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VIA HAND DELIVERY

March 31, 2010

Mr. Dane L. Finerfrock
Executive Secretary
Utah Radiation Control Board
State of Utah Department of Environmental Quality
168 North 1950 West
Salt Lake City, UT 84114-4850

Dear Mr. Finerfrock

**Re: White Mesa Uranium Mill State of Utah Groundwater Discharge Permit No. UGW370004-
Revised Infiltration and Contaminant Transport Modeling Report**

Pursuant to Part I.H.11 of the White Mesa Mill's Groundwater Discharge Permit, please find enclosed two copies of the Revised Infiltration and Contaminant Transport Modeling Report prepared by MWH Americas Inc.

Please contact me at 303-389-4132 or Harold Roberts at 303-389-4160 if you have any questions or require any further information.

Yours very truly,

DENISON MINES (USA) CORP.

Jo Ann Tischler
Director, Compliance and Permitting

Encl.

cc: Ron F. Hochstein
Harold R. Roberts
David C. Frydenlund
David E. Turk



Denison Mines (USA) Corp.

**Revised Infiltration and Contaminant Transport
Modeling Report, White Mesa Mill Site,
Blanding, Utah**

March 2010



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A handwritten signature in blue ink that reads "Jo Ann Tischler".

Jo Ann Tischler
Director, Compliance and Permitting

Encl.

cc: Ron F. Hochstein
Harold R. Roberts
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David E. Turk

**REVISED
INFILTRATION AND CONTAMINANT TRANSPORT
MODELING REPORT
WHITE MESA MILL SITE
BLANDING, UTAH
DENISON MINES (USA) CORP.**

March 2010

Prepared for:

**Denison Mines (USA) Corp.
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Prepared by:

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LIST OF ACRONYMS

$\mu\text{g/l}$	micrograms per liter
μm	micrometer
AE	actual evaporation
ADE	advection-dispersion equation
ANP	acid neutralization potential
AT	actual transpiration
bgs	below ground surface
cm/sec	centimeters per second
cm/d	centimeters per day
D & D	decommissioning and deconstruction
DRC	Division of Radiation Control
ET	evapotranspiration
FML	flexible membrane liner
ft/ft	feet per foot
GCL	geosynthetic clay liner
GWCL	Ground Water Compliance Limits
GWQS	Ground Water Quality Standards
HDPE	high-density polyethylene
HFO	hydrous ferric oxide
ICTM	infiltration and contaminant transport modeling
K_d	partition coefficient
L	length
M	mass
mg/L	milligrams per liter
mm/yr	millimeters per year
MSL	mean sea level
MWH	MWH Americas, Inc.
PE	potential soil evaporation
PET	potential evapotranspiration
pH	potentiometric hydrogen ion concentration
PT	potential transpiration

PVC	poly vinyl chloride
SCK·CEN	Belgian Nuclear Research Centre
T	time
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey

EXECUTIVE SUMMARY

This document presents the results of infiltration and contaminant transport modeling to support Denison Mines (USA) Corp.'s Ground Water Discharge Permit (Permit No. UGW370004 revised version dated 20 January 2010) (the "Permit") for its White Mesa uranium milling and tailings disposal facility (the "Mill"). As described in Part I.H.2 of the Permit, Denison is required to prepare an infiltration and contaminant transport modeling (ICTM) report.

The primary objectives of the infiltration and contaminant transport models are to demonstrate the long-term ability of the tailings cells cover system to adequately contain and control tailings contaminants and protect nearby groundwater quality of the uppermost aquifer.

This Revised ICTM Report was prepared based on comments received from the Utah Division of Radiation Control (DRC) on 2 February 2009 on the November 2007 ICTM Report and discussions at meetings held between the DRC, Denison, and MWH on 31 March 2009 and 2 September 2009.

BACKGROUND INFORMATION

Facility Description

The White Mesa Mill is located in southeastern Utah, approximately six miles south of Blanding, Utah. The Mill includes a mill facility and tailings cells located south of the Mill. The tailings cells comprise the following:

- Cell 1 – 55 acres, used for the evaporation of process solutions
- Cell 2 – 65 acres, used for storage of barren tailings sands
- Cell 3 – 70 acres, used for storage of barren tailings sands and evaporation of process solutions
- Cell 4A – 40 acres, used for storage of barren tailings sands and evaporation of process solutions
- Cell 4B – currently being permitted (approximately 40 acres to be used for storage of barren tailings sands and evaporation of process solutions).

The tailings cells generally were excavated into the underlying Dakota Sandstone and are separated by dikes composed of compacted earthen materials. In the vicinity of the tailings cells, the perched water table is approximately 75 to 115 ft below ground surface, which is 40 to 90 ft below the bottom of the tailings cells.

