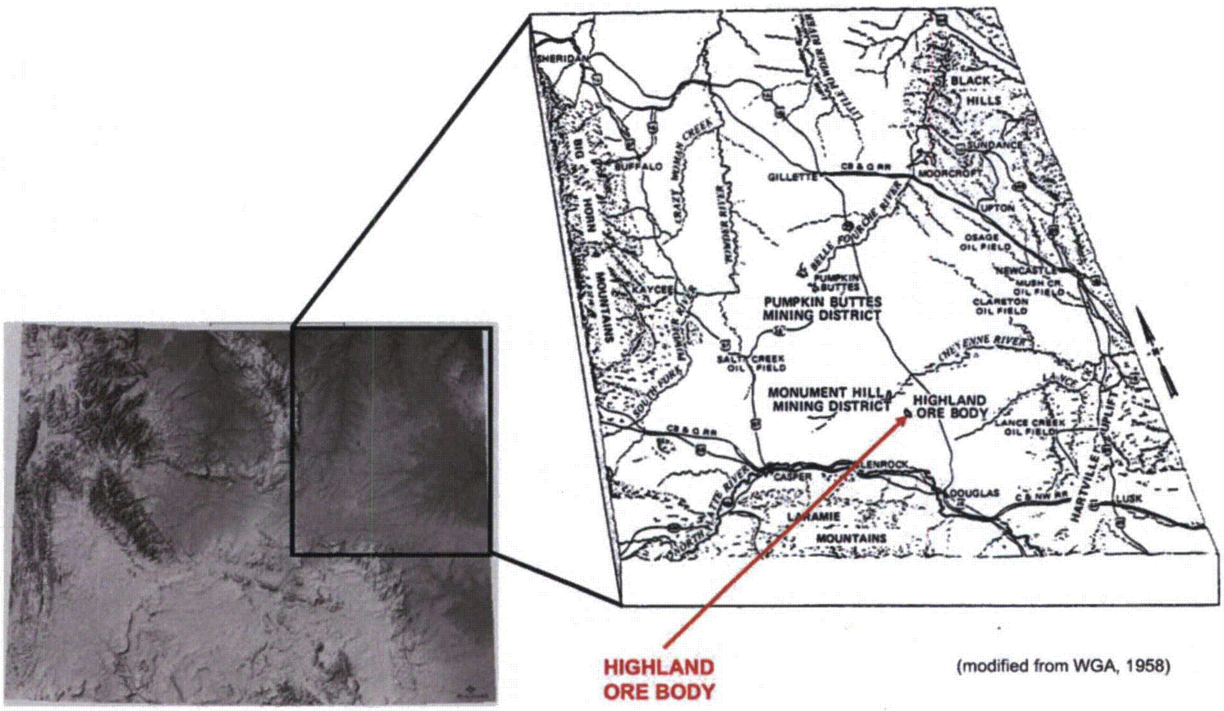

Figure 1 Location Map Showing the Highland Ore Body and Major Geographic Features in the Powder River Basin

From 1972 until 1984, Exxon Minerals Company/Exxon Coal and Minerals Company conducted surface mining operations to recover uranium from shallow sedimentary strata at the Site. Underground and in-situ mining operations have also been conducted in the area. Dewatering during mining operations created a large cone of depression in the potentiometric surface surrounding the surface mine pits. At the end of the mining operations, two of the four pits remained open and were allowed to fill with water, creating the Highland Pit Lake (Pit Lake). A Site location map is presented on Figure 2.

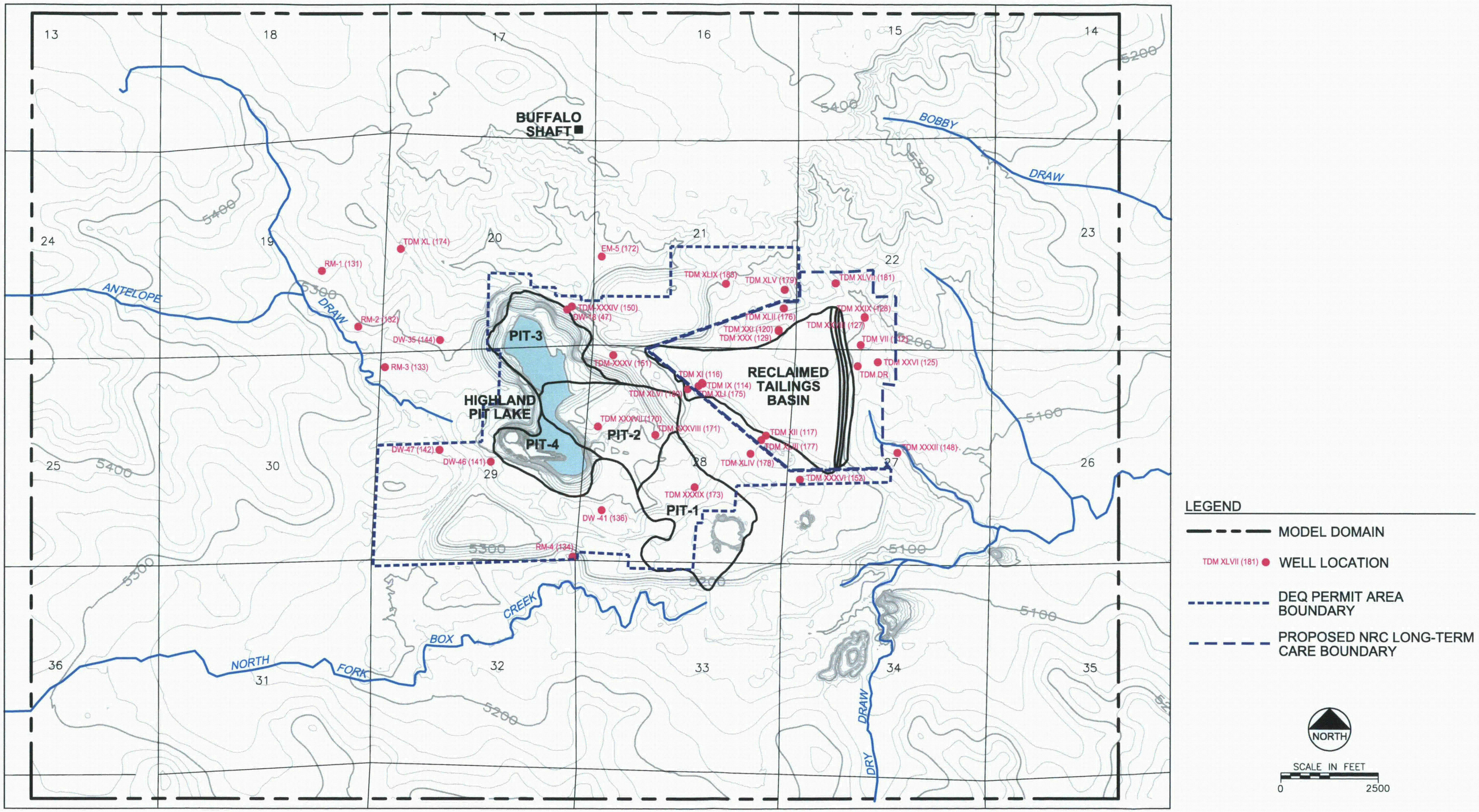

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FIGURE 2
HIGHLAND MINE SITE

In order to predict future water quality in the Pit Lake, a better understanding of processes controlling Pit Lake hydrochemistry is necessary. One such process is the groundwater flow component of the Pit Lake's hydrologic budget. Groundwater flow from the surrounding hydrologic units is a primary control in: 1) the rate of Pit Lake filling; 2) the long-term steady-state water level; 3) the ability of the Pit Lake to become a flow-through system; and 4) long-term mass balance and concentrations of constituents in the Pit Lake.

The long-term equilibrium of the Pit Lake is important because: 1) if the Pit Lake acts as a sink in the long term, concentrations of metals and salts will continue to increase in the Pit Lake with time; and 2) a flow-through system will allow discharge of Pit Lake water to North Fork Box Creek. In order to accurately estimate the long-term hydrochemical evolution of the Pit Lake, the groundwater component to and from the Pit Lake must be characterized. This characterization is the focus of this report.

A Site-wide numerical groundwater model has been developed to estimate the transient groundwater component of the Pit Lake. In the model, the Pit Lake and the surrounding aquifer are treated as two interdependent hydrologic systems. The systems are dependent on one another because groundwater exchange with the Pit Lake is driven by the hydraulic gradient between the Pit Lake and aquifer. Also, the Pit Lake elevation is, in part, determined by the flow the aquifer can transmit to the Pit Lake. Therefore, both systems must be characterized to estimate the future Pit Lake groundwater flow component. Each system has distinct controls that influence flow to the Pit Lake. Within the Pit Lake, water elevation (and, therefore, flow) is influenced by the Pit Lake geometry and non-groundwater components of the Pit Lake's hydrologic budget (e.g., evaporation, direct precipitation). The volume of water that the groundwater system can yield to the Pit Lake is dependent on the hydraulic properties of the stratigraphic units, as well as historical and future hydrologic stresses near the Site. The incorporation of all of these elements into the model allows for a comprehensive analysis that accurately represents the complex and interdependent behavior of the Pit Lake and groundwater hydrology at the Site.

Data presented in this report indicate that the Pit Lake will remain a hydrologic sink and that Pit Lake waters will not likely flow through the hydrologic strata and discharge to adjacent surface-water drainages.

1.2 Report Organization

The remaining sections of the report are organized as follows:

- Section 2: Summarizes the body of work relating to the groundwater and Pit Lake hydrology and the field investigation. This information serves as the conceptual foundation on which the numerical model is based.
- Section 3: Presents the design and calibration of the numerical model.
- Section 4: Discusses the model predictions of the hydrologic conditions at the Site.
- Section 5: Presents conclusions and recommendations for future work.

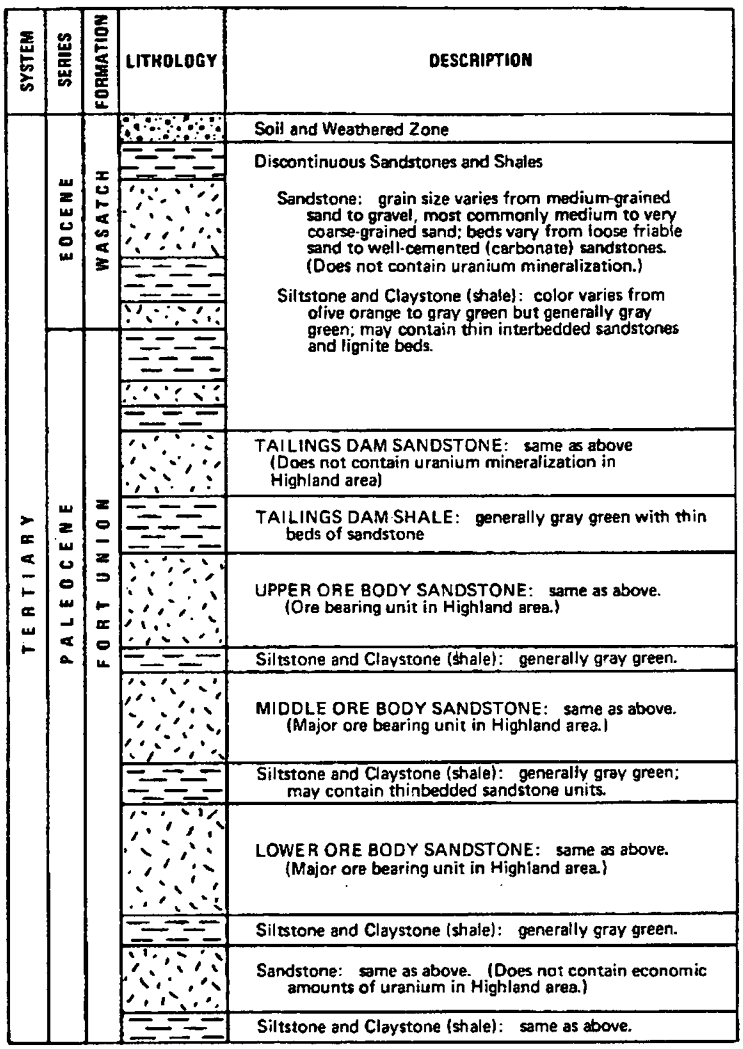
2.0 SITE HYDROLOGY

The geology and hydrogeology of the Site has been documented and discussed by numerous investigators. The conceptual model on which the numerical model is based has been developed from this body of work.

2.1 Groundwater Hydrology

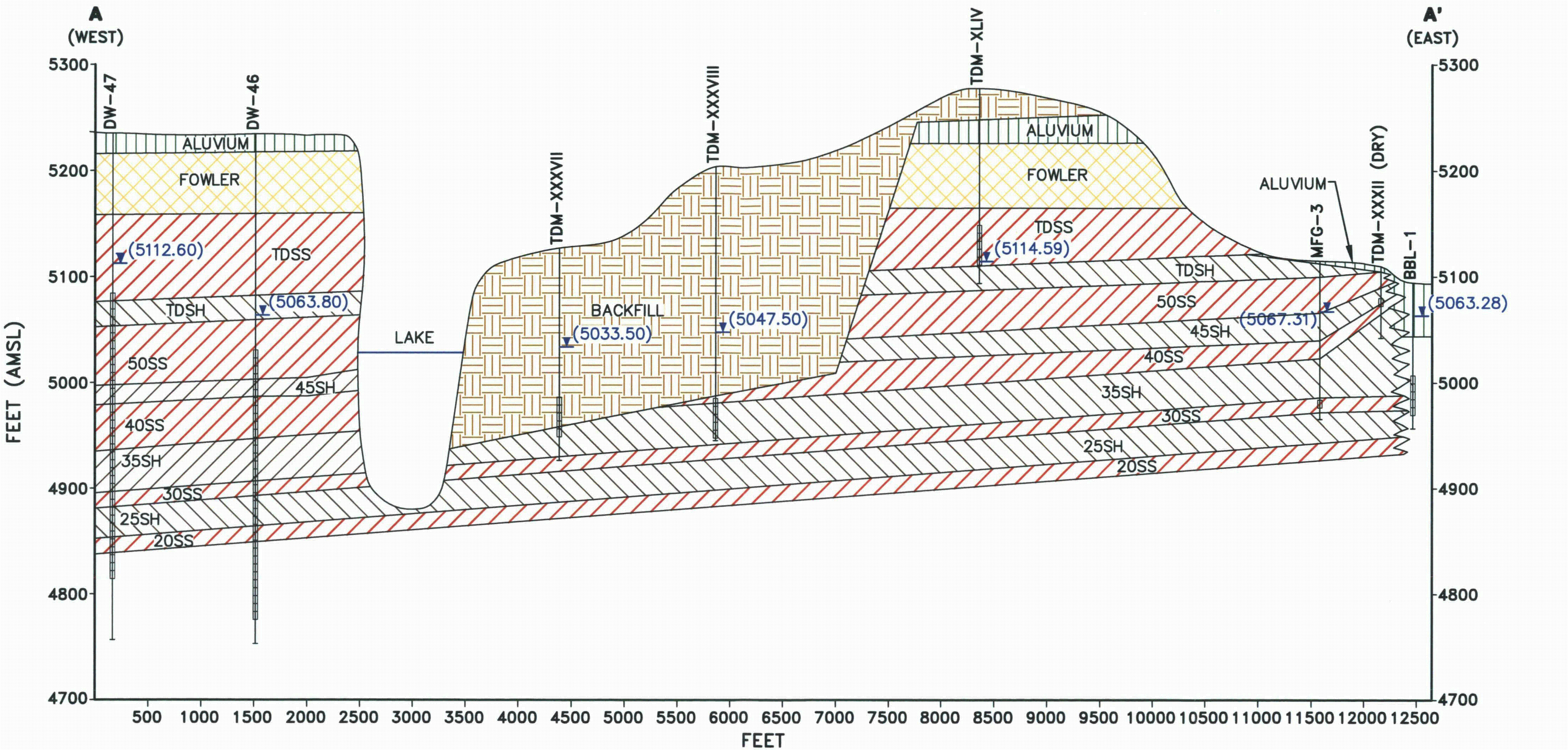
2.1.1 Stratigraphy

The geology of the Site consists of the sedimentary deposits within the Powder River Basin of northeastern Wyoming. The units of significance to this study lay within the upper Fort Union Formation (Paleocene), and, to a lesser extent, the lower Wasatch Formation (Eocene). A stratigraphic column of these units is presented on Figure 3. Regionally, the strata dip towards the west (Hunter, 1999), but in the study area, dip is approximately 0.5 degrees to the northwest. Figures 4 and 5 present a conceptual cross sections of the Site from west to east and north to south, respectively.



(From EPRCO, 1983)

Figure 3 Generalized Stratigraphic Column, Highland Area



NOTE:

1. SEE FIGURE 2 FOR CROSS-SECTION LOCATION IN PLAN VIEW

LEGEND:

- DW-47 — WELL/BORING ID
- BORING
- (5063.80) — GROUNDWATER ELEVATION (AMSL)
- WELL SCREEN
- BOTTOM OF BORING
- LITHOLOGIC CONTACT (DASHED WHERE INFERRED)
- POND
- FOWLER
- ALUVIUM
- SANDSTONE
- SHALE
- BACKFILL

GROUNDWATER ELEVATION (AMSL)

0 100' 200'
GRAPHIC SCALE (VERTICAL)

0 1000' 2000'
GRAPHIC SCALE (HORIZONTAL)

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FIGURE 4
CROSS SECTION A-A'

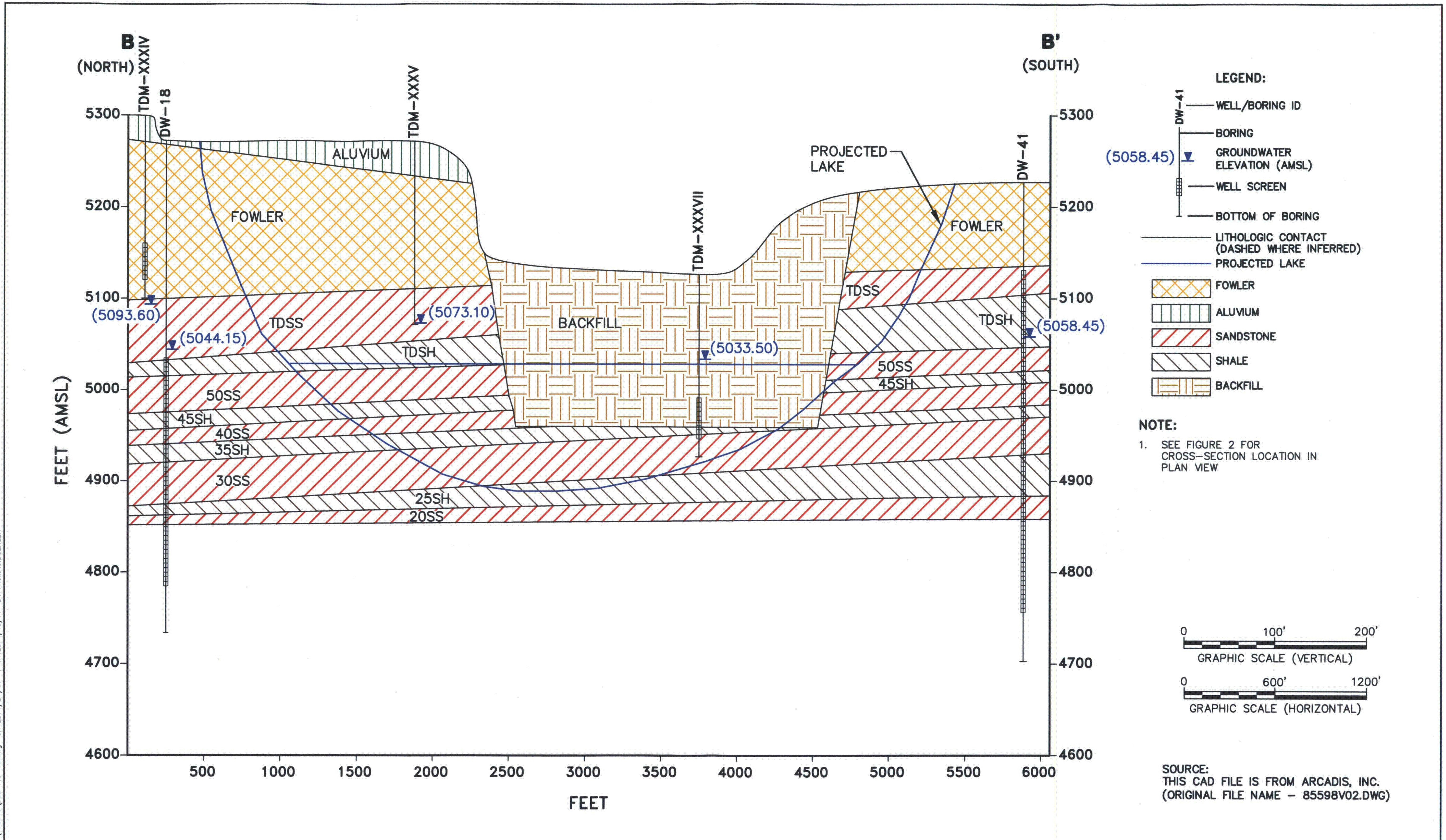

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FIGURE 5
CROSS SECTION B-B'

The Highland Sandstone Unit (HSU) of the Fort Union Formation is the host rock of most of the uranium ore in the area. The unit is 120 to 150 feet thick and consists of sand channel and floodplain facies (Hunter, 1999). The unit is divisible into three sandstone members that are separated by intervals of claystone and siltstone. Informal nomenclature refers to the sandstones from stratigraphically highest to lowest as 50-Sand, 40-Sand, and 30-Sand, and the fine-grained intervals as 45-Shale and 35-Shale (Hunter, 1999). The sandstones have also been referred to as the upper, middle, and lower sandstone members (Exxon Research Production Company [EPRC], 1983). All three members are laterally extensive throughout the study area and are generally composed of fine- to medium-grained, poorly lithofied, arkosic sandstone that typically ranges from 20 to 50 feet in thickness. The fine-grained intervals are approximately 9 feet and 35 feet thick in the area of the Pit Lake, respectively, but, in some locations, are altogether absent, and the sandstones are in vertical contact (Hunter, 1999).

Overlying the HSU in the study area is the Tailings Dam Shale (TDSH), a laterally pervasive interval of siltstone and claystone that ranges from 20 feet to 50 feet in thickness. The TDSH is overlain by the Tailings Dam Sandstone (TDSS). The TDSS is composed of sand channel and floodplain facies similar to the sandstone members of the HSU and is typically 30 feet to 50 feet in thickness. Unlike the underlying deposits, the TDSS is not laterally extensive across the study area. This unit has a well-defined northwest-trending western edge approximately 1 mile west of the Pit Lake (Hunter, 1999). Along this line, the TDSS grades laterally to finer-grained siltstone and claystone. Overlying the TDSS is a thick sequence of interbedded sandstone, siltstone, and claystone of the upper Fort Union Formation and the lower Wasatch Formation.

The undifferentiated Fort Union and Wasatch deposits are exposed at the surface over the majority of the area. Because the strata dip to the northwest, and topography slopes to the southeast, depth to the TDSS, TDSH, and HSU decreases from northwest to southeast until these units eventually crop out in the eastern portion of the Site.

2.1.2 Aquifer Properties

Numerous tests have been conducted in the vicinity of the Site in order to determine the hydraulic characteristics of the stratigraphic units. A compilation of the results of hydrologic tests conducted near the Site, the reported values of horizontal and vertical hydraulic conductivity/permeability, and storage coefficient are presented in Appendix A. Estimates of specific yield are not present in the data set, most likely due to the fact that specific yield can be determined only in unconfined conditions, and the units are confined throughout most of the study area. These results are summarized in Table 1, which presents the log mean, maximum, and minimum property values of each unit. The log mean of the horizontal hydraulic conductivity values in the TDSS and the Highland Sandstone members are 2.2 feet per day (ft/day) and 2.1 ft/day, respectively. The log mean values of vertical hydraulic conductivity are comparable to the horizontal estimates, suggesting that there is little to no vertical anisotropy in the sandstone units. Results from the TDSH, however, do imply anisotropy; the log mean horizontal hydraulic conductivity value (1.4×10^{-3} ft/day) is approximately an order of magnitude greater than the log mean vertical hydraulic conductivity value (9.8×10^{-5} ft/day). Storage coefficient for all of the units ranges from 1.2×10^{-5} to 4.8×10^{-4}.

Table 1 Summary of Hydraulic Properties

Parameter		Hydrologic Unit			
		TDSS	**TDSH**	**HSU Sandstone Members**	**HSU Shale Members**
Kh (ft/day)	n	16	6	74	0
	Min	0.0024	8.58×10^{-5}	1.80×10^{-2}	
	Max	23	2.66×10^{-2}	1.90×10^{1}	
	Log Mean	2.2	1.42×10^{-3}	2.1	
Kv (ft/day)	n	3	3	3	17
	Min	8.56	4.82×10^{-5}	1.79	2.64×10^{-7}
	Max	15.8	2.66×10^{-4}	9.9	2.61×10^{-3}
	Log Mean	10.6	9.82×10^{-5}	4.4	2.00×10^{-5}
S	n	1	1	10	0
	Min	4.80x10-4	2.40×10^{-4}	1.20×10^{-5}	
	Max	4.80x10-4	2.40×10^{-4}	2.50×10^{-4}	
	Log Mean	4.80x10-4	2.40×10^{-4}	6.52×10^{-5}	

Notes:
ft/day - feet per day
HSU - Highland Sandstone Unit
K_h - horizontal hydraulic conductivity
K_v - vertical hydraulic conductivity
max - maximum
min - minimum
n - Number of estimates
TDSH - Tailings Dam Shale
TDSS - Tailings Dam Sandstone

The existing database of hydraulic properties does not include estimates for the backfill material in Pits 1 and 2 (Figure 2). As part of this investigation, single well pump tests were conducted at two wells completed in the backfill to provide this information. On October 16, 2002, short-term tests were conducted at Wells 170 and 173. Well 170 was pumped at an average discharge rate of 3.9 gallons per minute (gpm) for approximately 8 hours, and Well 173 was pumped at 2.0 gpm for 75 minutes. Pumping and recovery data collected during both tests were analyzed with multiple methods. The average calculated transmissivity for Wells 170 and 173 are 26 square feet per day (ft^2/day) and 7 ft^2/day, respectively. Based on the saturated thickness at each well, the average hydraulic conductivity is 0.32 ft/day and 0.30 ft/day, respectively. Estimates of specific yield and storage coefficient have not been estimated for Wells 170 and 173 because they cannot be accurately determined from a single well test. A complete discussion of the testing procedure and the analytical methodology is presented in Appendix B.

2.1.3 Hydrologic Stresses

The Site is located in a regional groundwater discharge area. Prior to mining activity at the Site, regional groundwater flowed through the upper Fort Union Formation strata from the west, north, and south, and was discharged at outcrops of these strata along North Fork Box Creek and its tributaries (Dames & Moore, 1980). Little information is available regarding the steady-state water level at the Site prior to mining operations. Dames & Moore (1971) reported static water levels in tests wells at the Site at 5,112 feet above mean sea level (amsl). The static water level in Dewatering Well No. 4 was reported at 5,110 feet amsl in March 1971. Dewatering Well No. 4 is believed to have been located near Pit 1. These levels probably represent pre-mining conditions at the Site (Dames & Moore, 1978).

Beginning in 1972, Exxon Minerals Company/Exxon Coal and Minerals Company commenced mining operations at the Site that created a major disruption to the natural groundwater flow field. Surface or open-pit mine Pits 1 through 4 were sequentially excavated from 1972 to 1984 (Figure 2). During this time, total groundwater withdrawal from pit sumps and dewatering wells typically exceeded 1,000 gpm. The general chronology of the surface mine operations is presented in Table 2. Following excavation, Pits 1 and 2 were backfilled with overburden materials, while Pits 3 and 4 remained open. In March 1984, dewatering of Pits 3 and 4 ceased, the Pit Lake began to fill, and the large cone of depression in the potentiometric surface began to recover. Figure 6 presents hydrographs of the Pit Lake and surrounding wells that display the recovery of the potentiometric surface after the completion of mining operations.

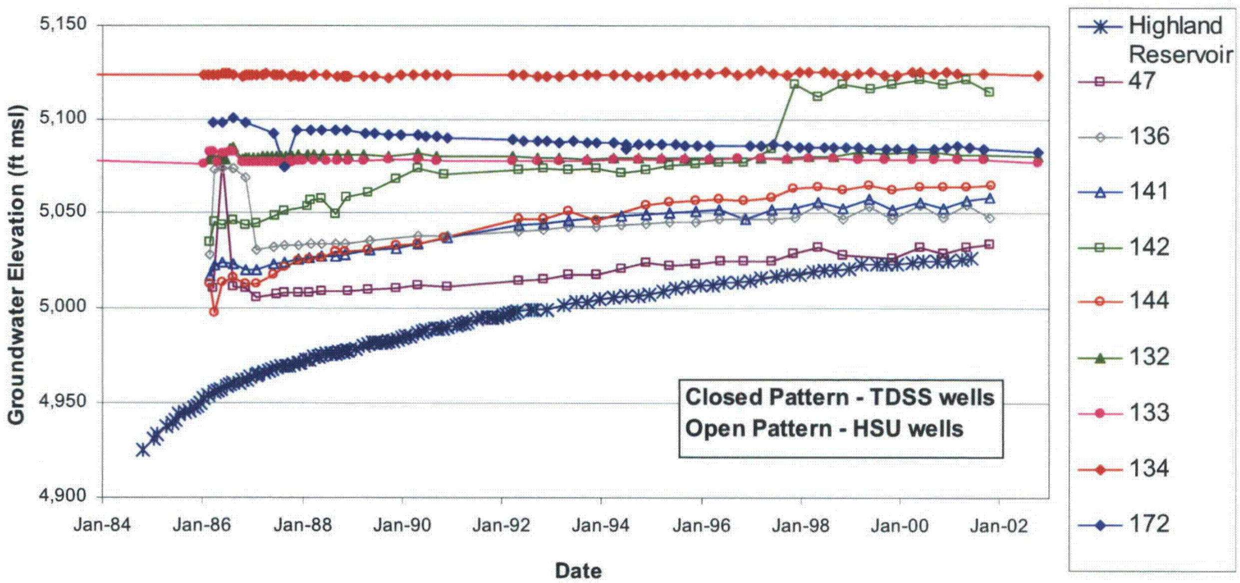


Figure 6 Hydrographs Near Highland Pit Lake

Table 2 Chronology of Mine Operations

Reporting Period (September to September)	Surface Mine				Underground Mine	Comments
	Pit 1	Pit 2	Pit 3	Pit 4		
1970 - 1973	Primary stripping beginning September 1970	Primary stripping beginning December 1972	- -	- -	- -	
1973 - 1974	Excavation continues	Excavation suspended in April 1974	- -	- -	Development beginning October 1973	
1974 - 1975	Excavation continues	Excavation resumed in February 1975	- -	- -	Excavation continues	
1975 - 1976	Excavation continues, pit expanded with "East Extension"	Excavation continues	- -	- -	Excavation continues	
1976 - 1977	Main pit mined out in November 1976, East Extension excavation continues, water production 300 gpm	Excavation continues, water production 500 gpm	Primary stripping beginning	- -	Excavation continues	
1977 - 1978	All excavation completed, backfilling	Excavation continues in eastern pit, backfilling in northern pit	Phase I (SE pit) excavation continues, total water production from 2 and 3 is 600 gpm	- -	Excavation continues	

Table 2 Chronology of Mine Operations (continued)

Reporting Period (September to September)	Surface Mine				Underground Mine	Comments
	Pit 1	Pit 2	Pit 3	Pit 4		
1978 - 1979	Backfilling	Excavation continues in west and south, backfilling	Phase I excavation continues, total water production from Pits 2 and 3 is 600 gpm	- -	Excavation continues	
1979 - 1980	Backfilling	Backfilling	Excavation in Phase I and II (NW pit), 600 gpm from all pits	Primary stripping beginning	Excavation continues	
1980 - 1981	Backfilling	Backfilling	Phase II excavation, 450 gpm from all pits	Excavation continues	Excavation continues	
1981 - 1982	- -	- -	450 gpm from all pits	Excavation continues	Excavation continues	No ore from surface mine
1982 - 1983	- -	- -	Excavation and backfilling, 400 gpm from all pits	Excavation continues	Completed	
1983 - 1984	- -	- -	Excavation completed some backfilling, 400 gpm from all pits	Excavation completed	Reclamation	Mining completed in March 1984, milling completed in June 1984

Source: Annual Wyoming Department of Environmental Quality Reports
Notes: gpm - gallons per minute

Additional groundwater withdrawal from underground mining occurred less than 1 mile north of the surface mine, at the Buffalo Shaft (Figure 7). Mine dewatering at this facility occurred from 1973 to 1983 (Table 2). Another underground mine was operated at the Golden Eagle Shaft (North Morton Mine), located approximately 3.5 miles west of the Site. Because of its distance from the Site, the effect of this operation on the Site hydrogeology is considered to be negligible.

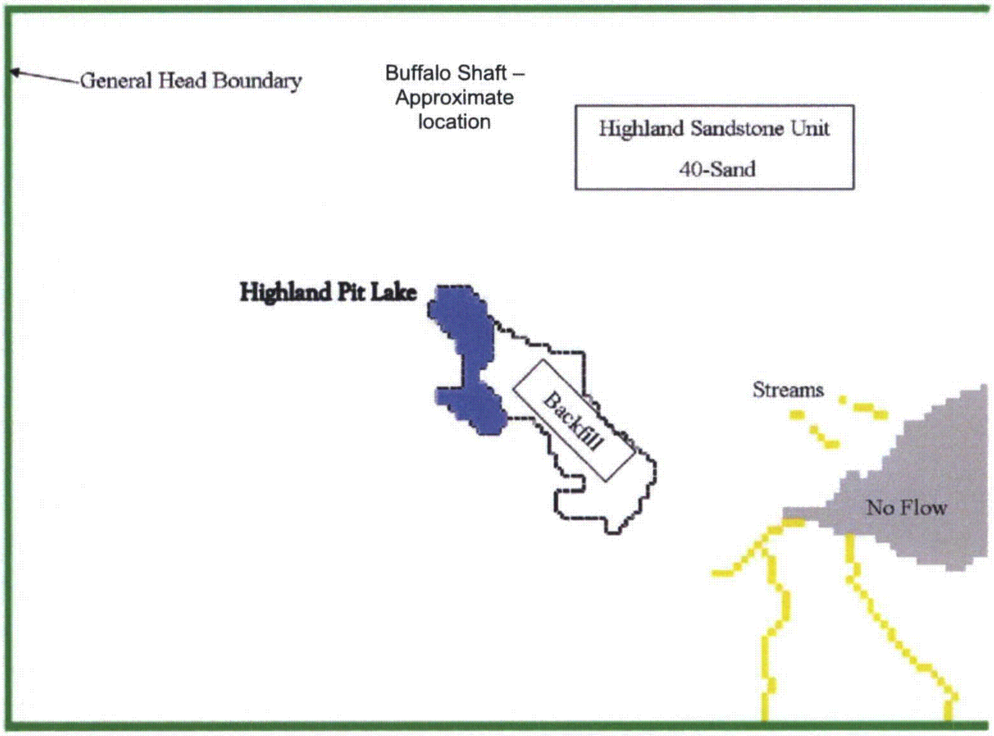


Figure 7 Layer 4 Properties and Boundary Conditions

The hydrogeology at the Site was also impacted by the placement of mill tailings in the unnamed tributary of North Fork Box Creek east of the surface mine operations (Figure 2). Tailings were deposited in this drainage beginning in 1972 and continued until the end of milling operations in June 1984. The deposition of tailings slurry over time created a groundwater mound beneath the impoundment. This mounding is evident in hydrographs from wells completed in both the TDSS and the 50-Sand (Figure 8). Waste, Water, and Land (WWL, 1984) estimated that flux from the tailings reached a maximum of approximately 180 gpm (34,500 cubic feet per day [ft^3/day]) in 1984 and decreased to 3.5 gpm (670 ft^3/day) by 1992.

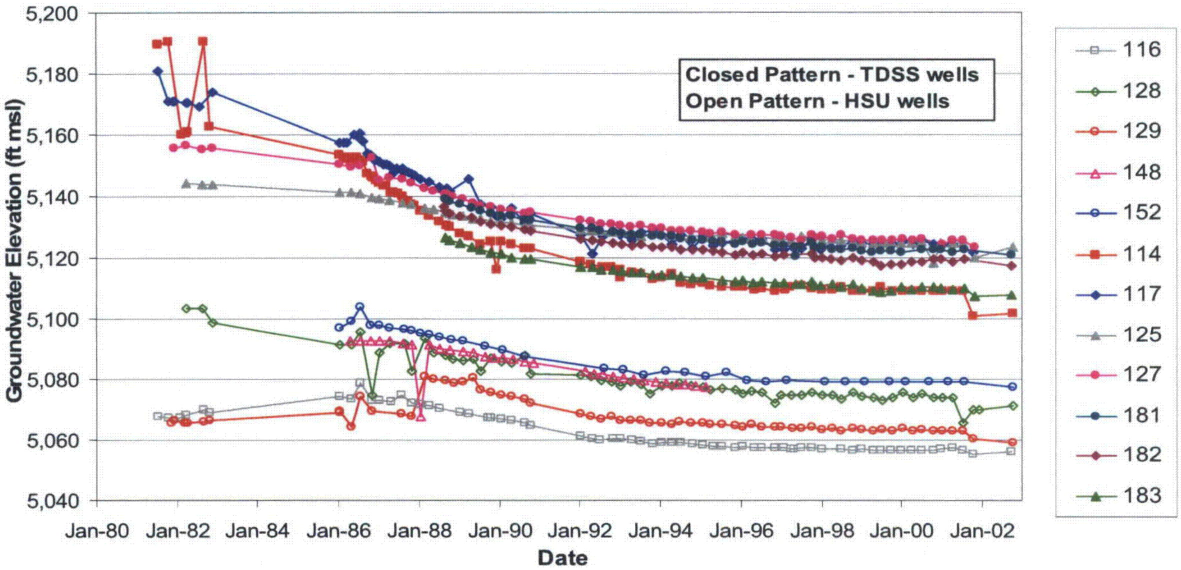


Figure 8 Hydrographs Near Tailings Impoundment

Other groundwater-related activities near the Site include the Corrective Action Program (CAP) and the in-situ mining operations to the north and west of the Pit Lake. These activities are not considered to be significant to the long-term Site hydrology. In November 1989, ExxonMobil Corporation (Exxon) began operating a CAP that consisted of pumping five existing wells (114, 117, 175, 177, and 178) completed in the TDSS located to the south and west of the tailings impoundment. Average annual pumping rates in the wells were generally less than 2 gpm, and hydrographs of these wells do not indicate any significant impact to the water levels (Figure 8). Beginning in 1985, in-situ leaching operations were conducted by Everest Minerals Corporation and Power Resources, Inc. in well fields to the north and west of the Site. Although injection and extraction rates of this operation are proprietary information, they would likely be in balance or have a small net extraction, and have no significant impact on groundwater flow conditions.

2.2 Pit Lake Hydrology

The present day configuration of the Pit Lake is the remnants of Pits 3 and 4, and the westernmost part of Pit 2 (Figure 2). Since it began to fill in 1984, the Pit Lake has risen 130 feet to an elevation of 5,030 feet amsl. The rate of water level rise has gradually decreased over time from an average rate of 30.0 feet per year in late 1984, to 0.9 feet per year between April 2000 and January 2003. The Pit Lake hydrograph is presented on Figure 6. The Pit Lake currently covers an area of 110 acres. Pit Lake geometry is presented on Figure 9, which displays the increase in Pit Lake volume and surface area with elevation.

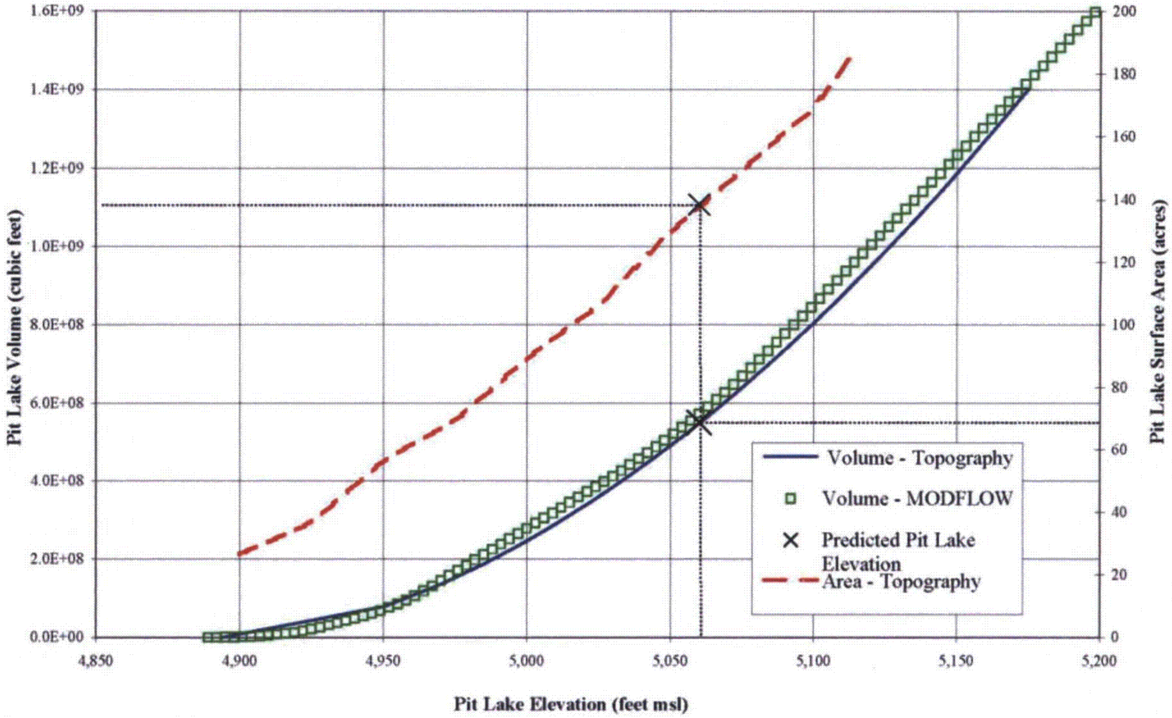


Figure 9 Pit Lake Geometry

ERPC and Shepherd Miller, Inc. (SMI) have conducted investigations of the Pit Lake hydrologic balance (ERPC, 1983; SMI, 1998). These studies identified the various components of the Pit Lake hydrologic budget. Hydrologic inflows to the Pit Lake include: 1) groundwater from the HSU and TDSS; 2) direct precipitation; 3) surface runoff of rain and snowmelt; and 4) discharge from the perched aquifer in the Antelope Draw drainage (Figure 2). To date, the elevation of the Pitt Lake has reached only the stratigraphic level of the TDSH; therefore, groundwater has entered the Pit Lake only via the HSU. Groundwater inflow is driven by the hydraulic gradient between the Pit Lake and the groundwater system; therefore, as the Pit Lake level rises, groundwater inflow will continue to decrease until steady-state conditions have been reached.

Precipitation data were reviewed from the three weather stations closest to the Site. The mean annual precipitation from these locations is 12.06 inches per year (0.0048 ft/day). Precipitation data are presented and summarized in Appendix C. The volume of water added to the Pit Lake from direct precipitation is equal to the precipitation rate multiplied by the surface area of the Pit Lake. Therefore, the direct precipitation component will increase as the Pit Lake fills and the surface area increases. Surface runoff and perched aquifer discharge were estimated by SMI (1998). These investigators assumed that surface runoff and perched aquifer discharge essentially act as constant inflows to Pit Lake, with flow rates of 7,260 ft^3/day and 14,520 ft^3/day, respectively.

Pit Lake outflows include: 1) evaporation; and, potentially, 2) groundwater to the HSU and TDSS. The mean annual evaporation rate from two stations near the Site is 45.2 inches per year (0.0103 ft/day) (Appendix C). Evaporation, like direct precipitation, is a function of the Pit Lake surface area and will increase as the Pit Lake fills. Outflow to the HSU and TDSS will occur only if the Pit Lake elevation reaches a sufficient level (5,070 ft amsl) to create a positive hydraulic gradient from the Pit Lake to the discharge area (North Fork Box Creek and its tributaries). If this occurs, the Pit Lake will become a flow-through system in which net inflows are balanced by net outflows.

The elevation of the Pit Lake will continue to rise until the hydrologic outflows equal the inflows. At this point, there will be no change in Pit Lake storage, and Pit Lake elevation will remain essentially constant. This will eventually occur as: 1) groundwater inflow decreases due to decreasing hydraulic gradient between the Pit Lake and groundwater system; 2) net evaporation increases due to increasing surface area as the Pit Lake fills; and 3) the Pit Lake potentially becomes a flow-through system. If Pit Lake inflows and outflows reach equilibrium before the Pit Lake elevation reaches the elevation of the discharge areas, then Pit Lake will remain a groundwater sink. In that case, the Pit Lake will not develop into a flow-through system.

3.0 GROUNDWATER MODEL

A numerical groundwater model has been developed to simulate future Pit Lake and groundwater conditions at the Site. The model simulates transient heads in both the Pit Lake and groundwater system according to the prescribed boundary conditions, initial conditions, and hydraulic properties. The simulation represents the time period from the beginning of mining operations in 1972 until 2100, when steady-state conditions will be well established. As such, the model simulation includes dewatering of the surface and underground mines, as well as subsequent Pit Lake filling and groundwater recovery.