Proposed Tailings Cover Design

The construction of a monolithic evapotranspiration (ET) cover is proposed to cap the entirety of all tailings cells. The proposed ET cover would be 2.84-m (9.3-ft) thick and would consist of (from top to bottom):

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil (sandy clayey silt) placed at 85% of Standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer
- 162 cm (5.3 ft) of random fill soil (sandy clayey silt) composed of 2.8 feet of random fill compacted to 95% of Standard Proctor dry density over 2.5 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

A monolithic ET cover is the preferred design to minimize infiltration and meet the radon attenuation standard. The proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon flux.

GENERAL MODELING APPROACH

To evaluate performance of the cover system, a model of the cover system was constructed to predict potential infiltration of water through the cover to the tailings. Several cover designs were tested with the cover system infiltration model including the currently permitted rock cover design and a proposed monolithic ET cover (and several

variations). Minimizing infiltration through the cover and preventing build-up of leachate head within the tailings are required for compliance with Part I.D.8 of the Permit.

An additional requirement of Part I.D.8 is that the final design construction and operation of the cover system will ensure that the groundwater quality at the compliance monitoring wells does not exceed the Ground Water Quality Standards (GWQS's) or Ground Water Compliance Limits (GWCL's). However, the cover system infiltration model cannot evaluate impacts to groundwater quality. To evaluate potential impacts to groundwater, a vadose zone model was constructed to predict potential flow and contaminant transport through the bedrock vadose zone beneath the tailings cells. To address specific requests of the DRC, the operational and dewatering phases of the tailings cells were included in the modeling in addition to the 200-year regulatory timeframe after the cells are closed (with the cover in place). For these simulations, potential water flux rates through the liners were estimated for the operational phase, dewatering phase, and post-closure steady state based on water levels estimated in the tailings cells. The bedrock vadose zone model evaluates the potential impacts of the tailings cell system as a whole (liner system, dewatering system, and cover system) on groundwater for the project lifecycle, including the operational phase (without cell cover system), the dewatering phase (with an interim cover only), and the 200-year regulatory post-closure period (with complete cover system, but with some limited water remaining in the tailings). For the 240-year period modeled, the potential flux rate and contaminant transport through the underlying bedrock vadose zone is dominated by the effect of the operational phase when the cells were not covered. As a result, the bedrock vadose zone model including the operational phase is not a reliable indicator of performance of the closed-cell cover system. However, even with the operational phase, model-predicted contaminant concentrations in vadose zone pore water entering the perched aquifer did not exceed the GWQS's or GWCL's for any downgradient monitoring wells, thus demonstrating compliance with Part I.D.8 of the Permit.

Other modeling and calculations were performed to support initial conditions and boundary conditions used in the cover system infiltration model and the bedrock vadose

zone flow and transport models. Specific details of the modeling are presented throughout the remainder of this report with supporting information provided in the appendices.

Following conceptual-model development, numerical modeling was completed with the following two basic models:

1. Cover Model: Infiltration modeling with HYDRUS-1D of the tailings cell cover system with daily precipitation and evapotranspiration to estimate potential long-term average infiltration rates to the tailings.
2. Bedrock Vadose Zone Model: Vadose zone flow and potential contaminant transport modeling with HP1 (HYDRUS-1D coupled with the geochemical program PHREEQC) through the bedrock vadose zone to the underlying perched aquifer during the operational phase, dewatering phase, and 200-year regulatory post-closure steady-state timeframes. Vadose zone properties were based on the results of a detailed sampling program performed to characterize geochemical properties of the bedrock. HYDRUS-1D was used to confirm the results for flow and transport of a conservative solute (chloride) predicted by HP1.

The contaminants modeled with HP1 included pH, major cations and anions necessary to achieve charge balance (aluminum, calcium, carbonate, chloride, magnesium, potassium, sodium, and sulfate), and selected trace elements (arsenic, cadmium, copper, iron, nickel, uranium, vanadium, and zinc). The most dependable indicators of site water quality and of potential cell failure are uranium and sulfate, due to their predominance, and chloride, due to predominance and mobility. In particular, chloride will migrate unretarded and act as a conservative tracer and thus would be expected to be detected before all other site contaminants. Uranium was included because it is one of the primary contaminants of concern.