Model input data were generated from the conceptual and quantitative knowledge of the Site discussed in Section 2.0. These values were then calibrated to measured Pit Lake and groundwater conditions to optimize the model's capacity to predict future groundwater and Pit Lake conditions.

3.1 Code

The U.S. Geological Survey (USGS) code, MODFLOW-2000, (Harbaugh et al., 2000) was used to solve the groundwater flow equations. MODFLOW-2000 is a three-dimensional, finite difference model that simulates groundwater flow through heterogeneous porous media. Its modular design allows for the incorporation of many different components, such as recharge, evapotranspiration, well pumpage, drains, rivers, lakes, and other boundary conditions, into the flow problem. Additionally, the model can simulate either confined or unconfined conditions for either transient or steady-state scenarios. MODFLOW-2000 also has the capability to solve equations other than the groundwater flow equation, such as solute transport and parameter estimation problems.

Groundwater Vistas Version 3.28 (Environmental Simulations, Inc., 2001) was used as a pre- and post-processing modeling environment in conjunction with MODFLOW-2000. The program couples a model design system with comprehensive graphical analysis tools, provides visualization of model development and results, and allows for enhanced model quality and accuracy.

3.2 Temporal Discretization

The simulation time line is divided into three basic intervals: 1) mining operations from October 1, 1972 until January 1, 1984; 2) Pit Lake filling and groundwater recovery from January 2, 1984 to January 1, 2003; and 3) Pit Lake filling and groundwater recovery from January 2, 2003 to January 1, 2100. The first interval represents the period of dewatering and depression of the potentiometric surface. The second interval represents groundwater recovery and the filling of the Pit Lake during the time period for which Pit Lake and groundwater elevation data are available for comparison to the model results. This interval was used for model calibration. The last interval of the simulation time line represents the model predictions of future groundwater recovery and Pit Lake filling.

The duration of the simulation is 128 years, and ends in the year 2100, allowing ample time for steady-state conditions to develop. The simulation is composed of 25 stress periods; the first 21 stress periods are generally annual increments from 1972 until 1992. During this part of the simulation, a large number of stress periods are required to represent the dynamic nature of pit dewatering/filling and tailings seepage. After 1992, stress period length was increased due to the slowing of Pit Lake filling and tailings seepage.

3.3 Spatial Discretization

The model domain represents a 20-square-mile area surrounding the Site (Figure 2). The domain is discretized into 100 rows, 139 columns, and 5 layers, and grid spacing is 200 feet in both the X and Y directions. A cross section of the model domain is presented on Figure 10. Figure 7 and Figures 11 through 14 present the distribution of the stratigraphic units in the five model layers. Layer 1 represents the undifferentiated sediments of the Fort Union and Wasatch Formations that overlie the TDSS horizon. Layer 2 represents the TDSS horizon and includes property zones that represent the TDSS and the finer-grained deposits where the TDSS is not present (Hunter, 1999). Layers 3, 4, and 5 represent the HSU sandstone members, 50-Sand, 40-Sand, and 30-Sand, respectively. The low-permeability TDSH, 45-Shale, and 35-Shale are implicitly modeled. In this approach, low-permeability units are represented only by a vertical conductance term between the overlying and underlying layers. Vertical fluxes are calculated based upon the vertical hydraulic conductivity and thickness (i.e., distance between sandstone units) of the low-permeability units. MODFLOW simulates implicitly modeled aquitards by estimating vertical groundwater flow only; groundwater flow in a horizontal direction is assumed to be negligible. This assumption is consistent with the hydrostratigraphic units identified in the area of the Pit Lake.

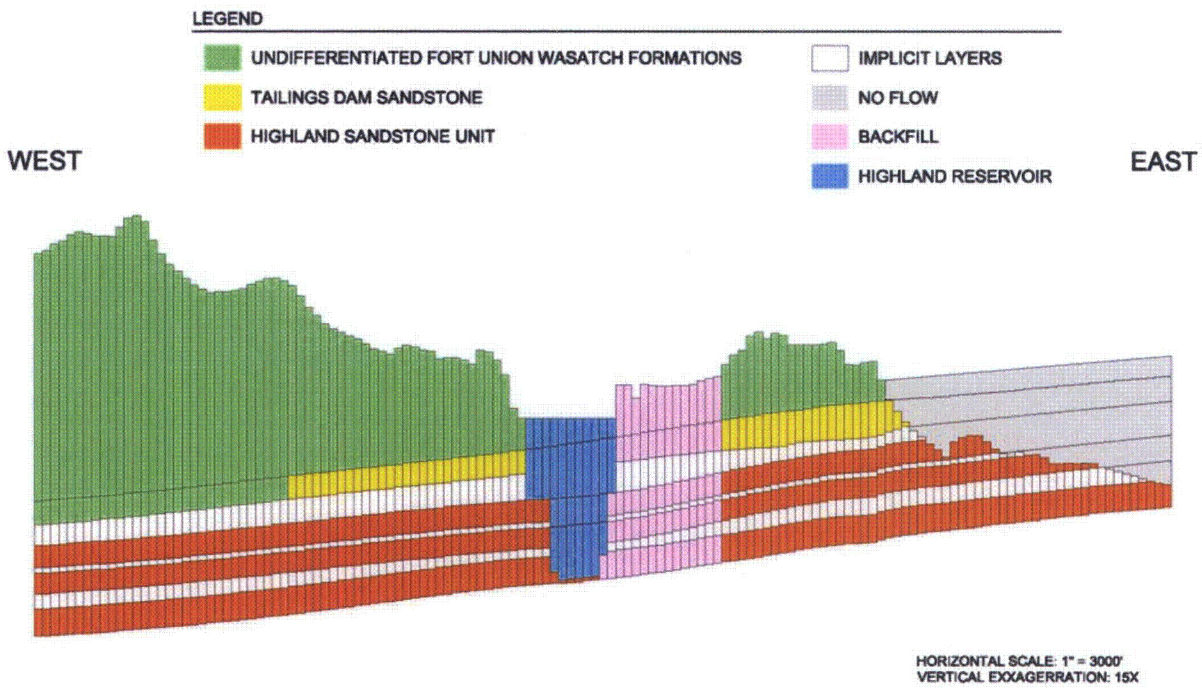


Figure 10 Model Cross Section Along Row 56

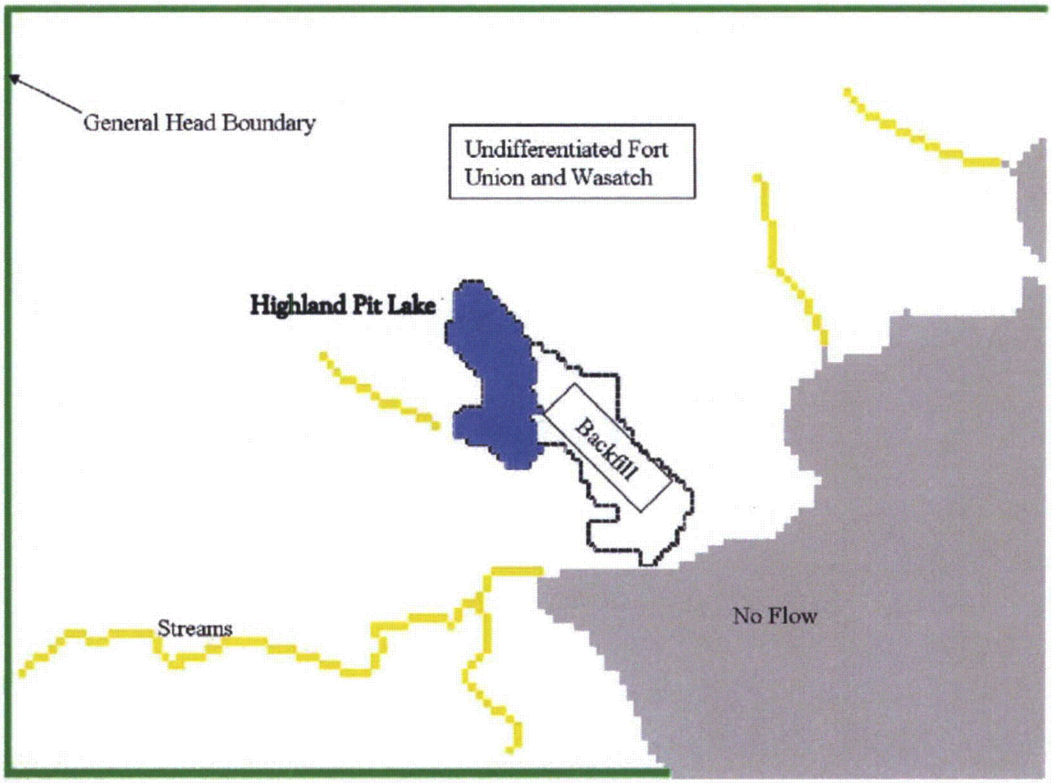


Figure 11 Layer 1 Properties and Boundary Conditions

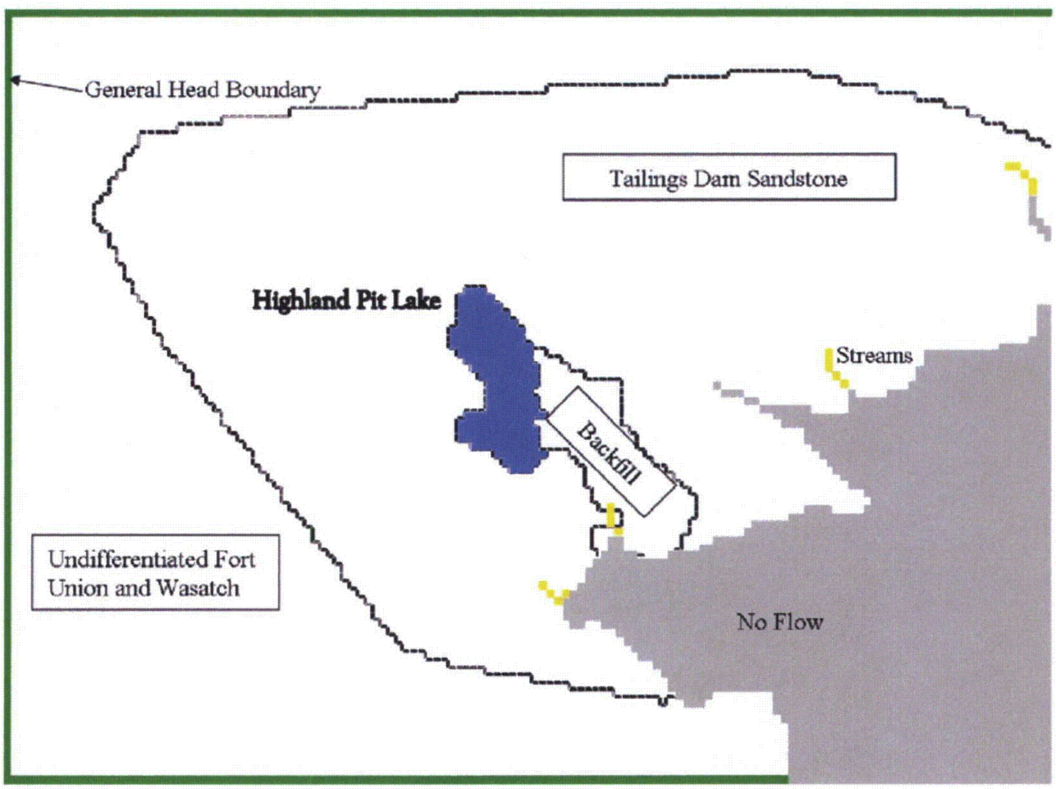


Figure 12 Layer 2 Properties and Boundary Conditions

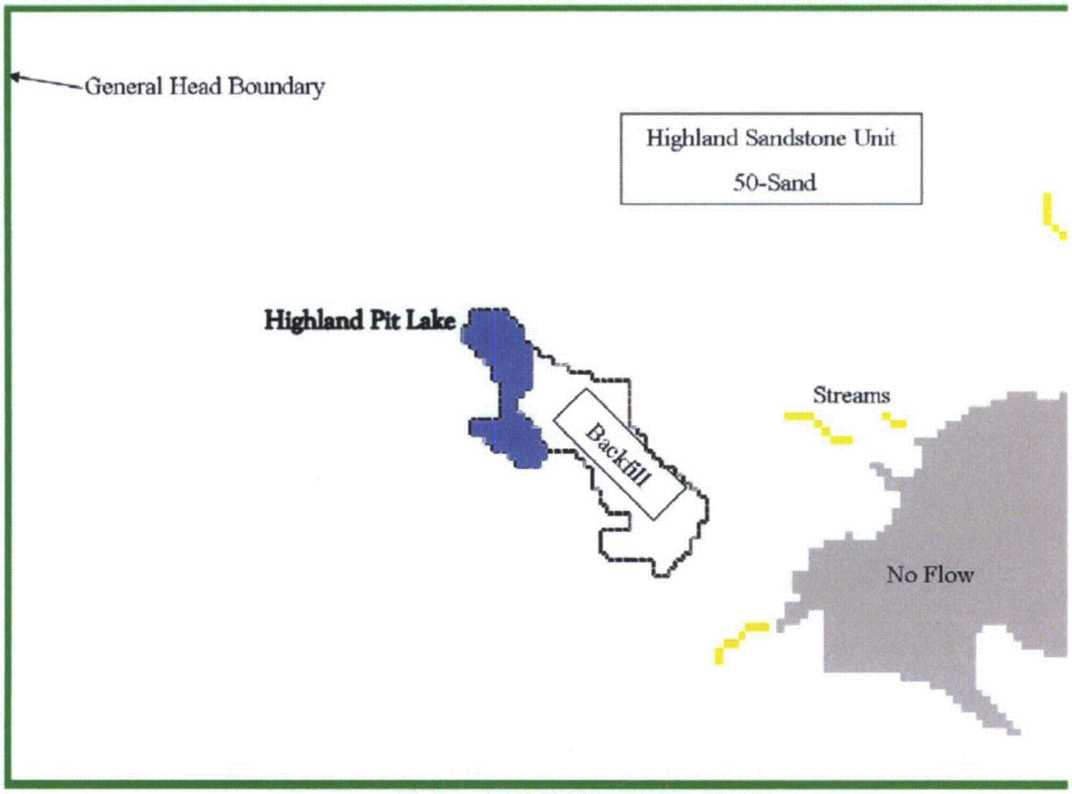


Figure 13 **Layer 3 Properties and Boundary Conditions**

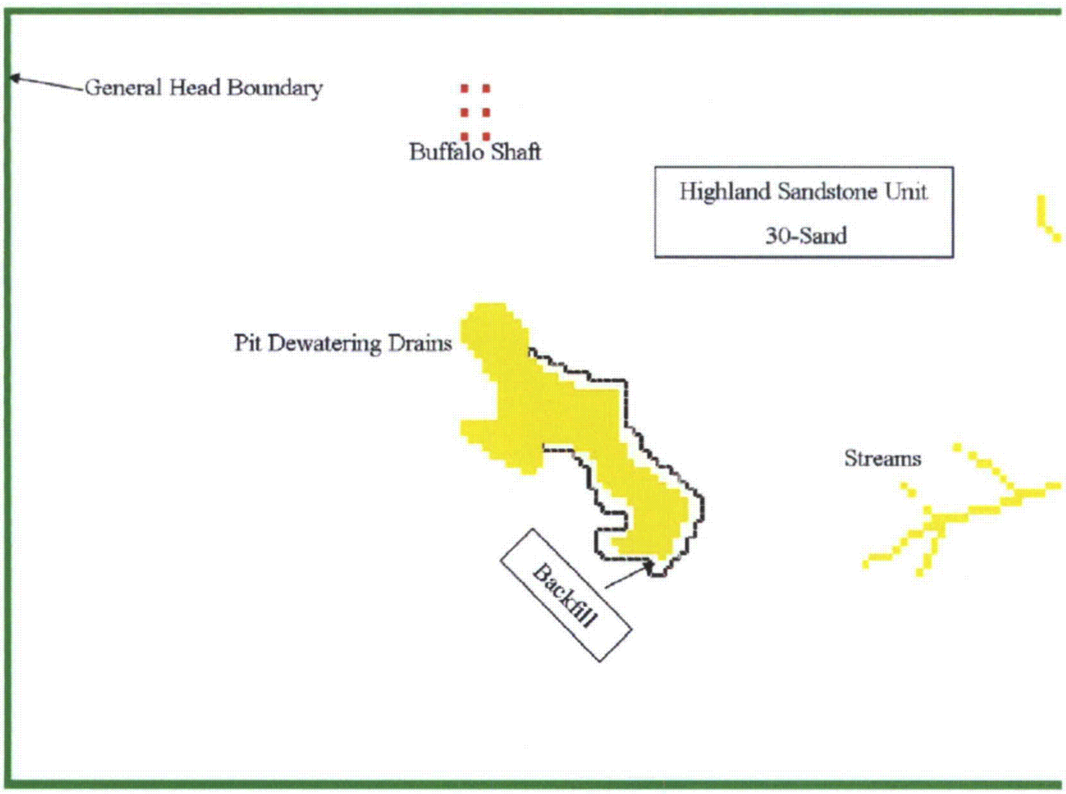


Figure 14 **Layer 5 Properties and Boundary Conditions**

The top of Layer 1 represents current Site topography. Other layer tops and bottoms represent the respective stratigraphic contacts for each layer and were estimated based on lithologic logs from Site wells. The elevation of the top and bottom of Layer 2 (TDSS) and the top of Layer 3 (50-Sand) across the Site were generated by spatial interpolation of the lithologic data. Data for the deeper stratigraphic contacts are relatively sparse, and these tops and bottoms were determined by assuming constant thickness across the Site. Model thickness of the 50-Sand, 40-Sand, and 30-Sand are 33 feet, 30 feet, and 40 feet, respectively. The distance between these layers (i.e., the thickness of 45-Shale and 35-Shale) have been modeled as 9 feet and 20 feet, respectively.

3.4 Boundary Conditions

Hydrologic boundary conditions incorporated into the model include flux through the west, north, and south edges of the domain; discharge to streams; dewatering of the four open-pit mines; dewatering of the Buffalo Shaft; and seepage from the tailings impoundment. Other Site activities, such as in-situ mining operations and CAP pumping, are not simulated because these stresses are considered to be negligible to the overall, long-term water balance. The influence of the in-situ leach well fields to the north and west of the Pit Lake are assumed to have no significant influence on Pit Lake hydrology. The operation of the in-situ leach well fields, by design, maintains a small hydraulic gradient toward the in-situ leach (ISL) well field. This operational procedure, which has negligible impact on the overall regional ground flux to the Pit Lake, prevents loss of the mining solution to the surrounding aquifer material and maximizes recovery of the pregnant mining solution. Figure 7 and Figures 11 through 14 present the locations of the boundary conditions incorporated into the model in each of the five layers.

As described in Section 2.1.1, the stratigraphic units outcrop in the eastern part of the Site. As a result, there are areas within the model layers where the simulated stratigraphical unit is not present because it has been removed by erosion. In these areas (i.e., east of the unit outcrop), no flow boundary conditions have been assigned to model cells (Figure 10).

3.4.1 Groundwater Flux

General head boundary cells (GHB) were placed along the northern, western, and southern domain edges in all five layers to simulate flow into the model from outside the domain. The function of the GHB is to estimate flow from a constant head source that is external to the model domain. Flow between the external source and the model domain is based upon on Darcy's Law, as follows:

$$Q_{i,j,k} = C_{i,j,k}(h_{GHB} - h_{i,j,k})$$

Where:

$Q_{i,j,k}$	=	flux between external source and cell i, j, k
$C_{i,j,k}$	=	conductance between external source and cell i, j, k
h_{GHB}	=	head at external source
$h_{i,j,k}$	=	head in cell i, j, k

Flux derived from the GHB cells was initially based on the highest pre-mining head (5,433 ft amsl) approximately 5 miles from the model domain and the conductance of the aquifer material ($C_{i,j,k}$). Figure 15 illustrates the pre-mining heads and gradients from which the initial GHB value was developed (Dames and Moore, 1980). Figure 15 also illustrates a circle described by the 5-mile radius from the Pit Lake. However, the head established for the model GHB cells is based on the estimated head 5 miles from the model boundary, which is slightly beyond the limits of Figure 15 but sufficiently far from the model domain to prevent perturbations of the regional flow field due to Site activities such as pit dewatering. Therefore the use of a pre-mining head value should remain appropriate during and after the mining period. The GHB head value of 5,433 ft amsl is a reasonable approximation of the heads at this distance from the Site.

Values of $C_{i,j,k}$ were adjusted to obtain approximate flux to the model domain. As stated above, flux is a function of head difference and conductance. Head was not considered as a calibration variable and was set as a constant. Conductance was varied to reasonably match the observed heads within the model domain.

As a verification of the estimated groundwater flux from the GHB, flux was also estimated using the Darcy's Law equation (Q=KiA). Fluxes were calculated for each layer using the values summarized in Table 3 and were compared to the model calculated fluxes at the same boundary and layer. Darcy fluxes were generally consistent with, but roughly 30% less than, the model calculated fluxes. This result is consistent with the slight systematic over-prediction of heads in the model domain. It should be noted that this GHB configuration and slight over-prediction of heads in the model domain is conservative in that it predicts slightly larger groundwater flows than actually may be flowing to the Pit Lake. This would tend to bias the predictions toward higher Pit Lake elevations and an increased likelihood of developing flow-through conditions.

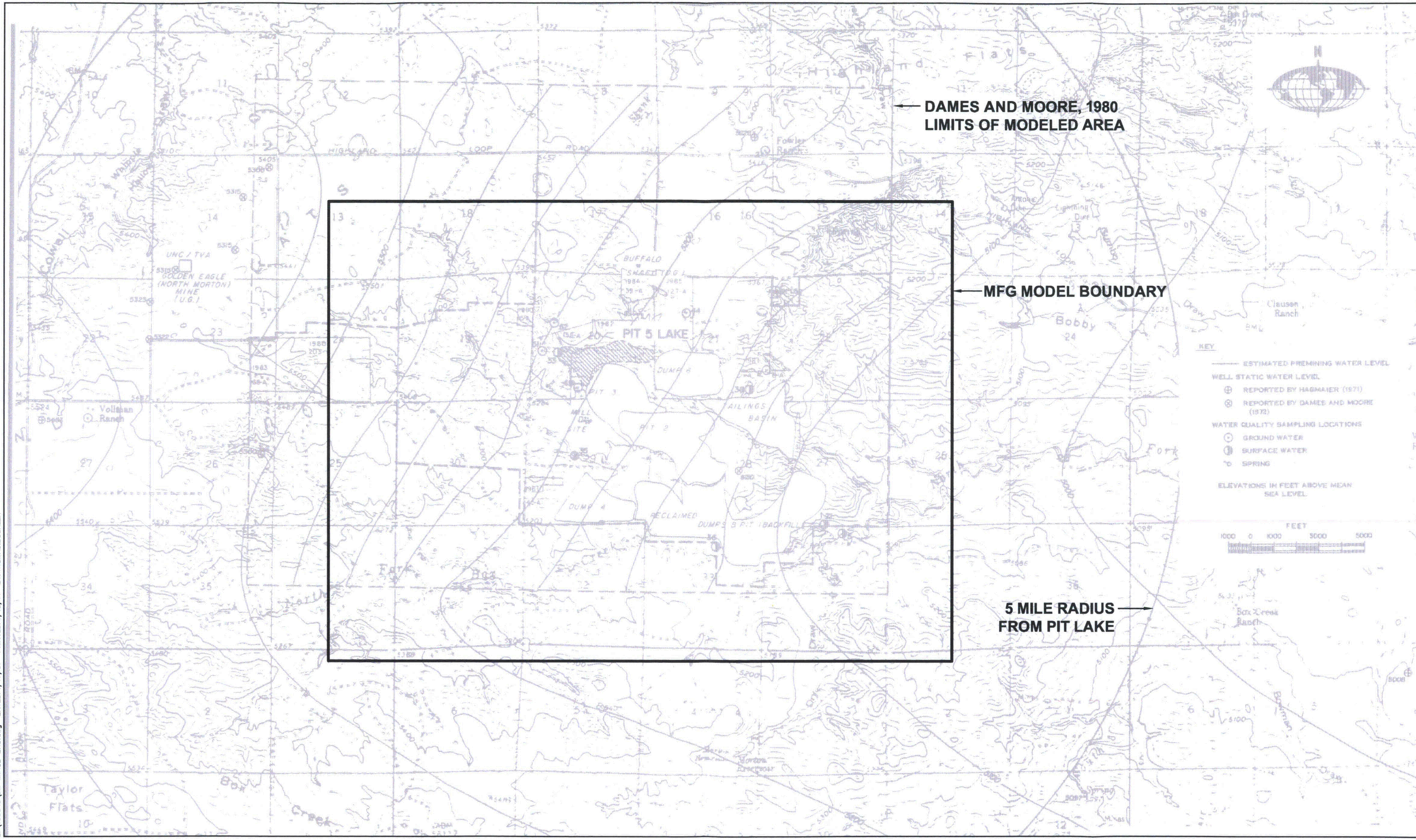
Table 3 Comparison of Calculated and Modeled Groundwater Flux from Western Model Boundary

Layer	k (ft/day)	Length (ft)	Thickness (ft)	Area (ft^2)	Gradient (ft/ft)	Darcy Flux (ft^3/day)	Model Flux (ft^3/day)	Difference (ft^3/day)	Difference (%)
1	0.5	20,000	368	7,360,000	0.0016	5,888	3,131	-2,757	46.82%
2	0.5	20,000	35	700,000	0.0016	560	3,130	2,570	458.93%
3	1.5	20,000	33	660,000	0.0016	1,584	284	-1,300	82.07%
4	1.5	20,000	30	600,000	0.0016	1,440	258	-1,182	82.08%
5	1.5	20,000	40	800,000	0.0016	1,920	344	-1,576	82.08%
total						**11,392**	**7,147**	**-4,245**	**37.26%**

Notes: ft/day - feet per day, ft – feet, ft^3/day - cubic feet per day, % - percent

3.4.2 Streams

Groundwater discharge to streams is simulated with the Drain Package by locating drain cells along stream channels and setting the drain elevation equal to the stream elevation. Drain cells are located along North Fork Box Creek, Antelope Draw, Bobby Draw, and the two unnamed tributaries to North Fork Box Creek east of the tailings impoundment (Figure 7 and Figures 11 through 14). The drain cells are placed in the appropriate layer so that they accurately represent the stream-aquifer interaction as the streams cut down through the stratigraphic section. The drain elevations were determined from USGS 7.5-minute topographic maps (Bobby Draw and Whipple Hollow, WY). The stream bed material in the area is composed primarily of silty sand. Freeze and Cherry (1979) provide estimates of the hydraulic conductivity of various sedimentary materials. The range of values for silty sand is 10^{-5} centimeter per second (cm/s) to 10^{-1} cm/s. An intermediate value of 3.5 ft/day (1.2 x 10^{-3} cm/s) was used in the model drains as being representative of this material and was not varied as part of the calibration process.



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Project No. 180549

April 2007

FIGURE 15
PRE-MINING WATER LEVELS (AFTER DAMES & MOORE, 1980) AND MODEL BOUNDARY

3.4.3 Surface Mine Dewatering and Pit Lake Filling

The model simulation includes both the dewatering of the four open pits and the subsequent filling of the Pit Lake. Pit dewatering is simulated with the Drain Package by placing drain cells in Layer 5 in the locations of the four surface mine pits (the Pit Lake and backfill areas are shown on Figure 2, Figure 7 and Figures 11 through 14). The drain cells are programmed as transient conditions such that they only actively remove water from the model during the stress periods that correspond to the dewatering phase of each pit. The timing of the modeled dewatering is obtained from annual reports submitted to the Wyoming Department of Environmental Quality (WDEQ), which are summarized in Table 2.

During the dewatering period for each pit, the model cells that represent the pit volume are dry; therefore, the assigned properties of these cells are not significant to the solution of these time steps. However, after dewatering in the pits is concluded, the model cells that represent the pit volumes re-saturate, and the properties of these cells are important to the solution. The model cells representing Pits 1 and 2 are assigned the hydrologic properties of the mining backfill.

Pit Lake filling is simulated with the "high K" technique, where the model cells that represent the Pit Lake volume are assigned the hydraulic properties of standing water. These properties include a hydraulic conductivity value significantly higher than the surrounding aquifer (50 ft/day vs. 1.5 ft/day), a specific yield value of 1.0, and a storage coefficient value equivalent to the compressibility of water (10^{-6}). The value 0f 50 ft/day was selected because higher contrast in adjacent model cells yielded numerical instabilities in the model and higher mass balance errors in the results. Additionally, there are no implicit layer "gaps" between layers, and the vertical hydraulic conductivity of the implicit layers (50 ft/day) is also relatively large, so there is no vertical resistance to flow within the Pit Lake. Pit Lake stage is computed in the same manner as heads elsewhere in the domain, but, because of high hydraulic conductivity, there is no gradient across the Pit Lake, and, because of the storage parameters, the model calculates the appropriate volume of water in the Pit Lake cells.

A critical aspect of the "high K" method is an accurate volume-stage relationship of the modeled Pit Lake. If this relationship is not accurate, then flow to/from the Pit Lake will result in an inaccurate calculation of Pit Lake stage. As a result, flow to/from the Pit Lake in the following timestep will be erroneous because it will be based on an incorrect Pit Lake stage. Figure 9 presents the Pit Lake volume-stage relationship determined from Site topography compared to the modeled relationship. This figure demonstrates the strong correlation between modeled and observed volume-stage relationship, and indicates that the flow to/from the Pit Lake will correspond to an accurate change in Pit Lake stage.

The other components of the Pit Lake hydrologic budget, including evaporation (Er: 45.2 inches/year), direct precipitation (Pr; 12.06 inches/year), surface runoff of rain and snowmelt (SR: 7,260 ft^3/year), and discharge of groundwater from the perched aquifer in the Antelope Draw drainage (PA: 14,520 ft^3/year), are incorporated into the model by grouping them into a single flow term (Q) with the following expression.

$$Q = \text{Area} \times (P_r - E_r) + SR + PA$$

$$Q = \text{Area (f2)} \times (-7.566\times10^{-3}\ \text{ft/day}) + 21{,}780\ \text{ft}^3\text{/day}$$

This function is evaluated for each stress period and is applied to the modeled Pit Lake area as a specified flux per-unit area with the Recharge Package. The values of each component are discussed in Section 2.2. Figure 9 describes the stage-volume and stage-area relationships for the Pit Lake.

3.4.4 Tailings Seepage

The addition of water into the system from the tailings impoundment is simulated with the Recharge Package. Initial model estimates of tailings seepage were obtained from WWL (1984). These rates are incorporated into the model as rates per unit area by dividing by the total modeled tailings area. The tailings seepage rate was refined during calibration. As stated in Section 2.1.3, the initial seepage was estimated as 180 gpm in 1984 and was estimated to have diminished to 3.5 gpm by 1992. The final calibrated seepage rates were slightly higher than estimated by WWL (220 gpm in 1984 and 5.1 gpm by 1992). Figure 16 presents the modeled tailings seepage flux as a function of time. Table 4 summarizes the tailings seepage flux values.

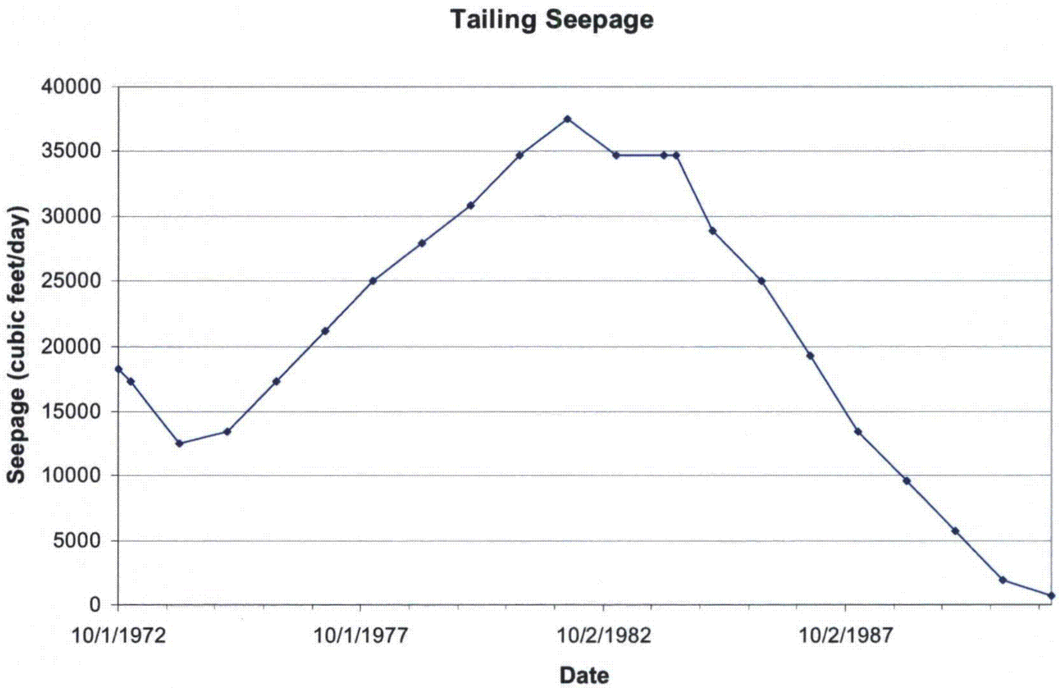


Figure 16 Distribution of Tailings Seepage

Table 4 Summary of Modeled Tailings Seepage

	Stress Period	Start Time Date	Start Time Days	Duration (days)	Tailings Seepage[a] (gpm)	Tailings Seepage (ft^3/day)
Pit Dewatering	1	10/1/1972	0	92	95	18,286
	2	1/1/1973	92	365	90	17,324
	3	1/1/1974	457	365	65	12,512
	4	1/1/1975	822	365	70	13,474
	5	1/1/1976	1,187	366	90	17,324
	6	1/1/1977	1,553	365	110	21,174
	7	1/1/1978	1,918	365	130	25,023
	8	1/1/1979	2,283	365	145	27,911
	9	1/1/1980	2,648	366	160	30,798
	10	1/1/1981	3,014	365	180	34,648
	11	1/1/1982	3,379	365	195	37,535
	12	1/1/1983	3,744	365	180	34,648
	13	1/1/1984	4,109	90	180	34,648
Pit Filling	14	3/31/1984	4,199	276	180	34,648
	15	1/1/1985	4,475	365	150	28,873
	16	1/1/1986	4,840	365	130	25,023
	17	1/1/1987	5,205	365	100	19,249
	18	1/1/1988	5,570	366	70	13,474
	19	1/1/1989	5,936	365	50	9,624
	20	1/1/1990	6,301	365	30	5,775
	21	1/1/1991	6,666	365	10	1,925
	22	1/1/1992	7,031	-7,031	4	674

Notes:
[a] - estimated from WWL (1984) and EPR (1984)
ft^3/day - cubic feet per day
gpm - gallons per minute

3.4.5 Underground Mine Dewatering

The dewatering of the underground mine operations at the Buffalo Shaft is simulated with the Well Package. Timing and rates of the modeled dewatering are obtained from annual reports to the WDEQ (Table 2). Six wells were placed in Layer 5 of the model and were pumped at rates identified from review of the annual reports. Table 5 summarizes the modeled dewatering rates developed form the WDEQ records and applied to the model.

Table 5 Summary of Modeled Underground Mine (Buffalo Shaft) Dewatering

Beginning Date	Ending Date	Stress Period	Stress Period Length (days)	Flux per well (ft^3/day)	Total Flux (ft^3/day)
10/1/1972	1/1/1973	1	92	0	0
1/1/1973	1/1/1974	2	365	0	0
1/1/1974	1/1/1975	3	365	0	0
1/1/1975	1/1/1976	4	365	0	0
1/1/1976	1/1/1977	5	366	0	0
1/1/1977	1/1/1978	6	365	0	0
1/1/1978	1/1/1979	7	365	7,700	46,200
1/1/1979	1/1/1980	8	365	8,341	50,046
1/1/1980	1/1/1981	9	366	11,485	68,910
1/1/1981	1/1/1982	10	365	12,030	72,180
1/1/1982	1/1/1983	11	365	12,030	72,180
1/1/1983	1/1/1984	12	365	12,030	72,180
1/1/1984	3/31/1984	13	90	0	0
3/31/1984	1/1/1985	14	276	0	0
1/1/1985	1/1/1986	15	365	0	0
1/1/1986	1/1/1987	16	365	0	0
1/1/1987	1/1/1988	17	365	0	0
1/1/1988	1/1/1989	18	366	0	0
1/1/1989	1/1/1990	19	365	0	0
1/1/1990	1/1/1991	20	365	0	0
1/1/1991	1/1/1992	21	365	0	0
1/1/1992	1/1/2002	22	3,653	0	0
1/1/2002	3/31/2013	23	4,107	0	0
3/31/2013	3/31/2032	24	6,940	0	0
3/31/2032	3/31/2097	25	23,741	0	0

Notes:
ft^3/day - cubic feet per day

3.5 Initial Conditions

A steady-state simulation representing pre-mining hydrogeologic conditions provides the initial heads for the transient simulation. This simulation incorporates the pre-mining topographic surface and only natural boundary conditions (groundwater flux and streams). Additionally, mining-related disturbances in the flow field were modified to better represent natural conditions. Specifically, the properties of the mining-backfill in Pits 1 and 2 were changed to the respective property values in each layer. Also, stream channels that have been disrupted by burial or excavation were modified to follow their pre-mining course. During model calibration, any changes to properties and boundary conditions in the transient simulation were also made in the initial condition simulation to maintain consistency between the two scenarios.

3.6 Calibration

The main focus of the modeling effort was to: 1) develop a calibrated groundwater flow model from which reliable estimates of the flows to the Pit Lake could be made in support of predicting the ultimate concentration of various constituents in the Pit Lake due to evapo-concentration; and 2) to determine whether flow through the Pit Lake to the downgradient aquifer material would occur. The groundwater model has been calibrated to observed transient data to improve the accuracy of the simulation. In the calibration process, model input parameters are adjusted within reasonable ranges to improve agreement between model behavior and Site observations. Measured water levels from the Pit Lake and Site wells have served as targets for comparison with model-calculated water levels. Input parameters that were varied during the calibration include hydraulic conductivity, specific yield, general head boundary conductance, tailings seepage, vertical hydraulic conductivity of the implicit layers (i.e., leakance), and surface recharge to the Pit Lake.

The primary targets for the calibration were the Pit Lake elevation measurements recorded since 1984. Data from 25 wells were also included in the calibration procedure. These wells are presented in Table 6. Overall, 1,369 individual head targets were incorporated into the calibration procedure. Not all wells at the Site with measured groundwater elevations were included in the calibration. Some wells that are located in areas of high well density were excluded from the calibration so that one particular area would not improperly bias the final calibration statistics. Other wells were excluded due to screened intervals in multiple or uncertain hydraulic units. Wells with anomalous and ambiguous data were also excluded from the calibration.

Table 6 Model Calibration Statistics

Target	Layer	Mean Residual[a] (feet)	Absolute Mean Residual (feet)	Absolute Mean Error[b] (percent)
Highland Pit Lake	4	-6.2	8.73	3.82
EM-5 (Well 172)	2	-2.31	9.23	4.04
RM-2 (Well 132)	2	-17.99	17.99	7.88
RM-3 (Well 133)	2	-11.95	11.95	5.23
RM-4 (Well 134)	2	-1.38	9.65	4.22
TDM-IX (Well (114)	2	-10.29	10.92	4.78
TDM-XL (Well 174)	2	-3.26	9.43	4.13
TDM-XLIV (Well 178)	2	-13.9	13.9	6.09
TDM-XLIX (Well 183)	2	-4.09	9.26	4.05
TDM-XLVIII (Well 181)	2	-0.66	9.91	4.34
TDM-XXI (Well 120)	2	-7.58	9.58	4.2
TDM-XXVI (Well 125)	2	-8.89	10.54	4.61
TDM-XXXIV (Well 150)	2	0.86	11.01	4.82
TDM-XXXV (Well 151)	2	-2.96	9.12	3.99
TDM-XI (Well 116)	3	-13.1	13.1	5.74
TDM-XXIX (Well 128)	3	-24.59	24.59	10.76
TDM-XXX (Well 129)	3	-28.99	28.99	12.69
TDM-XXXII (Well 148)	3	-12.82	12.82	5.61
TDM-XXXVI (Well 152)	3	-6.99	8.86	3.88
DW-18 (Well 47)	4	-11.85	11.85	5.19
DW-41 (Well 136)	4	-7.02	9.01	3.94
DW-46 (Well 141)	4	-4.93	9.17	4.01
TDM-XXXIX (Well 173)	5	-8.49	10	4.38
TDM-XXXVII (Well 170)	5	-12.98	12.98	5.68
TDM-XXXVIII (Well 171)	5	-11.66	11.66	5.1
All Targets		**-9.36**	**12.17**	**5.33**

Notes:
[a] - Observed value minus calculated value
[b] - Based on total head response of 228.44 feet

The quality of the model calibration has been assessed through both statistical and qualitative evaluation of the observed and calculated water levels. Figure 17 presents the observed and calculated data from the Pit Lake. The calculated data accurately represent both the trend and magnitude of the observed Pit Lake elevations.

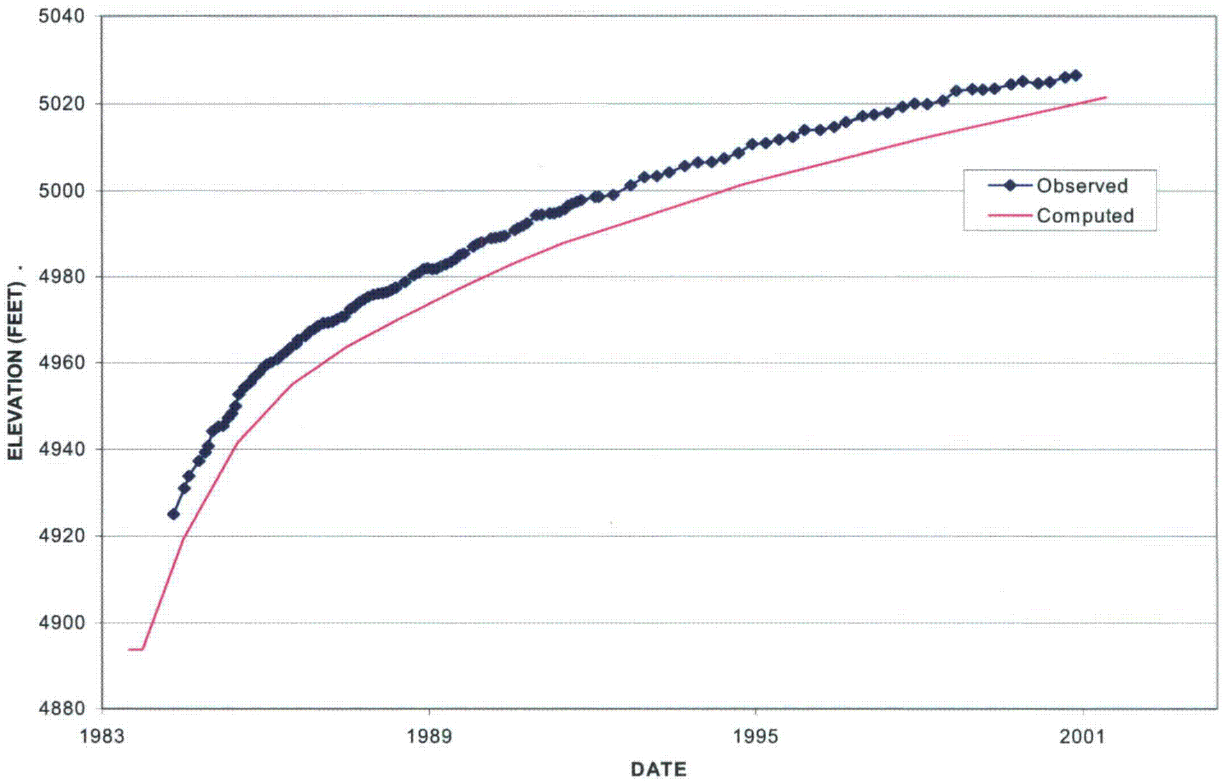


Figure 17 Highland Pit Lake Calibration

Figure 18 presents a plot of the observed versus calculated heads for data from the Pit Lake and all of the wells. On this plot, points plotting along a 1:1 slope (horizontal:vertical) represent a perfect calibration (observed equals calculated). Figure 18 shows that the calibration points generally tend along this slope. The points are evenly distributed above and below the line of 1:1 slope, indicating that the model is not biased toward under- or over-predicting the observed data. Additionally, the points are distributed along the line of 1:1 slope over the complete range of the data, indicating that the model is reasonably accurate throughout the domain.