To evaluate the potential “worst case” for build-up of water in the tailings (“bathtub effect”), the model-predicted long-term average water flux rate through the tailings cell

cover system was used to estimate the total amount of water entering the tailings during the 200-year regulatory timeframe. By assuming a completely impermeable liner system (i.e., no water flow through the liners; all water that infiltrated through the cover was accumulated in the cells), the total amount of water entering the tailings through the cover would be accumulated in the cell. By dividing this total water flux by the tailings porosity, the potential rise in water levels in the tailings was calculated for this worst-case scenario. Under this scenario, there would be no impacts to groundwater, because no water would be leaving the cells.

MODEL RESULTS

The HYDRUS-1D infiltration model was used to predict potential water fluxes through the tailings cell cover system. The HP1 bedrock vadose zone contaminant transport model was used to predict the potential flow and transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace elements) solutes through the bedrock vadose zone to the perched aquifer. Sensitivity analyses were performed to evaluate the impacts that uncertainty in parameter input values have on model results.

Model-Predicted Water Flux Rate for Tailings Cell Cover System

The model-predicted average long-term water flux rate through the proposed monolithic ET tailings cell cover, assuming a historical climate record (based on climatic data recorded between 1932 and 1988), was 0.45 mm/yr. The average long-term water flux rate corresponds to approximately 0.1% of the average annual amount of precipitation recorded at the Blanding weather station. This is in contrast to an average long-term infiltration rate of 34 mm/yr predicted for the currently permitted rock cover design. The increased performance and reduction of infiltration for the ET cover relative to the original rock cover design, is attributed to the presence of vegetation and associated root water uptake via transpiration. The model-predicted water flux rate through the monolithic ET cover indicates that the available storage capacity of the cover should be sufficient to significantly reduce infiltration, and the ET cover should function properly as designed.

A monolithic ET cover is the preferred design to minimize infiltration necessary to meet the Permit requirements (Part I.D.8) and meet the radon attenuation standard. The material thicknesses for the different cover layers were based on the results of radon attenuation modeling to achieve the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Furthermore, the proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration and biointrusion, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon flux.

Evaluation of Build-up of Waters in Tailings

To evaluate the potential for build-up of water in the tailings ("bathtub effect"), the long-term average water flux rate through the tailings cell cover system (predicted with the infiltration model) was used to calculate the amount of water entering the tailings during the 200-year regulatory timeframe specified by the Permit. The amount of water expected to migrate through the cover and enter the tailings cells (i.e., assuming all recharge to the tailings can act to increase the amount of head on the liner) was then used to calculate the maximum potential rise in water levels in the tailings assuming no water flow through the liners (i.e., all water that infiltrated through the cover was accumulated in the cells). The assumptions for evaluating the "bathtub effect" result in an end-member scenario expected to produce a conservative estimate of closed-cell cover system performance.

The amount of water calculated to enter the tailings after 200 years is equal to 90 millimeters (0.3 feet) of water. Assuming a tailings porosity of 57%, the calculated water-level rise on the liner is approximately 160 millimeters (0.53 feet). Consequently, a significant build-up of water ("bathtub effect") within the cells is not anticipated and the leachate head within the tailings is not predicted to rise above or over-top the maximum liner elevation (which typically is greater than 20 feet above the bottom of the cell), meeting the requirement of the Permit (Part I.D.8).

Bedrock Vadose Zone Flow and Contaminant Transport Modeling

The bedrock vadose zone flow and contaminant transport model was used to predict potential flow rates and contaminant transport rates through the bedrock vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. Solute transport models were developed for the bedrock vadose zone beneath Cell 1 (contingency cell identified for the potential disposal of decommissioning and deconstruction debris), Cells 2 & 3, and Cells 4A & 4B. For simplicity, a vadose zone thickness of 12.8 meters (42 feet) was assumed for all of the simulations. This is a conservative assumption given that the average vadose zone thicknesses beneath Cell 2, Cell 3, and Cell 4A are 19.2 m (63 ft), 20.1 m (66 ft), and 17.1 m (56 ft). HP1 was used to simulate potential solute transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace elements) solutes through the bedrock vadose zone beneath the tailings cells.

Potential water flux rates through the primary liner installed beneath Cells 2 & 3 and the secondary liner installed beneath Cells 4A & 4B were calculated using the Giroud-Bonaparte Equation. Estimates of potential water flux rates through the liners were used as an upper boundary condition (time-dependent flux) for the HP1 model used to predict flow and solute transport through the bedrock vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. The average long-term water flux rate through the ET cover (predicted with the infiltration model) was used as an upper boundary condition (constant flux) for Cell 1 to represent the post-closure steady-state period. The bottom of Cell 1 (if constructed) will contain a soil liner compacted to achieve low permeability, but this layer was not included in the modeling, which yields conservative estimates of solute transport through the bedrock vadose zone.

The calculated potential water flux rates through the liners were multiplied by the average solute concentrations measured in the tailings slimes drains to yield a time-dependent mass flux rate applied as an upper boundary condition to the top of the bedrock vadose zone. The average solute concentrations were used as input to represent the source term solution chemistry of the tailings pore water.

Cells 2 & 3 Model-Predicted Water Flux Rate. The potential water flux rate at the bottom of the bedrock vadose zone (immediately above the perched aquifer) is predicted to reach a maximum value of approximately 7.5 mm/yr after 25 years of tailings cell operation (note that tailings cells are not covered during this period). The potential flux rate is then predicted to rapidly decline in response to decreased head (saturated thickness) that occur in the tailings during the dewatering phase, ultimately reaching a long-term steady state value of approximately 0.7 mm/yr during the 200-year regulatory post-closure period. There is considerable evidence that the cells are not leaking. Consolidation of fine-grained tailings and deposition of tailing slimes, coupled with the chemical nature of the pore water (e.g., precipitation of gypsum and amorphous mineral phases), is anticipated to essentially seal some of the defects, which would act to decrease the potential flux rates through the liners.

Cells 2 & 3 Model-Predicted Chloride Concentration. The model-predicted increase in chloride concentrations at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years (including operational, dewatering, and post-closure periods) of transport is 0.01 mg/L. The chloride concentration at the bottom of the vadose zone represents the model-predicted addition of chloride as a result of the potential flux from the tailings cells. While there is naturally-occurring chloride in the vadose zone, the modeling assumed no initial chloride for simplicity, and because there is a lack of data concerning background chloride concentrations and the distribution of chloride within the vadose zone. Furthermore, the model-predicted chloride concentration is the solute concentration in vadose zone pore water that will reach the perched aquifer; however, the predicted concentration is not equal to the concentration in groundwater. A model was not constructed to determine the actual (diluted) concentration in groundwater because the chloride concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL for chloride, which is 10 mg/L. The minimum GWCL (for chloride and all other solutes modeled) was selected from the list of monitoring wells located immediately downgradient from the tailings cells (i.e., monitoring wells MW-5, MW-11, MW-12, MW-14, MW-15, MW-23, MW-24, MW-28, MW-29, MW-30, and MW-31; GWCL's for these wells are specified in the Permit).

Cells 2 & 3 Model-Predicted Sulfate Concentration. The model-predicted sulfate concentration at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years of transport is 0.014 mg/L. The distribution of sulfate within the bedrock vadose zone is controlled by the amount of gypsum that may precipitate from solution. The sulfate concentration at the bottom of the bedrock vadose zone represents the model-predicted addition of sulfate as a result of the potential flux from the tailings cells. A model was not constructed to determine the actual (diluted) concentration in groundwater because the sulfate concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL for sulfate, which is 532 mg/L for monitoring wells located immediately downgradient from the tailings cells.

Cells 2 & 3 Model-Predicted Uranium Concentration. Uranium is not predicted to reach the bottom of the bedrock vadose zone beneath Cells 2 & 3 during the 240-year timeframe. Adsorption of uranium onto the surface of hydrous ferric oxide (HFO) present in the bedrock vadose zone limits the transport distance below the liner. The depth at which the model-predicted uranium concentration is approximately equal to the minimum GWCL (0.0049 mg/L) after 240 years is 2.3 meters (8 feet) below the tailing cell liner system; a minimum of 10.5 meters (34 feet) above the perched water table. The uranium concentration within the bedrock vadose zone represents the model-predicted addition of uranium as a result of the potential flux from the tailings cells. HFO is the only solid phase that serves as a potential sorption site of uranium and other trace elements, which is a conservative assumption because other phases (e.g., hematite, quartz, clays, etc.) also participate in surface complexation reactions.

Cells 2 & 3 Model-Predicted Concentration of Other Trace Elements. The sorption of uranium was competitive because additional trace elements were modeled. Solutes included in the model were based on their elevated concentrations in the tailings pore water as compared to the GWCLs. Transport of the following trace elements was modeled: arsenic, cadmium, copper, nickel, vanadium, and zinc. Similar to uranium, these solutes were predicted to migrate a limited distance below the liner (e.g., a few meters).

Cells 4A & 4B Model-Predicted Water Flux Rate. The calculated potential flux of water through the secondary liner beneath Cells 4A & 4B for the maximum head within the leak detection system during the operational and dewatering periods is approximately 8×10^{-5} mm/yr. The potential flux rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state because the increase in water levels is anticipated to be minor. Therefore, the model-predicted water flux rate at the bottom of the bedrock vadose zone (immediately above the perched aquifer) during post-closure steady-state is 8×10^{-5} mm/yr.