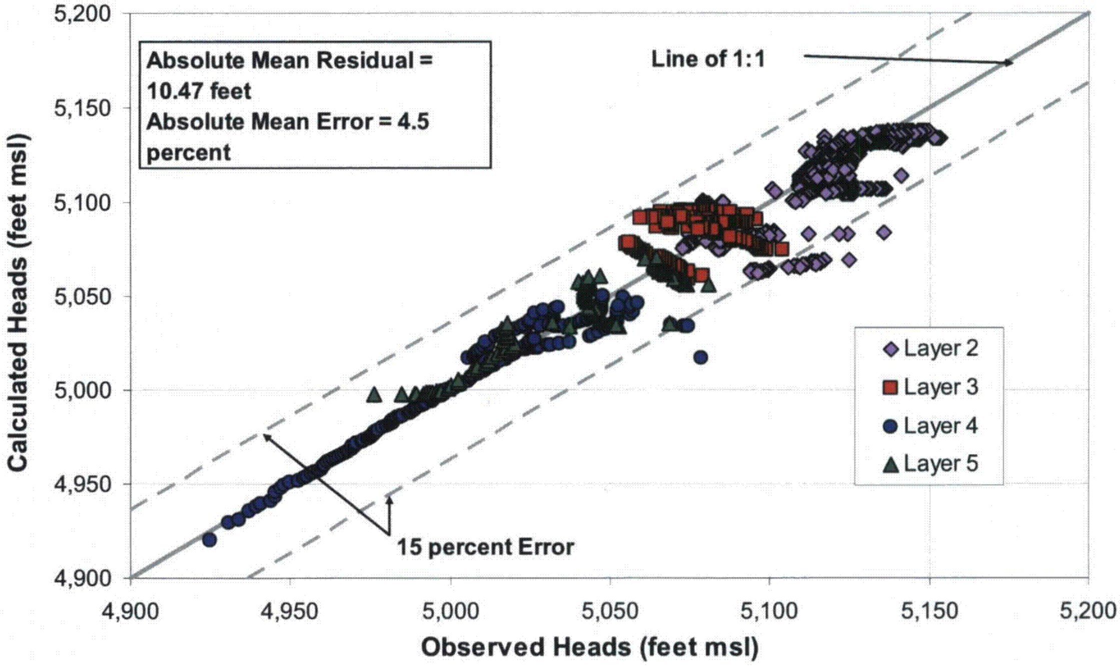


Figure 18 Observed vs. Calculated Heads

As shown in Table 6, the absolute mean residual (difference between observed and calculated head) of all of the calibration points is 12.17 feet. Model error is determined by dividing the absolute mean residual by the range of calculated heads over the entire simulation. Based on the overall head change of 228.44 feet, the absolute mean error is 5.33%. This mean error is considered good given the wide range of calculated head change. The absolute mean error is less than 15% in 1,345 of the 1,369 of the calibration points (98.2%). These statistics indicate that, even though calculated heads at individual wells may differ from observed measurements, the model reasonably approximates the overall behavior of the modeled system.

The favorable calibration results indicate that the model produces a reasonable representation of observed transient groundwater and Pit Lake conditions at the Site. The calibration results also provide high levels of confidence in the groundwater model's ability to predict future hydrologic conditions as the system approaches steady state. The final calibrated values of the parameters are presented in Table 7.

Table 7 Calibrated Model Parameters

Stratigraphic Unit	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	Specific Yield	Storage Parameter
Undifferentiated Fort Union and Wasatch	0.5	0.5	0.05	2.00×10^{-4}
Tailings Dam Sandstone	3	3	0.2	4.80×10^{-4}
Highland Sandstone Unit (50-Sand, 40-Sand, 30-Sand)	1.5	1.5	0.1	7.50×10^{-5}
Tailings Dam Shale[a]	Na	5.00×10^{-4}	na	Na
Highland Sandstone Unit (45-Shale, 35-Shale)[a]	Na	1.00×10^{-1}	na	Na
Backfill Material	1	1	0.5	1.00×10^{-4}

Notes:
ft/day - feet per day
[a] - Implicit Model Layer

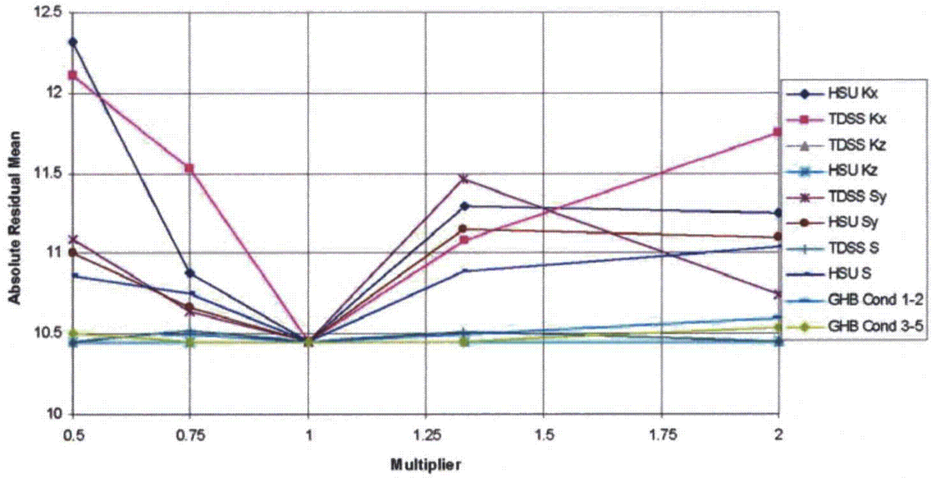
Boundary Conditions	Head (ft amsl)	Conductance per unit saturated thickness (ft/day)	Multiplier on WWL (1984) Estimated Transient Flux	Rate (ft/day)
General Head Boundary	5433	$1.38 \times 10^{-4} – 3.76 \times 10^{-4}$	na	na
Tailings Seepage	na	na	1.5	na
Recharge	na	na	na	0

Notes:
ft amsl - feet above mean sea level
ft/day - feet per day
na – not applicable

3.7 Sensitivity Analysis

A sensitivity analysis has been performed on the parameters believed to be most critical to the results of the groundwater model. Ten parameters were selected, and independent model simulations were run in which a single parameter was altered by a applying a multiplier to the calibrated parameter value. The results of every run were saved and compared to the calibrated model run using key statistical indicators. The comparisons show the relative extent to which the model results change in response to a change in the value of a particular parameter (i.e., how sensitive the model is to that parameter).

The parameters that were selected for analysis include hydraulic conductivity, specific yield, and storage coefficient of the TDSS and HSU sandstone members, vertical conductivity of the implicit layers, GHB conductances, and surface recharge. Each parameter was evaluated with four multipliers: 0.25, 0.5, 1.33, and 2.0. The simulations that were run to analyze surface recharge required an alteration of the calibrated model because the calibrated model value is 0, and, as such, a multiplier has no effect. For these runs, a value equivalent to 10% of yearly precipitation was used as the base, and multipliers of 0, 0.5, 1.0, and 2.0 were applied successively. The results of the recharge analyses are presented along with the other parameter results on Figure 19.



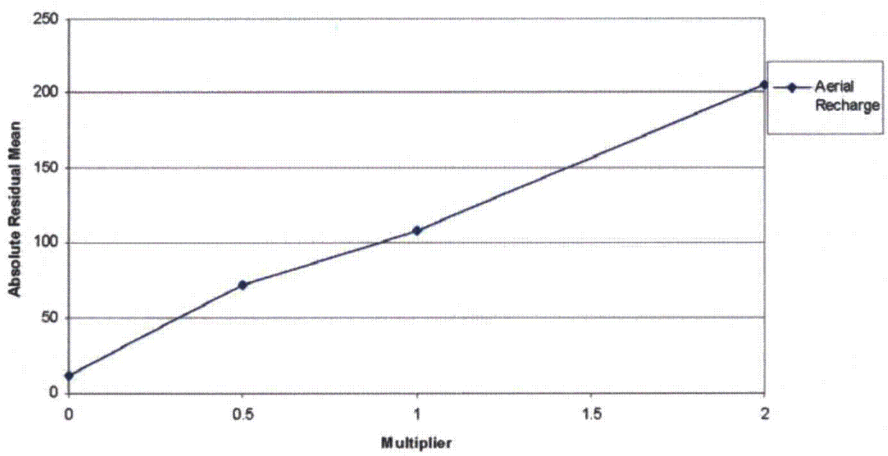


Figure 19 Sensitivity Analysis

The results of the sensitivity analysis indicate the calculated heads are most sensitive to variations in surface recharge. An increase from 0 to 5% of precipitation caused the absolute residual mean to increase from 10.45 feet to 71.72 feet, an increase of 586%. Therefore, the assumption of 0% surface recharge appears to be appropriate.

Heads were moderately sensitive to modifications in hydraulic conductivity and storage parameters (specific yield and storage coefficient) of the TDSS and the HSU sandstone members. The variations to these parameters resulted in increases of the absolute residual mean of 1 to 18% of the calibrated value of 12.17 feet. Heads are relatively insensitive to GHB conductance and vertical conductivity of the implicit layers. The absolute residual mean varied by less than 1% for all of these parameters.

4.0 PREDICTED HYDROLOGIC CONDITIONS

4.1 Pre-Mining Conditions

Because only sparse data are available before the beginning of mining operations, the pre-mining hydrogeologic conditions at the Site are not well known. Therefore, the initial conditions predicted with the calibrated properties and boundary conditions provide insight into pre-mining Site hydrology. The initial conditions of Layer 3 (50-Sand) are presented on Figure 19. Generally, the entire system is in the hydraulic equilibrium, and the heads are the same in all layers. The pre-mining steady-state groundwater elevation in the current area of the Pit Lake is estimated to be approximately 5,120 feet amsl. This is consistent with the perceived pre-mining water levels of approximately 5,110 reported by Dames & Moore (1971, 1978).

This estimate of pre-mining conditions differs significantly from that estimated by EPRC (1983). These investigators estimated the pre-mining potentiometric surface based on a hypothesized intermediate flow system between the Site and Blizzard Heights to the west. No data from the Site were used in the development of the potentiometric surface. The EPRC pre-mining head in the current location of the Pit Lake was assumed to be approximately 5,200 feet amsl, and the hydraulic gradient was assumed to be 0.0040. The smaller values of both hydraulic gradient and saturated thickness estimated in the current model suggest that groundwater flow through the strata underlying the Site is considerably less than previously believed. This is significant to Pit Lake hydrology because less groundwater flow is available to fill the Pit Lake.

4.2 Long-Term Conditions

The period of the model simulation representing hydrologic conditions from 2004 to 2100 provides the prediction of future water-level rise and the long-term steady-state elevation in the Pit Lake. The Pit Lake hydrograph is presented on Figure 20 and demonstrates that the calculated water level will rise an additional 30 feet from the current level until steady-state elevation of approximately 5,060 feet amsl is reached. Steady-state conditions are estimated to occur in the year 2054, 70 years after filling began. Based on this prediction, the Pit Lake is currently 81% full by elevation and 69% full by volume.

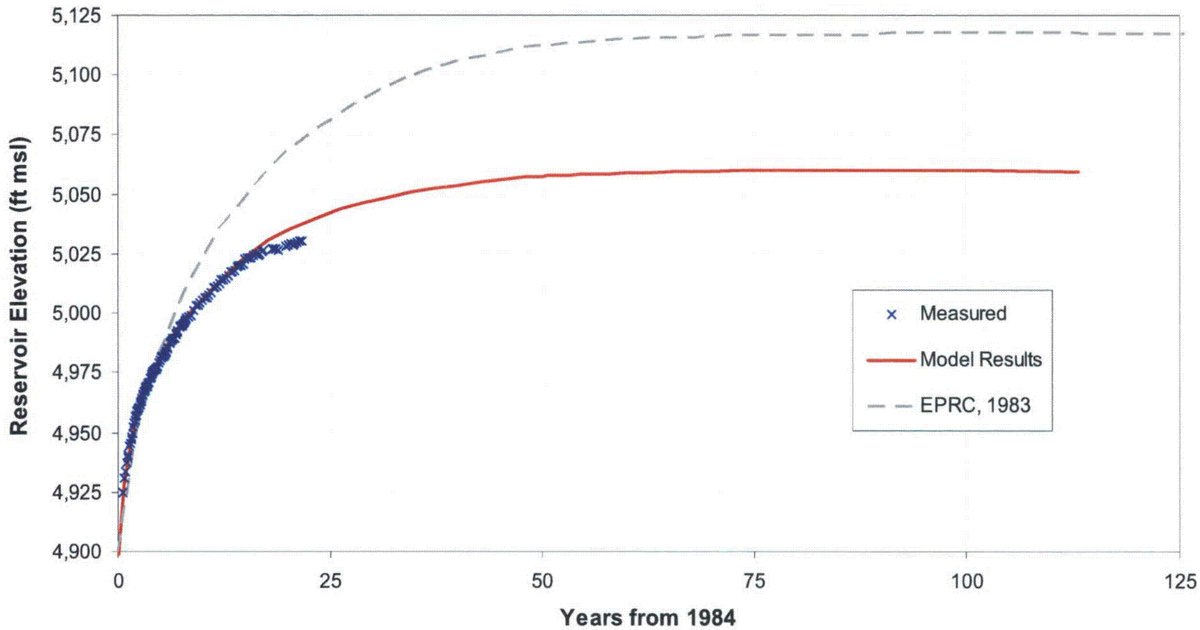


Figure 20 Modeled Pit Lake Hydrographs

The calculated long-term steady-state potentiometric surfaces for the five model layers are presented on Figures 21 through 25. The heads in all layers are essentially in hydraulic equilibrium and indicate the radial flow of groundwater toward the Pit Lake. The primary difference between each layer is that there is increasingly more saturated area to the east of the Pit Lake with depth. In Layer 1 (undifferentiated Fort Union and Wasatch formations), no groundwater reaches the Pit Lake, and the area surrounding the Pit Lake and all of the area to the east is dry. In Layer 2 (TDSS), groundwater from the west flows to the Pit Lake, while most of the unit east of the Pit Lake is dry. Heads in Layers 3 through 5 (50-Sand, 40-Sand, and 30-Sand) indicate that groundwater flows to the Pit Lake from all directions.

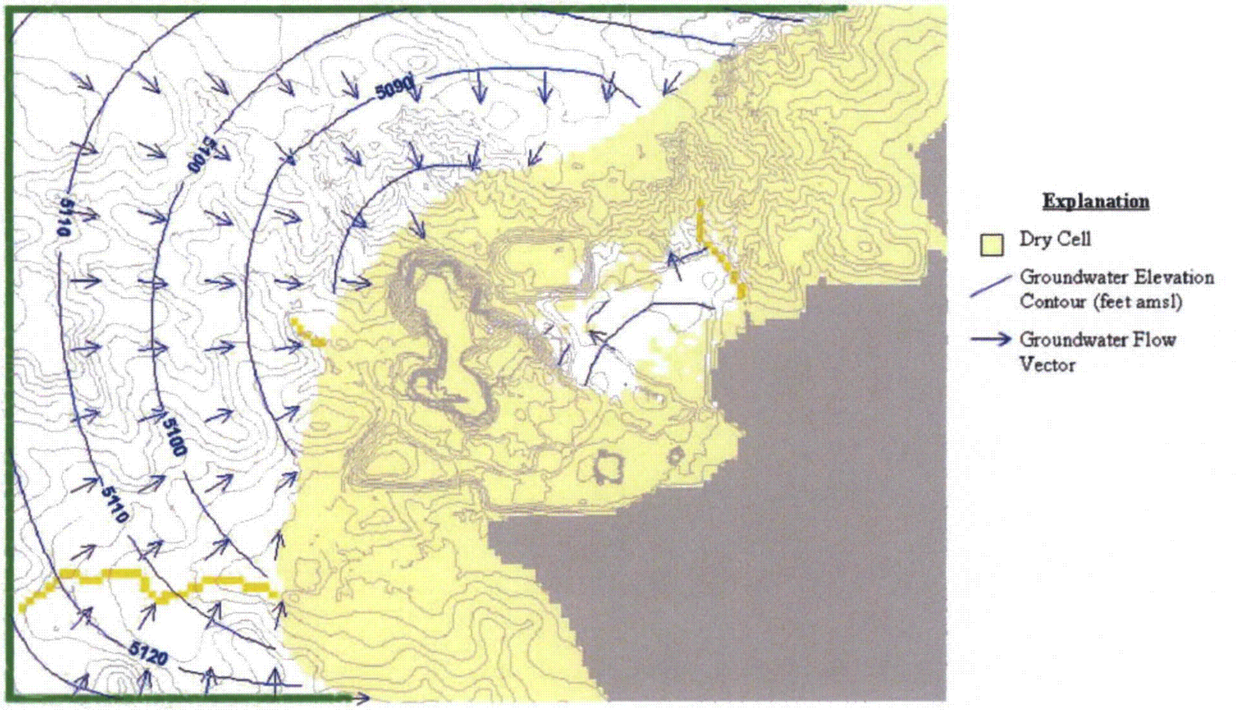


Figure 21 Layer 1 Long-term Heads

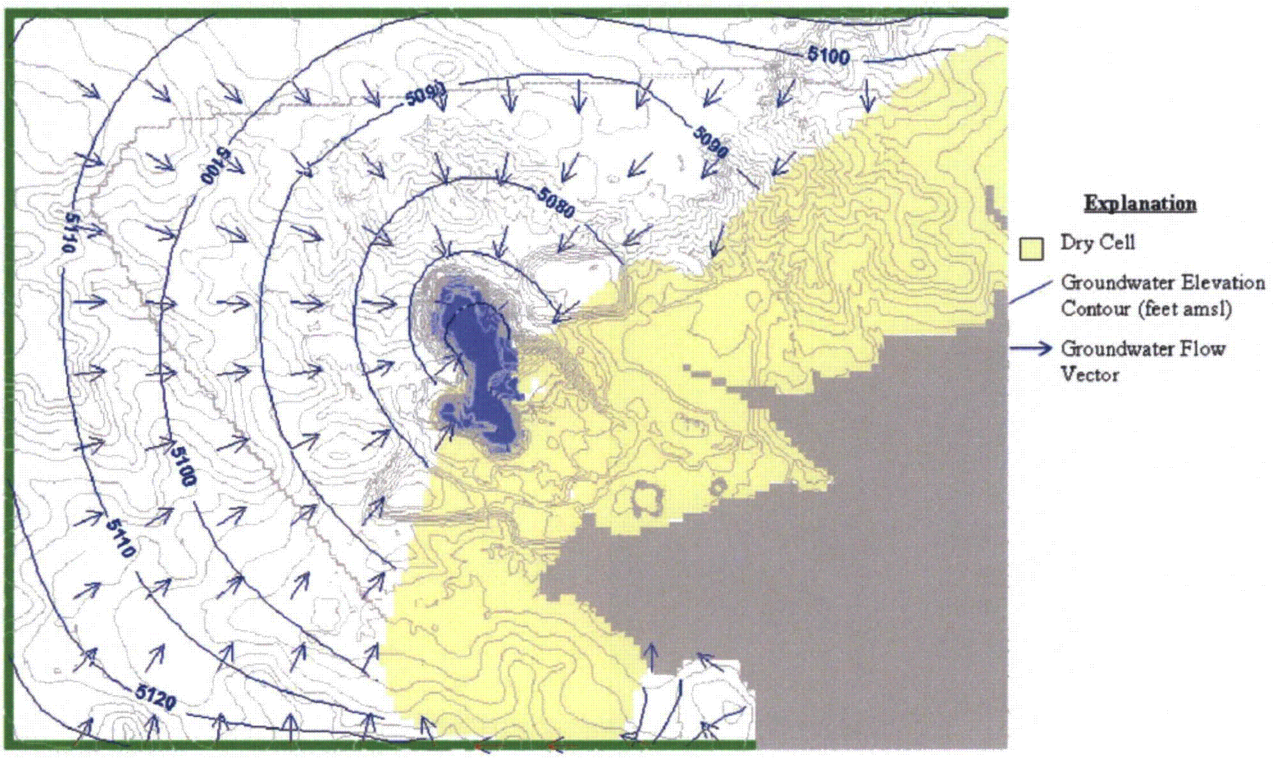


Figure 22 Layer 2 Long-term Heads

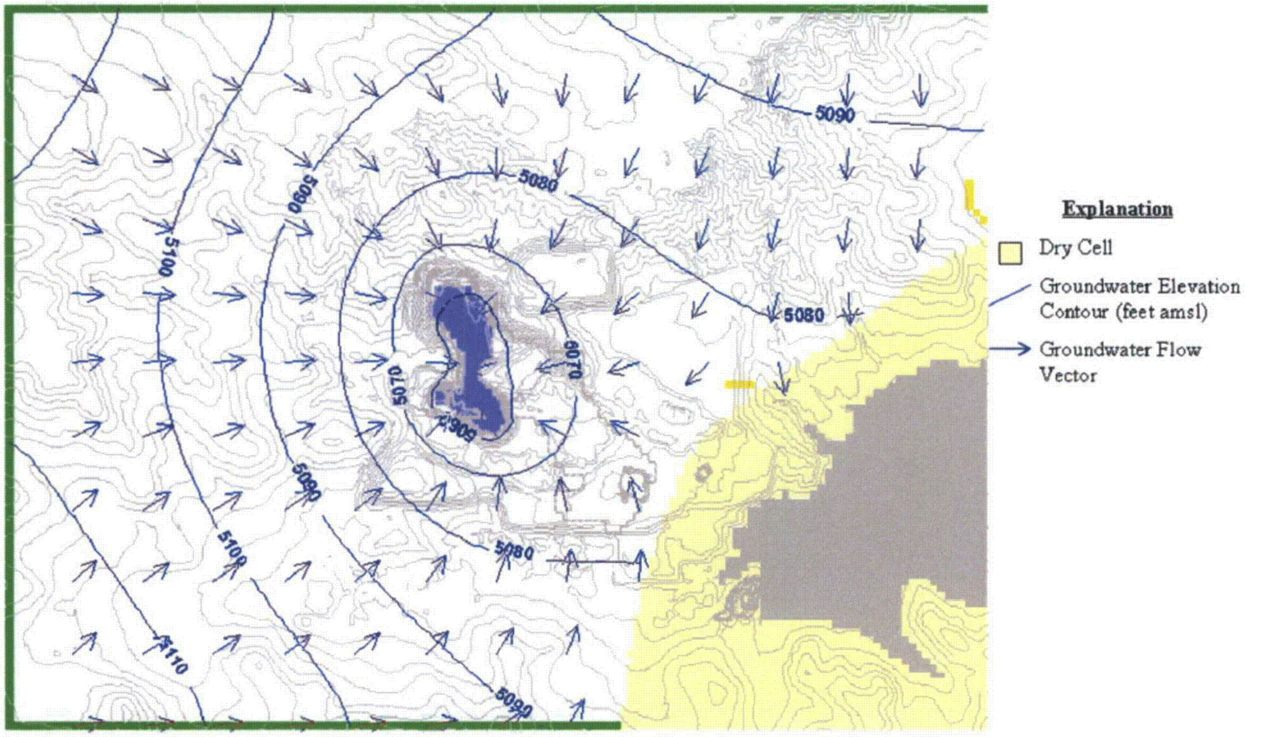


Figure 23 Layer 3 Long-term Heads

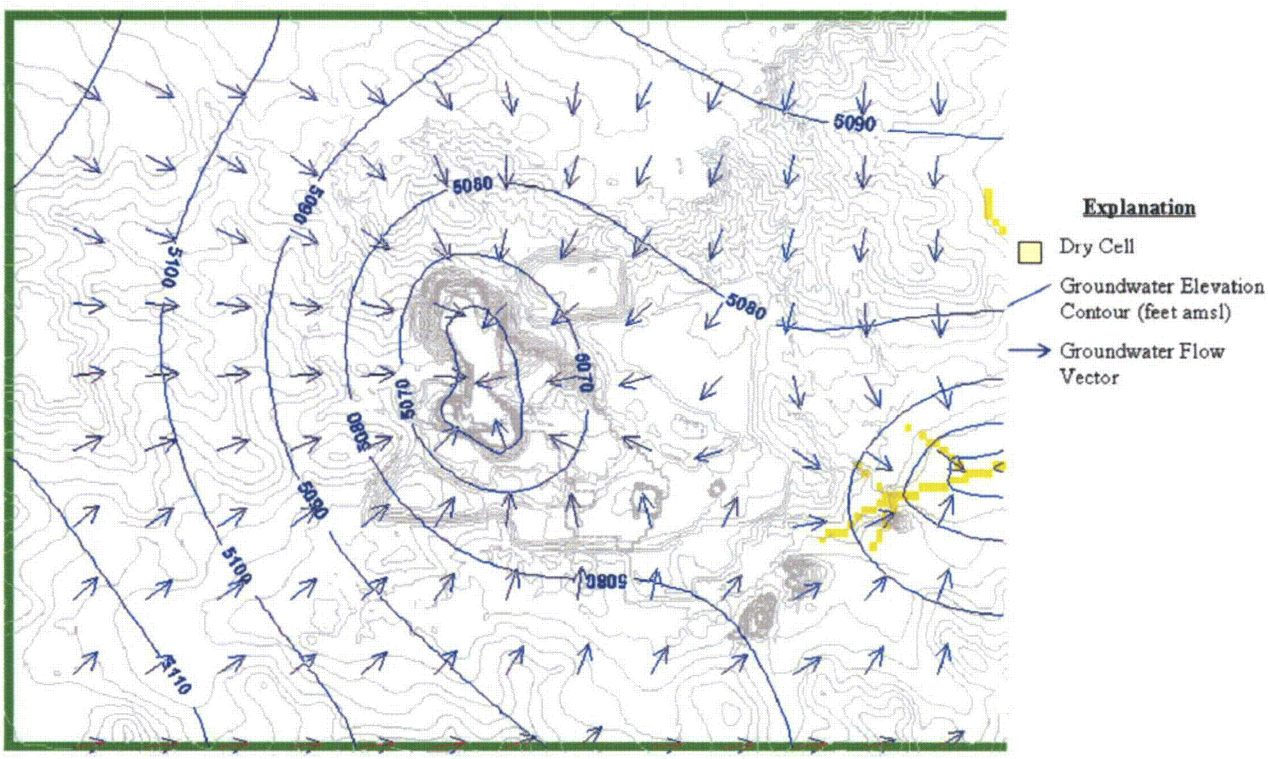


Figure 24 Layer 4 Long-term Heads

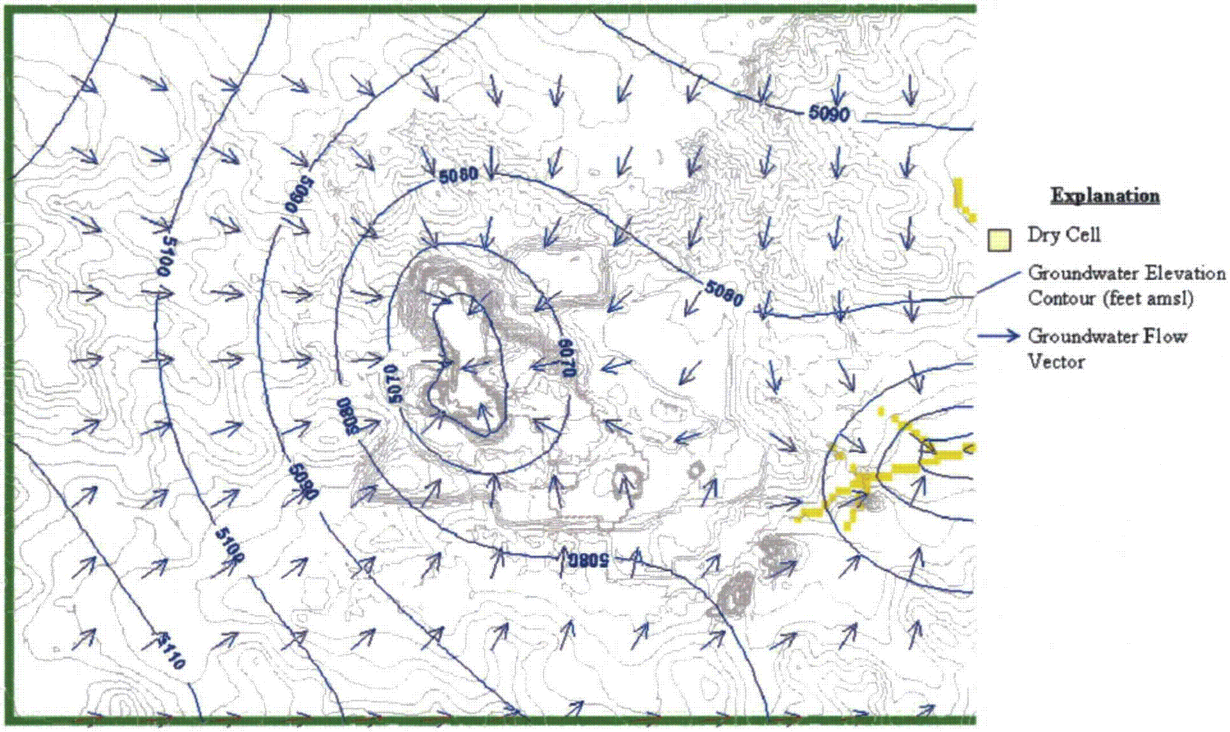


Figure 25 Layer 5 Long-term Heads

The calculated long-term potentiometric surfaces indicate that the Pit Lake will remain a sink to the surrounding groundwater system. The Pit Lake is at the center of a potentiometric low, and groundwater flow is toward the Pit Lake in all directions in all layers. As a result, there is no component of outflow from the Pit Lake to the groundwater system, and the Pit Lake is not predicted to become a flow-through system.

The Pit Lake will remain a groundwater sink because the balance between Pit Lake inflows (groundwater, direct precipitation, and surface runoff) and outflow (evaporation) reaches equilibrium before the water level rises to the elevation of the discharge area. As a result, a hydraulic divide exists between the Pit Lake and the discharge areas, and there is no positive gradient to drive flow from the Pit Lake toward the discharge points along North Fork Box Creek and its tributaries.

These results challenge those of previous investigations, including those of EPRC (1983), SMI (1998), and Carovillano (1998). These investigators predicted that the long-term steady-state Pit Lake elevation would be at least 5,117 feet amsl and that the Pit Lake would become a flow-through system. Figure 20 shows that the EPRC (1983) Pit Lake hydrograph overestimates the observed Pit Lake elevations, as well as the model-generated hydrograph. EPRC (1983) estimated groundwater flow to the Pit Lake with an analytical solution modeling radial flow from the HSU and the TDSS. An important parameter in this type of solution is initial head, which was taken from the EPRC pre-mining flow net discussed in Section 4.1. This value results in an overestimate of groundwater flow to the Pit Lake; therefore, EPRC (1983) predicted that the Pit Lake would fill faster than has been observed. Additionally, the relatively large groundwater flows allowed the predicted Pit Lake elevation to rise to a higher steady-state level. It is believed that, with a more accurate estimate of initial head, the EPRC (1983) analysis would have resulted in a better match with the observed data and a lower steady-state Pit Lake elevation. It should be noted that, at the time of the EPRC (1983) study, no Pit Lake elevation data were available, so the investigators did not have the luxury of calibrating their groundwater flow predictions to measured data.

The SMI (1998) study was an update the EPRC (1983) model, in which the groundwater flow components were revised. However, assumption of initial head was retained, and, as a result, the SMI (1998) predictions also over-predict the steady-state Pit Lake elevation.

Carovillano (1998) developed a steady-state numerical groundwater model to estimate the long-term steady-state Pit Lake and groundwater elevations at the Site. As in this study, the "high K" method was used to simulate the Pit Lake, but the volume of the modeled Pit Lake was not compared to the actual Pit Lake volume. Therefore, although a good calibration of Pit Lake elevation was achieved, there is no way in which the groundwater flux to the Pit Lake could be validated. The groundwater flux to the Pit Lake is ultimately responsible for the steady-state Pit Lake elevation. An overestimate of Pit Lake volume would result in overestimated groundwater fluxes to the Pit Lake, as well as an overestimated steady-state Pit Lake elevation.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A numerical modeling analysis of the transient groundwater conditions has been conducted in order to address uncertainties relating to the hydrochemical evolution of the Pit Lake at the Highland Mine Site. The MFG analysis incorporates both the interdependent behavior of the groundwater and Pit Lake hydrology, as well as the distinct processes and components unique to each system. The results indicate that the Pit Lake will continue to fill until the water level reaches a steady-state elevation of approximately 5,060 feet amsl in the year 2054. Under these conditions, the Pit Lake elevation will remain well below the elevation of the regional discharge area in North Fork Box Creek and its tributaries. As a result, the Pit Lake will not discharge water to the groundwater system and will not become a flow-through system.

These results differ from those of previous investigations, which predicted that the Pit Lake would eventually develop into a flow-through system (ERPC, 1983; Carovillano 1998; SMI, 1998). However, the results of this investigation reflect improvements from previous investigations because: 1) the analysis is based on revised initial conditions that are consistent with measured pre-mining water levels measured at the Site; 2) the Pit Lake elevation has been calibrated to 19 years of observed data; and 3) the model incorporates the Pit Lake geometry, allowing for accurate estimates of groundwater flow into the Pit Lake. These improvements over the previous investigations have produced more accurate predictions of long-term Pit Lake and groundwater hydrology.

6.0 REFERENCES

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APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
TDM VIII	TDSS		Core Analysis	112.9-113.2	372	m/d	3,117	md			Exxon, 1983ba	gas flood
TDM XII	TDSS		Core Analysis	127.4-127.8	2,804	m/d	2,992	md			Exxon, 1983b	gas flood
TDM XX	TDSS		Core Analysis	122.7-123.1	6,390	m/d	5,522	md			Exxon, 1983b	gas flood
TDM XXI	TDSS		Drawdown		1,190	m/d					Exxon, 1983b	12 gpm, >1000 min
TDM XII	TDSS		Drawdown		2,220	m/d					Exxon, 1983b	12 gpm, >1000 min
TDM VIII	TDSS		Drawdown		7,930	m/d			4.80E-04	--	Exxon, 1983b	8 gpm, >1000 min
TDM VIII	TDSS		Recovery		7,420	m/d					Exxon, 1983b	8 gpm, >1000 min
2700-0505	OSS		Core Analysis	384-411	1,672	m/d	3,450	m/d			Exxon, 1983b	gas flood
0865-0875	OSS		Core Analysis	353-361	1,036	m/d					Exxon, 1983b	gas flood
0819-4950	OSS		Core Analysis	695-764	2,236	m/d					Exxon, 1983b	gas flood
2700-2310	OSS		Core Analysis	650-704	3,079	m/d					Exxon, 1983b	gas flood
4260-0940	OSS		Core Analysis	627-659	3,235	m/d					Exxon, 1983b	gas flood
4260-0940	OSS		Core Analysis	745-795	3,103	m/d					Exxon, 1983b	gas flood
2650-0320	OSS		Core Analysis	367-400	2,288	m/d	1,687	m/d			Exxon, 1983b	gas flood
0600-0810	OSS		Core Analysis	633-667	834	m/d	626	m/d			Exxon, 1983b	gas flood
TDM XX	OSS		Drawdown		2,060	m/d					Exxon, 1983b	9.6 gpm, >1000 min, upper and middle OSS
TDM VI-1	OSS		Drawdown		6,260	m/d			1.90E-04	--	Exxon, 1983b	12 gpm, >1000 min, middle OSS
1	TDSH		Core Analysis	60.5	3.6	m/d					Exxon, 1983b	gas flood
1	TDSH		Core Analysis	75.5	1	m/d					Exxon, 1983b	water flood
1	TDSH		Core Analysis	80.5	9.3	m/d					Exxon, 1983b	water flood
1	TDSH		Core Analysis	85.5	0.1	m/d					Exxon, 1983b	water flood
4	TDSH		Core Analysis	35.5	0.15	m/d					Exxon, 1983b	water flood
4	TDSH		Core Analysis	40.5	0.03	m/d					Exxon, 1983b	water flood

APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
RM-1	TDSS		Drawdown		0.1	ft/day					Hydro-Engineering, 1985	1.5 gpm, 25 min
RM-2	TDSS		Drawdown		0.89	ft/day					Hydro-Engineering, 1985	1.1 gpm, 35 min
RM-2	TDSS		Recovery		5.8	ft/day					Hydro-Engineering, 1985	1.1 gpm, 35 min
RM-3	TDSS		Drawdown		8	ft/day					Hydro-Engineering, 1985	1.1 gpm, 35 min
RM-3	TDSS		Drawdown		22	ft/day					Hydro-Engineering, 1985	1.9 gpm, 20 min
RM-4	TDSS		Drawdown		23	ft/day					Hydro-Engineering, 1985	2.7 gpm, 35 min
TDM IX	TDSS		Recovery		0.13	ft/day					Hydro-Engineering, 1985	7.7 gpm,
TDM IX	TDSS		Drawdown		0.23	ft/day					Hydro-Engineering, 1985	2.6 gpm, >100 min
TDM XXXI	??		Recovery		2.1	ft/day					Hydro-Engineering, 1985	0.4 gpm, 21 min
TDM XXXII	OSS		Recovery		0.25	ft/day					Hydro-Engineering, 1985	0.8 gpm, >40 min
TDM XXXVI	OSS		Drawdown		0.059	ft/day					Hydro-Engineering, 1985	1.2 gpm, 8 min
TDM XXXVI	OSS		Recovery		0.1	ft/day					Hydro-Engineering, 1985	1.2 gpm, 8 min
TDM XXXVI	OSS		Drawdown		0.063	ft/day					Hydro-Engineering, 1985	0.7 gpm, >20 min
TDM XXXIII	??		Constant Head		4	ft/day					Hydro-Engineering, 1985	3-4 gpm, >60 min

APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
TDM XXXIV	OSS		Constant Head		0.018	ft/day					Hydro-Engineering, 1985	
TDM XXXV	TDSS		Constant Head		0.0024	ft/day					Hydro-Engineering, 1985	
PRI A field	OSS	20SS	Drawdown		49.1	gpd/ft2			7.68E-05	--	Everest, 1987	48-hr test in 20SS, average of 16 observation wells, b = 15 ft
PRI A field	OSH	15SH	Drawdown				5.10E-09	cm/s			Everest, 1987	
PRI A field	OSH	15SH	Core Analysis				1.10E-08	cm/s			Everest, 1987	
PRI A field	OSH	15SH	Core Analysis				1.60E-08	cm/s			Everest, 1987	
PRI A field	OSH	35SH	Core Analysis				2.30E-10	cm/s			Everest, 1987	
PRI A field	OSH	35SH	Core Analysis				1.70E-09	cm/s			Everest, 1987	
PRI B field	OSS	30SS	Drawdown		68.2	gpd/ft2					Everest, 1988a	24-hr test in 30SS, average of 8 observation well, b=15 ft
PRI C field	OSS	50SS	Drawdown		4.1	ft/day			5.00E-05	--	Everest, 1988b	72-hr test in 50SS, average of 27 observation wells, b=29 ft
PRI C field	OSH	45SH	Drawdown				1.30E-08	cm/s			Everest, 1988b	
PRI C field	OSH	55SH	Drawdown				1.10E-08	cm/s			Everest, 1988b	
PRI C field	OSH	45SH	Core Analysis				9.30E-11	cm/s			Everest, 1988b	
PRI C field	OSH	55SH	Core Analysis				1.50E-10	cm/s			Everest, 1988b	
PRI D field	OSS	40SS	Drawdown/ Recovery		3.7	ft/day			3.50E-05	--	PRI, 1990	tests in 40SS, average of 19 observation wells, b=40 ft
PRI D ext field	OSS	40SS??	Drawdown/ Recovery		1.81	ft/day			3.94E-05	--	PRI, 2000	average of 18 observation wells
PRI D field	OSH	45SH	Drawdown				3.95E-09	cm/s			PRI, 1990	average of 2 wells
PRI D field	OSH	35SH	Drawdown				1.01E-07	cm/s			PRI, 1990	average of 2 wells
PRI E field	OSS	50SS	Drawdown/ Recovery		7.2	ft/day			3.00E-05	--	PRI, 1991	average of 3 tests, 61 observation wells, b=35 ft
PRI E field	OSH	55SH	Drawdown				3.39E-08	cm/s			PRI, 1991	average of 2 observation wells, same as THSH??

APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
PRI F field	OSS	40SS/50SS	Drawdown		2.2	ft/day			2.04E-04	--	PRI, 1993	average of 94 observation wells
PRI F field	OSH	35SH	Core Analysis				3.70E-09	cm/s			PRI, 1993	
PRI F field	OSH	35SH	Core Analysis				2.80E-09	cm/s			PRI, 1993	
PRI F field	OSH	55SH	Core Analysis				4.20E-07	cm/s			PRI, 1993	
PRI F field	OSH	55SH	Core Analysis				9.20E-07	cm/s			PRI, 1993	
PRI H field	OSS	40SS/50SS	Drawdown/ Recovery		2.19	ft/day			5.33E-05	--	PRI, 1998	average of 2 tests, 63 observation wells
PRI H field	TDSH		Drawdown/ Recovery				9.40E-08	cm/s	2.40E-04	--	PRI, 1998	average of 5 observation wells, test#1
PRI H field	TDSH		Core Analysis				1.70E-08	cm/s			PRI, 1998	
PRI H field	TDSH		Core Analysis				2.60E-08	cm/s			PRI, 1998	
PRI H field	OSH	35SH	Core Analysis				7.20E-09	cm/s			PRI, 1998	
PRI H field	OSH	35SH	Core Analysis				1.20E-08	cm/s			PRI, 1998	
D&M T.W	OSS		Not specified	Not specified	2,500	ft/yr					D&M, 1978b	Pumped at 55 gpm for 2.3 days
D&M 3A	OSS		Not specified	Not specified	4,400	ft/yr			1.20E-05		D&M, 1978	Observation well for D&M T.W.
D&M 5A	OSS		Not specified	Not specified	6,800	ft/yr					D&M, 1978	Observation well for D&M T.W.
Dewater #4	OSS		Not specified	Not specified	366	ft/yr					D&M, 1978	Pumped at 52 gpm for 4.9 days
Dewater #10	OSS		Not specified	Not specified	323	ft/yr					D&M, 1978	Pumped at 47 gpm for 0.19 days
TW #1	OSS		Not specified	Not specified	310	ft/yr					D&M, 1978	Pumped at 9.9 gpm for 0.33 days
TW #2	OSS		Not specified	Not specified	940	ft/yr					D&M, 1978	Pumped at 82 gpm for 0.33 days
1	OSS		Core Analysis	Not specified	1,011	md					D&M, 1978	Core from Highland West
2	OSS		Core Analysis	Not specified	776	md					D&M, 1978	Core from Highland West
3	OSS		Core Analysis	Not specified	1,341	md					D&M, 1978	Core from Highland West
4	OSS		Core Analysis	Not specified	774	md					D&M, 1978	Core from Highland West
5	OSS		Core Analysis	Not specified	707	md					D&M, 1978	Core from Highland West
6	OSS		Core Analysis	Not specified	1,270	md					D&M, 1978	Core from Highland West

APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
Inj.	OSS		Core Analysis	Not specified	1,250	md					D&M, 1978	Core from Highland West
A	OSS		Core Analysis	Not specified	551	md					D&M, 1978	Core from Highland West
B	OSS		Core Analysis	Not specified	1,024	md					D&M, 1978	Core from Highland West
C	OSS		Core Analysis	Not specified	1,234	md					D&M, 1978	Core from Highland West
D	OSS		Core Analysis	Not specified	910	md					D&M, 1978	Core from Highland West
E	OSS		Core Analysis	Not specified	834	md					D&M, 1978	Core from Highland West
F	OSS		Core Analysis	Not specified	1,142	md					D&M, 1978	Core from Highland West
Inj.-1	OSS		Pulse Test	Not specified	1,104	md					D&M, 1978	Highland West Pilot Area
Inj.-2	OSS		Pulse Test	Not specified	1,212	md					D&M, 1978	Highland West Pilot Area
Inj.-3	OSS		Pulse Test	Not specified	910	md					D&M, 1978	Highland West Pilot Area
Inj.-4	OSS		Pulse Test	Not specified	1,326	md					D&M, 1978	Highland West Pilot Area
Inj.-5	OSS		Pulse Test	Not specified	1,645	md					D&M, 1978	Highland West Pilot Area
Inj.-6	OSS		Pulse Test	Not specified	1,265	md					D&M, 1978	Highland West Pilot Area
DM-1	OSS			544-695	580	ft/yr					D&M, 1978	North Morton Ranch Area
DM-4	OSS			523-618	740	ft/yr					D&M, 1978	North Morton Ranch Area
DM-5	OSS			531-605	760	ft/yr					D&M, 1978	North Morton Ranch Area
DM-6	OSS			527-587	490	ft/yr					D&M, 1978	North Morton Ranch Area
DM-8	OSS			527-709	600	ft/yr					D&M, 1978	North Morton Ranch Area
DM-1A	OSS			240-260	2,000	ft/yr					D&M, 1978	North Morton Ranch Area
DM-4A	OSS			190-210	240	ft/yr					D&M, 1978	North Morton Ranch Area
DM-8A	OSS			250-270	190	ft/yr					D&M, 1978	North Morton Ranch Area
DM-1B	OSS			380-400	390	ft/yr					D&M, 1978	North Morton Ranch Area
DM-4B	OSS			400-420	68	ft/yr					D&M, 1978	North Morton Ranch Area
DM-5B	OSS			400-420	15	ft/yr					D&M, 1978	North Morton Ranch Area
DM-6B	OSS			340	93	ft/yr					D&M, 1978	North Morton Ranch Area
DM-SP1	OSS			540-560	1,100	ft/yr					D&M, 1978	North Morton Ranch Area
DM-1P	OSS			560-640	1,100	ft/yr					D&M, 1978	North Morton Ranch Area
DM-2P	OSS			580-680	950	ft/yr					D&M, 1978	North Morton Ranch Area
DM-3P	OSS			580-620	810	ft/yr					D&M, 1978	North Morton Ranch Area

APPENDIX A
HYDROLOGIC TESTS CONDUCTED NEAR HIGHLAND MINE SITE

Location	Hydrologic Unit	Hydrologic Sub-Unit	Test Type	Interval (ft bgs)	Reported Horizontal		Reported Vertical		Reported Storage		Reference	Comments
DM-4P	OSS			520-620	1,100	ft/yr					D&M, 1978	North Morton Ranch Area
DM-5P	OSS			540-600	1,700	ft/yr					D&M, 1978	North Morton Ranch Area
DM-5P2	OSS			540-600	1,700	ft/yr					D&M, 1978	North Morton Ranch Area
DM-6P	OSS			560-600	790	ft/yr					D&M, 1978	North Morton Ranch Area
DM-7P	OSS			580-660	990	ft/yr					D&M, 1978	North Morton Ranch Area
DM-8P	OSS			580-670	950	ft/yr					D&M, 1978	North Morton Ranch Area
DM-9P	OSS			640-720	440	ft/yr					D&M, 1978	North Morton Ranch Area
WELL #2	OSS		Drawdown	115-340	6.80E-04	cm/s			2.50E-04		Golder, 1979	
WELL #1	OSS		Drawdown	100-285	4.00E-04	cm/s					Golder, 1979	

Notes:
cm/sec - centimeters per second
D&M - Dames and Moore
ft bgs - feet below ground surface
ft/d - feet per day
ft/yr - feet per year
gpd/ft^2 - gallons per day per foot squared
gpm- gallons per minute
hr - hour
m/d - meters per day
min - minute
OSH - Ore Body Shale
OSS - Ore Body Sandstone
PRI - Power Resources Incorporation
TDSH - Tailings Dam Shale
TDSS - Tailings Dam Sandstone
[a] - Exxon Production Research Company. 1983. Surface Mine Reclamation Lake Study for Highland Uranium Operations (Updated) (April).
[b] - Dames & Moore. 1978. Identification of Futer Water Problem, Highland Uranium Mine and Mill (March 15).

APPENDIX B
AQUIFER TEST REPORT

MFG, Inc.
Environmental and Engineering Consultants

TECHNICAL MEMORANDUM

DATE: **November 20, 2002** **SMI # 180548**

TO: **Paul Sorek**

FROM: **Joe Reed**

SUBJECT: **Aquifer Test Report**

COPY:

On October 16, 2002, short term single well aquifer tests were performed on wells 170 and 173 at the Highlands site. Data were recorded with In-Situ Trolls and verified with hand measurements. Data were analyzed using the Aquifer$^{\text{Win32}}$ program.

Well 170 was completed in backfill with the screen interval 140 to 180 feet below ground surface. Well 170 was constructed with 4-inch PVC in an assumed 8-inch diameter borehole. The static water level measured before the start of the test was 98.46 feet below the top of the PVC drop pipe. The discharge during the test was measured with a totalizing flow meter and verified with multiple bucket and stopwatch measurements. The top of the dedicated electric submersible pump was approximately 170 feet below ground surface and was equipped with a 4.0 gpm discharge orifice to regulate discharge. The pump was not equipped with a check valve. Test duration was about eight hours, the average pumping rate was about 3.9 gpm, and a maximum drawdown of 19.9 feet was measured. The well was allowed to recover almost 16 hours before ending the test.

Well 173 was completed in backfill with the screen interval 160 to 200 feet below ground surface. Well 173 was constructed with 4-inch PVC in an assumed 8-inch diameter borehole. The static water level measured before the start of the test was 176.39 feet below the top of the PVC drop pipe. The discharge during the test was measured with multiple bucket and stopwatch measurements. The top of the dedicated electric submersible pump was approximately 201 feet below ground surface and was equipped with a 2.0 gpm discharge orifice to regulate discharge. The pump was not equipped with a check valve. Test duration was about 95 minutes, the average pumping rate was about 1.875 gpm, and a maximum drawdown of 16.7 feet was measured. The well was allowed to recover over 16 hours before ending the test. After about 75 minutes, the discharge started to decrease and water levels started recovering. Pumping was terminated when the discharge fell below the minimum rate required to cool the submersible pump. It is unknown why the pump was unable to maintain the 2 gpm discharge rate selected for the test.

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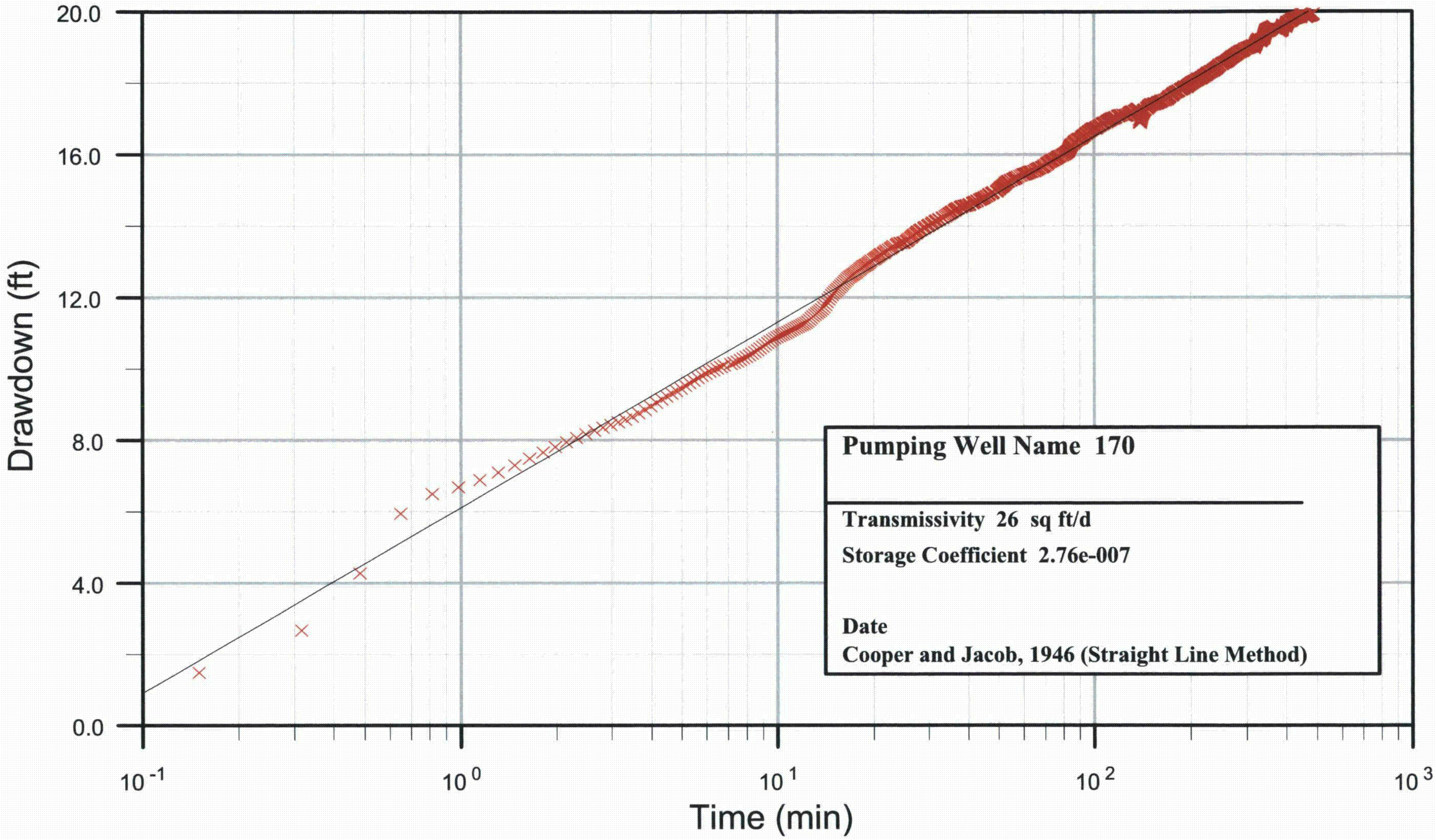
Plots of the test analysis are attached. Test results are summarized in Table 1. The analysis of the Well 170 data indicated a range of transmissivities of 18 to 31 ft^2/day and storage coefficients of 2.76e-007 to 4.65e-007. The analysis of Well 173 data indicated a range of transmissivities of 6 to 9 ft^2/day and storage coefficients of 1.94e-006 to 8.96e-007.

Table 1 Test Results

Well	Analysis Method	Transmissivity (ft^2/day)	Storage Coefficient
170	Cooper and Jacob	26	2.76e-007
170	Theis	31	3.01e-007
170	Neuman	18	4.65e-007
170	Theis Recovery	28	NA
173	Cooper and Jacob	6	2.00e-006
173	Theis	9	8.96e-007
173	Neuman	6	1.94e-006

Cooper and Jacob



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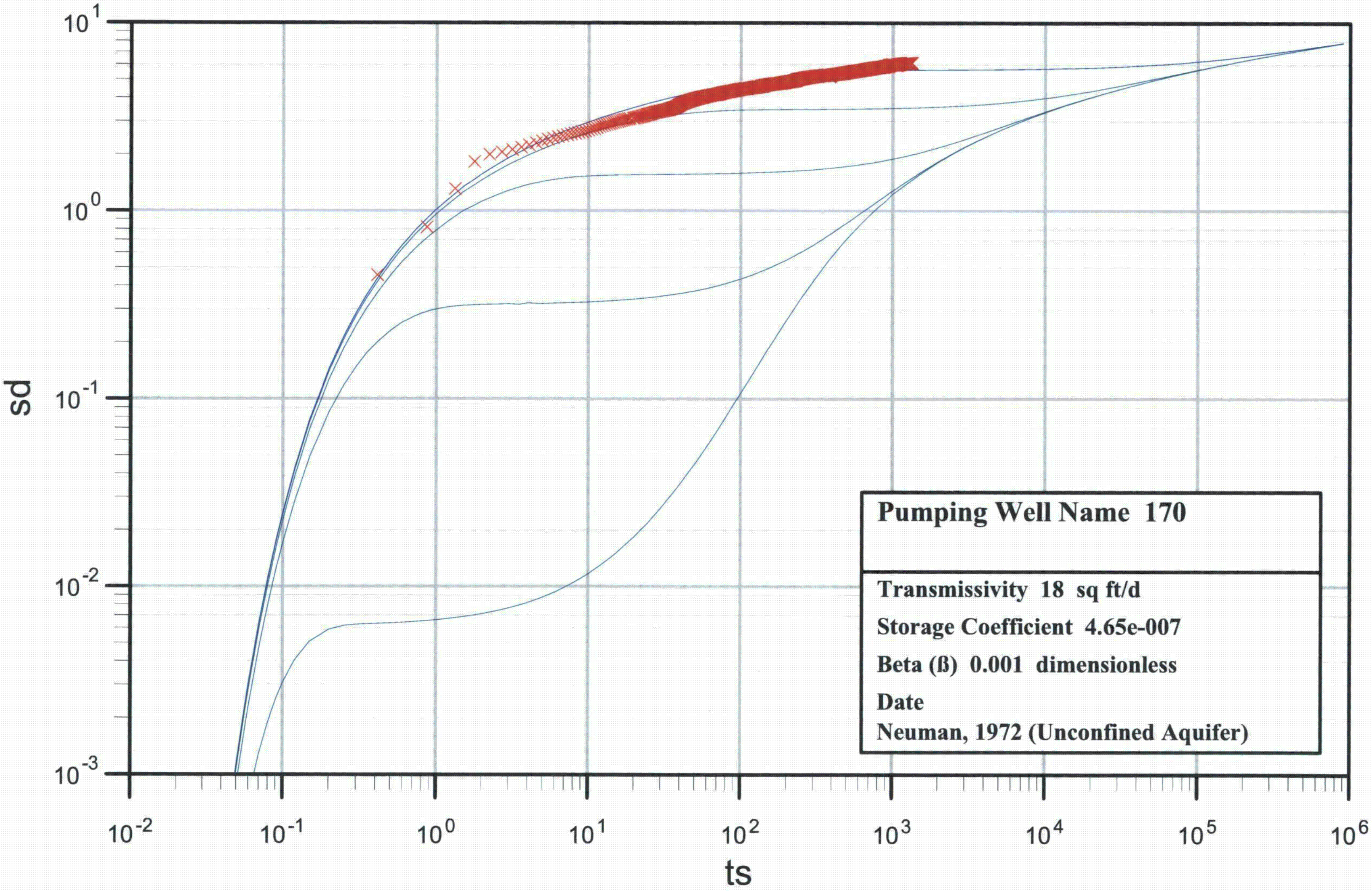

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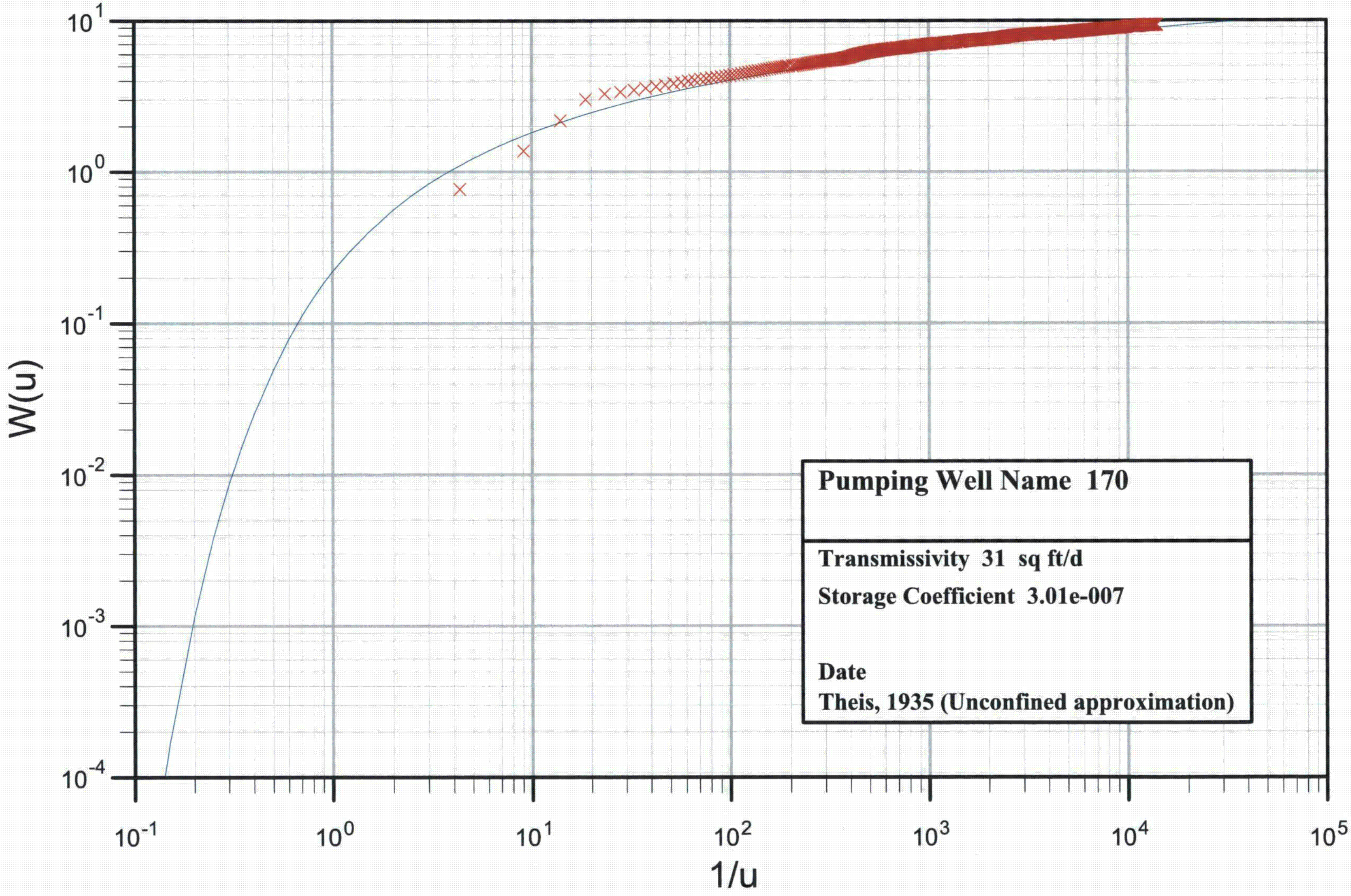

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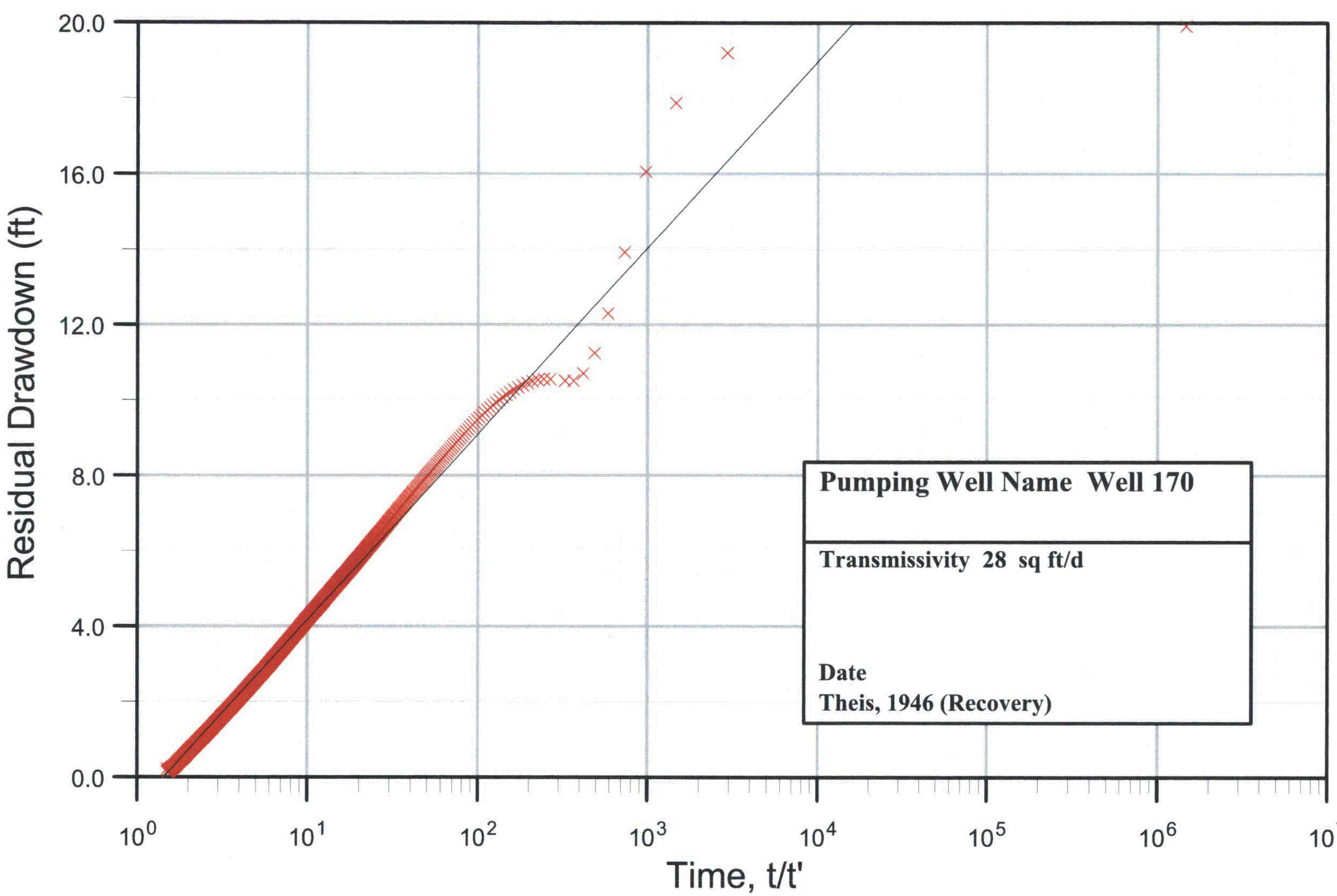

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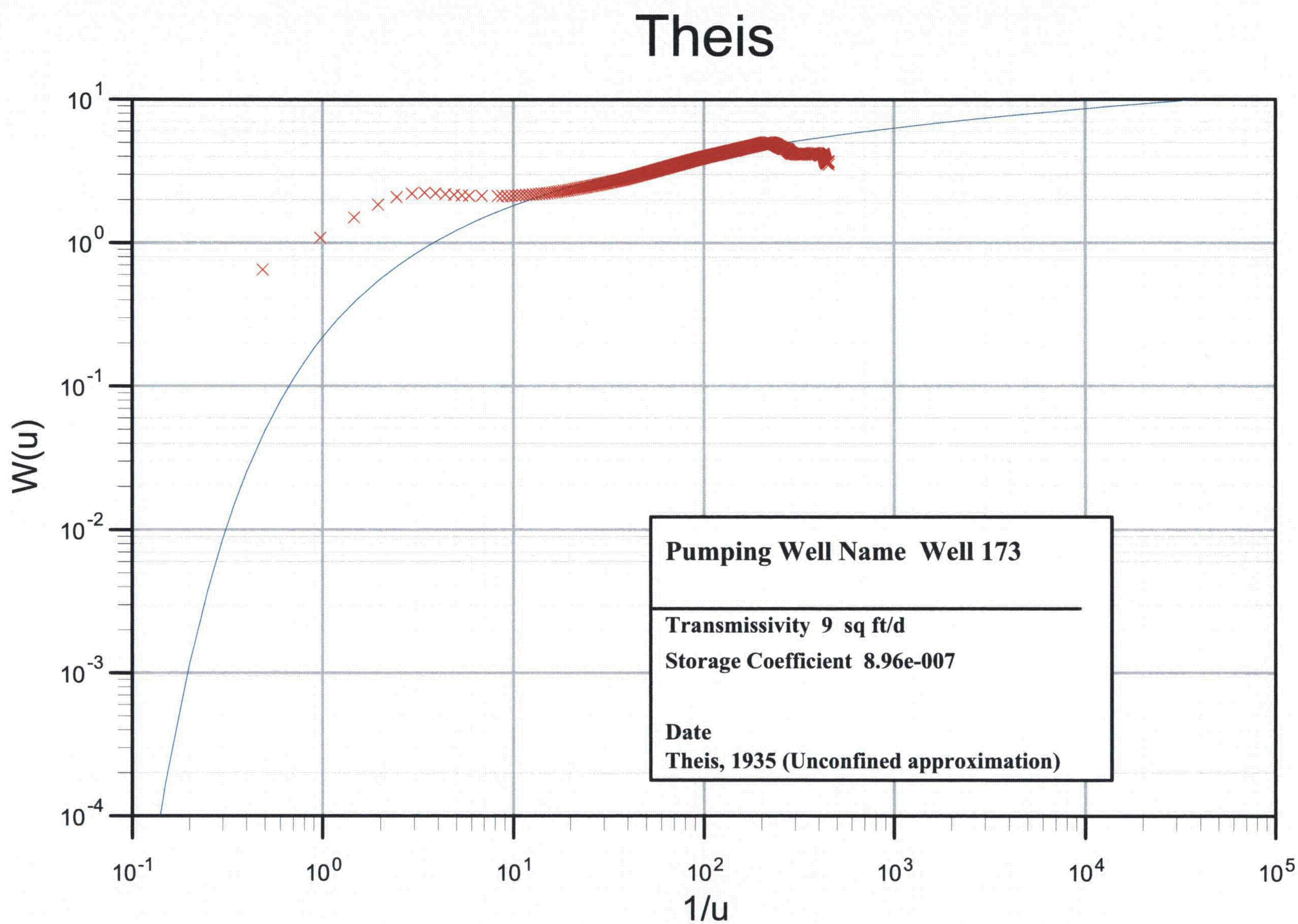

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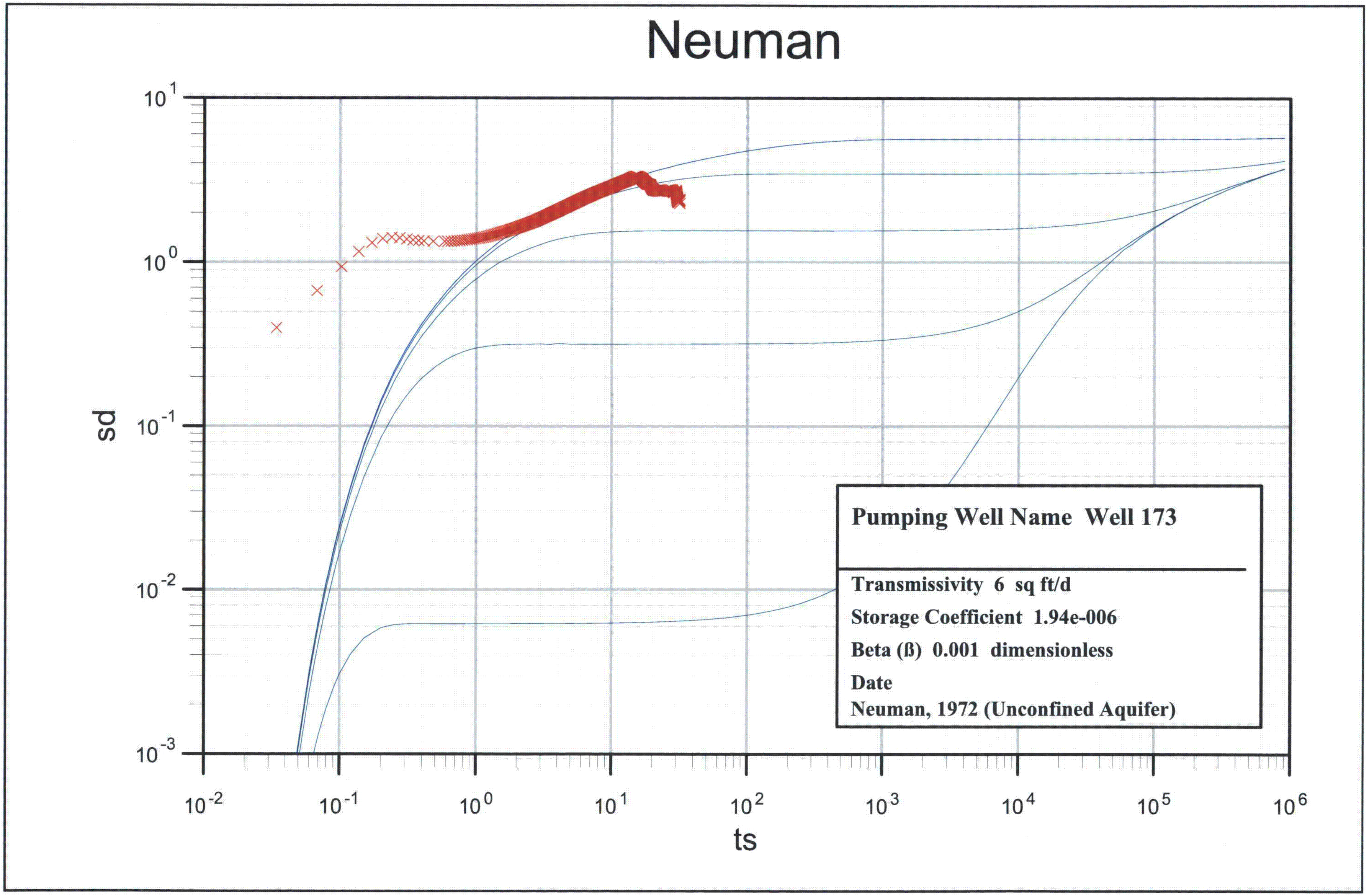

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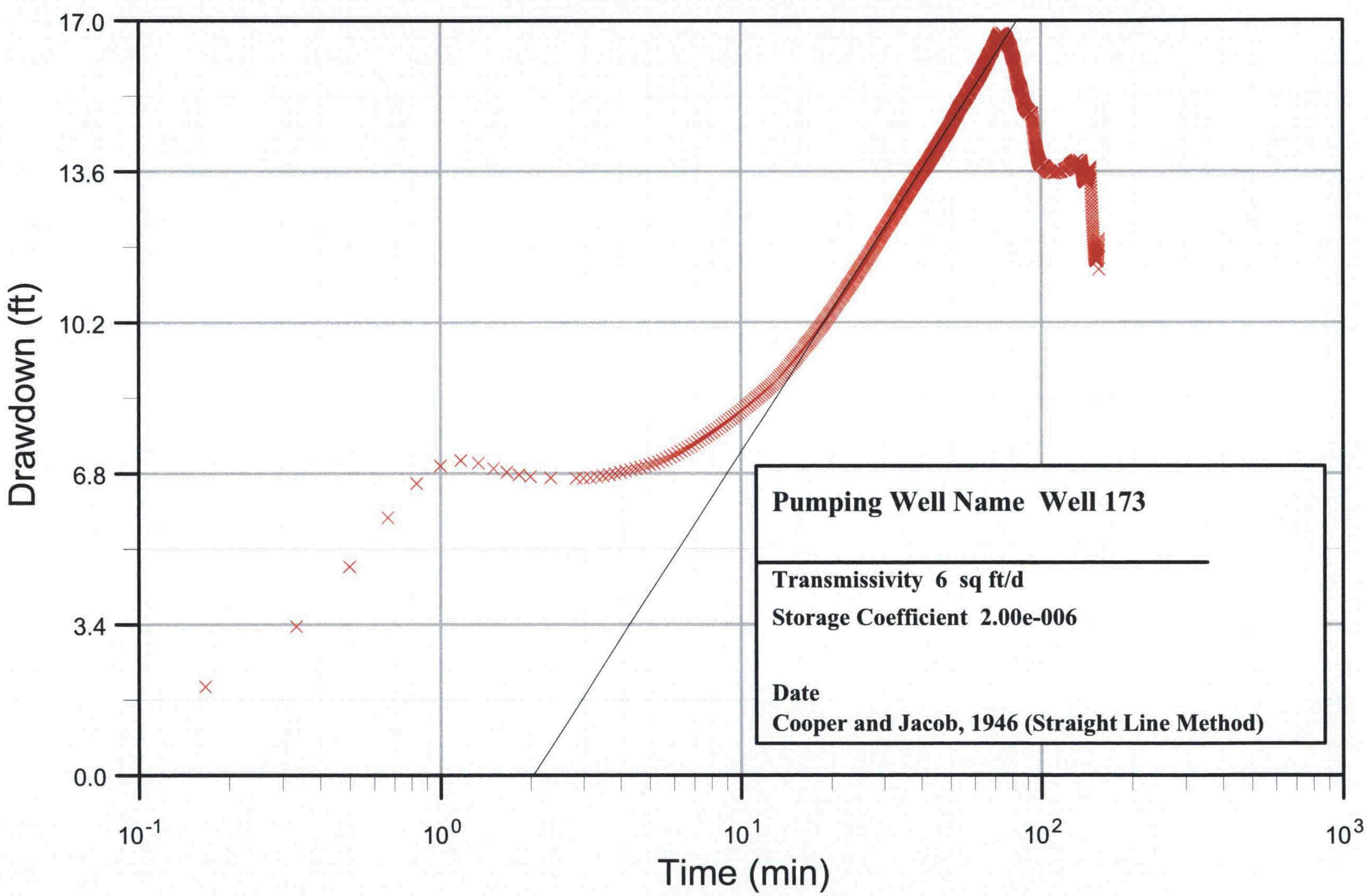

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APPENDIX C
HIGHLAND PIT LAKE PRECIPITATION, PAN EVAPORATION, AND SURFACE-WATER RUNOFF DATA

MFG, Inc.
Environmental and Engineering Consultants

TECHNICAL MEMORANDUM

DATE: **January 8, 2003** **SMI # 180548**

TO: **Paul Sorek**

FROM: **Joe Reed**

SUBJECT: Highland Reservoir precipitation, pan evaporation, and surface water runoff data

COPY:

PRECIPITATION DATA

Data from three weather stations were used to estimate average monthly and average yearly precipitation at the Highland site. The three stations were Bill (Station Number 725), Douglas Aviation (Station Number 2693), and Glenrock 5 ESE (Station Number 3950). Station summaries are presented in Tables 1, 2, and 3. Figure 1 presents a graph of the average monthly precipitation data for each of the stations as well as the average monthly data of the three stations. Table 4 presents the monthly average of the three monthly averages.

PAN EVAPORATION DATA

Pan evaporation data for the Highland Reservoir site was obtained from the Department of Agricultural Engineering, University of Wyoming, Laramie's "Design Information For Evaporation Ponds In Wyoming" published by the Wyoming Water Research Center (WWRC-85-21). Table 5 presents means, standard deviations, and high and low evaporation values (in inches) from estimates using the Kohler-Nordenson-Fox equation with a coefficient of 0.7 and Table 6 presents means, standard deviations, and high and low net evaporation values (in inches) from estimates using the Kohler-Nordenson-Fox equation with a coefficient of 0.7.

SURFACE WATER RUNOFF RATE

Runoff was calculated in the Exxon Production Research Company, EPRCO, 1983, Surface Mine Reclamation Lake Study for Highland Uranium Operations (Updated) using several different methods which are summarized in Table 7. Evaluating the results of all methods and noting the expected inaccuracies in the various estimates, the average runoff to rainfall ratio was estimated to be 6%.

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Table 1 Station Bill Precipitation Summary

Station: BILL	Parameter: Precipitation	% Coverage: 89	
PO Code: WY	Latitude: N43:15:00	Begin M/Yr: 09/1948	
Stn ID: 725	Longitude: W105:16:00	End M/Yr: 07/1978	
County: CONVERSE	Elevation: 4715	# Record Years: 30	
Years: 1949-61,64-72			

Precipitation (in)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
# Days	806	706	734	750	861	840	861	837	840	837	802	805	9679
Avg Day	0.01	0.01	0.02	0.05	0.09	0.06	0.05	0.03	0.03	0.02	0.01	0.02	0.03
# Valid	26	25	24	25	28	28	28	27	28	27	27	26	22
Maximum	2.03	1.75	1.84	3.48	7.72	4.11	5.31	3.52	2.81	2.08	1.75	3.16	16.41
Max Yr	1949	1953	1950	1971	1978	1967	1951	1972	1961	1961	1953	1949	1971
Minimum	0	0	0	0.19	0.14	0	0	0	0	0	0	0	5.16
Min Yr	1977	1977	1962	1961	1966	1973	1959	1976	1960	1973	1961	1960	1960
Average	0.38	0.33	0.59	1.41	2.67	1.83	1.51	0.86	0.88	0.67	0.43	0.53	11.8
Std Dev	0.47	0.36	0.54	0.87	2.02	1.01	1.22	0.82	0.73	0.57	0.4	0.66	2.89
Skew	1.98	2.42	1.02	0.76	1.26	0.49	1.41	1.34	0.82	0.63	1.52	2.46	-0.52
Kurt	6.79	10.15	2.9	2.84	3.83	2.58	4.73	4.79	2.84	2.52	5.41	9.73	2.7

Table 2 Station Douglas Aviation Precipitation Summary

Station:	DOUGLAS AVIATION				Parameter: Precipitation				% Coverage: 95				
PO Code:	WY				Latitude: N42:45:00				Begin M/Yr: 08/1962				
Stn ID:	2693				Longitude: W105:23:00				End M/Yr: 01/1995				
County:	CONVERSE				Elevation: 4805				# Record Years: 34				
Years:	1963-65,67,69-74,76-77,80-81,84,87-89,92-94												
					Precipitation (in)								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
# Days	942	847	944	932	976	935	984	986	946	910	956	954	11312
Avg Day	0.01	0.02	0.03	0.06	0.07	0.06	0.05	0.03	0.03	0.02	0.02	0.01	0.03
# Valid	30	30	30	31	31	32	32	32	32	29	32	31	21
Maximum	1.15	1.5	2.07	4.34	7.48	5.7	4.61	3.25	2.95	2.51	2.01	0.93	17.54
Max Yr	1972	1993	1983	1971	1991	1967	1973	1972	1973	1994	1983	1992	1993
Minimum	0.03	0.07	0.19	0.17	0.23	0	0.19	0.03	0	0	0.06	0.07	6.55
Min Yr	1989	1979	1963	1987	1974	1980	1980	1964	1969	1988	1964	1971	1974
Average	0.39	0.43	0.8	1.64	2.27	1.7	1.48	0.78	0.86	0.72	0.66	0.4	11.95
Std Dev	0.24	0.3	0.53	1.1	1.56	1.39	1.01	0.64	0.72	0.52	0.45	0.22	3.15
Skew	1.11	1.62	0.87	0.64	1.28	1.11	0.85	1.91	1.02	1.22	0.64	0.99	0.2
Kurt	4.43	6.38	2.78	2.64	4.84	3.61	3.82	7.76	3.66	5.43	3.29	3.41	1.94

Table 3 Station Glenrock 5 ESE Precipitation Summary

Station: GLENROCK 5 ESE	Parameter: Precipitation	% Coverage: 98
PO Code: WY	Latitude: N42:50:00	Begin M/Yr: 08/1948
Stn ID: 3950	Longitude: W105:47:00	End M/Yr: 12/1998
County: CONVERSE	Elevation: 4948	# Record Years: 51
Years: 1949-56,58-59,61-62,64-75,77,80-84,88-98		

Precipitation (in)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
# Days	1510	1344	1442	1456	1544	1488	1514	1581	1514	1545	1507	1518	17963
Avg Day	0.01	0.02	0.03	0.05	0.08	0.06	0.04	0.02	0.03	0.03	0.02	0.01	0.03
# Valid	49	48	47	49	50	50	49	51	50	50	51	50	41
Maximum	1.34	1.5	3.02	5.67	7.7	6.41	4.24	2.13	5.43	3.43	2.54	1.4	21.85
Max Yr	1949	1952	1975	1973	1971	1967	1977	1953	1973	1998	1979	1987	1971
Minimum	0	0	0.1	0.07	0.27	0	0.15	0	0.06	0	0	0	6.4
Min Yr	1983	1977	1959	1988	1994	1984	1980	1970	1983	1987	1974	1991	1988
Average	0.44	0.44	0.78	1.57	2.38	1.77	1.15	0.73	1	1.05	0.6	0.36	12.43
Std Dev	0.33	0.37	0.59	1.14	1.6	1.4	0.94	0.54	1.08	0.75	0.58	0.3	3.67
Skew	0.84	1.04	1.49	1.49	1.31	0.91	1.71	0.77	2.07	0.7	1.6	1.43	0.7
Kurt	2.85	3.41	5.76	6.27	4.38	3.67	5.73	3.17	7.47	3.3	5.55	5.36	3.16

Table 4 Average Precipitation

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0.40	0.40	0.72	1.54	2.44	1.77	1.38	0.79	0.91	0.81	0.56	0.43	12.06

Table 5 Means, Standard Deviations, and High and Low Evaporation Values (in inches) from Estimates Using the Kohler-Nordenson-Fox Equation With a Coefficient of 0.7

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pathfinder	Mean	0.9	1.1	2.1	3.5	5	6.5	7.5	6.6	4.5	2.6	1.3	0.9	42.5
	St Dv	0.2	0.3	0.5	0.6	0.8	0.9	0.6	0.6	0.7	0.5	0.2	0.2	2.4
	High	1.2	1.8	3.3	4.9	6.3	8.3	8.9	7.9	5.4	3.4	1.9	1.3	46.2
	Low	0.5	0.6	1.4	2.2	3.5	4.5	6.2	4.9	2.8	1.4	0.7	0.6	35.5
Whalen	Mean	1.7	1.9	2.6	3.5	4.7	6.3	7.6	6.9	5.1	3.6	2.2	1.8	47.9
	St Dv	0.5	0.5	0.6	0.6	0.6	0.9	0.6	0.7	0.7	0.7	0.4	0.4	3
	High	3.3	3	3.7	4.6	6.4	8.7	8.7	8.3	6.7	4.8	3.3	2.6	54.5
	Low	0.7	1.1	1.2	2.4	3.6	4.8	6.1	5.2	3.3	1.9	1.5	0.9	40.2
Pathfinder/Whalen	Average Mean	1.3	1.5	2.4	3.5	4.9	6.4	7.6	6.8	4.8	3.1	1.8	1.4	45.2

Table 6 Means, Standard Deviations, and High and Low Net Evaporation Values (in inches) from Estimates Using the Kohler-Nordenson-Fox Equation With a Coefficient of 0.7

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pathfinder	Mean	0.6	0.7	1.5	2.2	3.5	5.1	6.8	6	3.7	1.7	0.9	0.6	33.3
	St Dv	0.4	0.5	0.7	1.1	1.6	1.7	0.9	1.1	1.2	1.1	0.4	0.3	4
	High	1	1.7	2.6	4.5	5.9	8.3	8.4	7.8	5.3	3.1	1.9	1.1	39.9
	Low	-0.9	-0.2	-0.2	0.5	0.1	1.1	5	2.4	1	-0.8	-0.2	-0.4	19.8
Whalen	Mean	1.3	1.5	1.9	2	2.5	3.9	5.9	5.9	3.7	2.9	1.7	1.3	34.8
	St Dv	0.4	0.6	1	1.2	2.1	2.2	1.5	1.1	1.6	1.1	0.5	0.5	5.5
	High	2	2.8	3.5	4	6.3	7.7	8.5	8	5.6	4.4	2.6	2.2	45.3
	Low	0.4	0.6	-0.4	-0.2	-3.7	-0.9	2.6	3.5	-1.1	0.1	0.8	0.2	21.6
Pathfinder/Whalen	Average Mean	1.0	1.1	1.7	2.1	3.0	4.5	6.4	6.0	3.7	2.3	1.3	1.0	34.1

Table 7 Annual Surface Water Runoff as a Percent of Average Annual Rainfall

Source	Value	Comments
Craig and Rankl (1978)	0.68 in; 5.5%	Actual hydrograph measurements for Sage Creek near Orpha, 12 events over 8 years from 0.32 to 1.41 in, correlated and applied to mean Highland rainfall events.
SCS method	1.10 in; 8.9%	This result was verified by regrouping mean annual storm occurrences and using Antecedent Moisture Condition (AMC) modifications.
USGS Office, Cheyenne	0.40 in; 3.3%	9-10 years records: Frank Draw near Orpha, Sage Creek near Orpha, McKenzie Draw near Casper.
USGS (1976)	3.00 in; 24.4% 1.63 in; 13.0%	Power correlation with drainage area based on 8 gages (20 years) in quarter of Wyoming containing Highland. Predictions probably high near Highland due to variation in topography and small amount of data.
Smith (1974)	0.30 in; 2.4%	Based on up to 20 years of streamflow records done specifically for Wyoming.

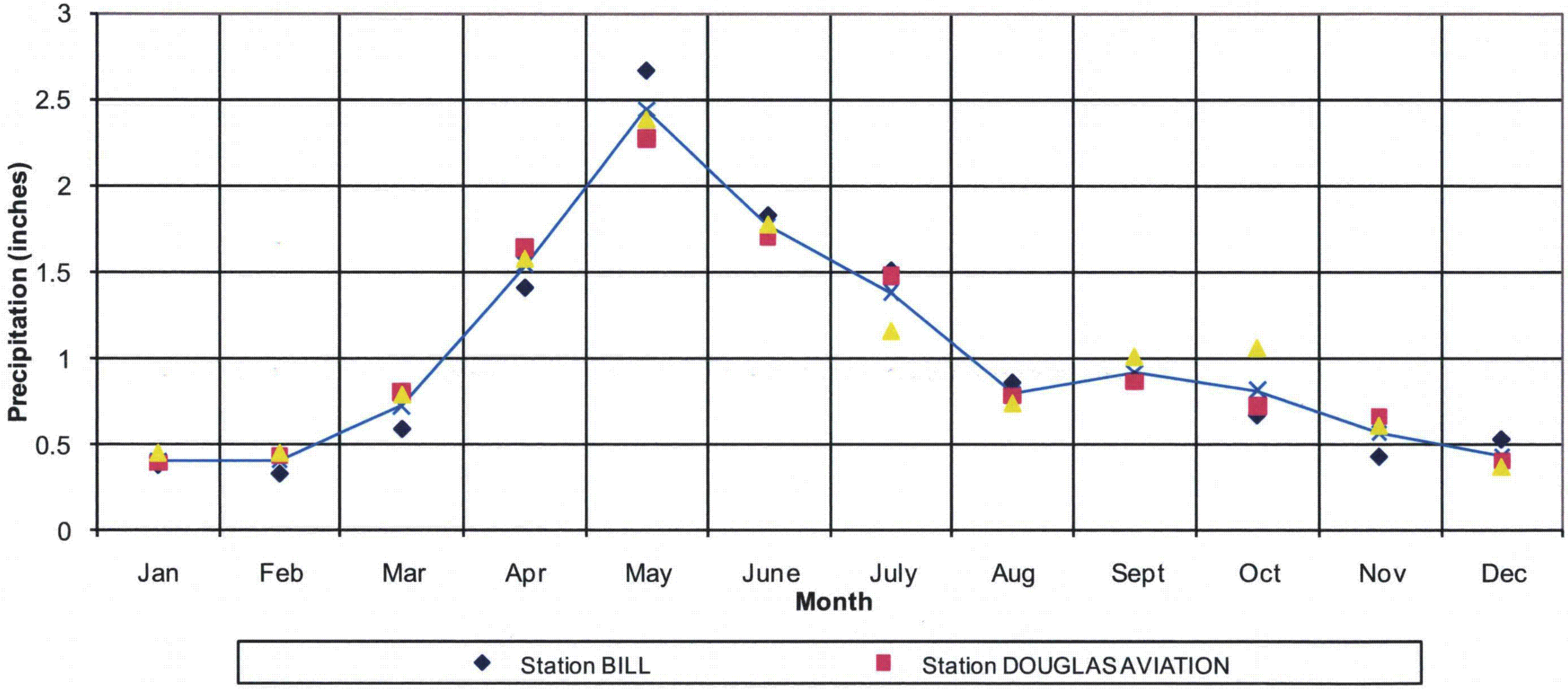

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FIGURE 1
AVERAGE PRECIPITATION

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