Cells 4A & 4B Model-Predicted Concentrations. For all practical purposes, chloride is not predicted to reach the bottom of the bedrock vadose zone during the 12-year operational and 200-year post-closure periods (the chloride concentration predicted to reach the water table at 212 years was 5×10^{-14} mg/L). The chloride concentration is not predicted to exceed the 10 mg/L minimum GWCL anywhere in the vadose zone because of the diminutive chloride mass flux rate entering the vadose zone. Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the fact that the model predictions demonstrate nearly zero impact, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was considered unnecessary.

Cell 1 Model-Predicted Water Flux Rate. If Cell 1 is constructed for decommissioning and deconstruction disposal, it will include a soil liner compacted to achieve low permeability and will be covered with the monolithic ET cover. The cover design will be the same as the monolithic ET cover proposed for the other cells. Consequently, the long-term average infiltration rate would be equivalent to the value presented for the other cells. The model-predicted water flux rate at the bottom of the vadose zone (immediately above the perched aquifer) during 200-year post-closure steady-state is predicted to be approximately 0.5 mm/yr.

Cell 1 Model-Predicted Concentrations. The source term of the decommissioning and deconstruction debris is assumed to equal the concentrations assigned to the tailings pore water, which is anticipated to lead to conservative predictions that over predict the

potential impacts. For all practical purposes, chloride is not predicted to reach the bottom of the bedrock vadose zone during the 200-year transport timeframe (the chloride concentration predicted to reach the water table at 200 years was 7×10^{-9} mg/L). Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the diminutive transport distance, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was considered unnecessary.

CONCLUSIONS

The assumptions used to construct the numerical models to predict infiltration through the cover and potential impacts to the perched groundwater system, generally were either conservative or based on anticipated conditions. As a result, the predictions are considered to be conservative. The proposed monolithic ET cover will minimize infiltration into the tailings, will prevent build-up of leachate head on the cell liner, and will be protective of groundwater quality; contaminant concentrations are not predicted to exceed the GWCS's or GWCL's at the compliance monitoring wells specified in the Permit, thus demonstrating compliance with the Permit. Furthermore, the results of the radon attenuation modeling demonstrate that the proposed monolithic ET cover will attenuate radon fluxes thereby achieving the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24).

1.0 INTRODUCTION

This document presents the results of infiltration and contaminant transport modeling to support Denison Mines (USA) Corp.'s Ground Water Discharge Permit (Permit No. UGW370004 revised version dated 20 January 2010) (the "Permit") for its White Mesa uranium milling and tailings disposal facility (the "Mill"). As described in Part I.H.2 of the Permit, Denison is required to prepare an infiltration and contaminant transport modeling (ICTM) report.

Denison has engaged MWH Americas, Inc. (MWH) to work with Denison personnel to develop the assumptions and data for the infiltration and contaminant transport models and interpret the model results.

1.1 OBJECTIVES OF INFILTRATION AND CONTAMINANT TRANSPORT MODELS

The primary objectives of the infiltration and contaminant transport models are to demonstrate the long-term ability of the tailings cells cover system to adequately contain and control tailings contaminants and protect nearby groundwater quality of the uppermost aquifer.

1.2 PERMIT REQUIREMENTS

Part I.H.2 (Infiltration and Contaminant Transport Modeling Work Plan and Report) of Denison's Permit presents the requirements for infiltration and contaminant transport modeling, as summarized below.

An infiltration and contaminant transport modeling report that demonstrates the long-term ability of the tailings cells cover system to adequately contain and control tailings contaminants and protect nearby groundwater quality of the uppermost aquifer must be submitted to the Utah Division of Radiation Control (DRC) for Executive Secretary approval. This report shall demonstrate how the tailings cell engineering design and

specifications will comply with the minimum performance requirements of Part I.D.8 for Closed Cell Performance Requirements] of the Permit.

The infiltration and contaminant transport modeling report must describe:

- Applicable and pertinent historic studies and modeling reports relevant to the tailings cell cover design and tailings cell system performance.
- Information necessary for infiltration and contaminant transport modeling, including representative input values for vadose zone and aquifer soil-water partitioning (K_d) coefficients, tailings source term concentrations, tailings waste leach rates, vadose zone and aquifer velocities and dispersivity, contaminant half-life or other rates of decay, etc. If any required information is not currently available, conservative assumptions can be used for the model input.
- Computer models that will be used to simulate long-term performance of the tailings cells cover system. Specific information on model design, including governing equations and their applicability to site conditions, grid design, duration of simulation, and selection of time steps must be described.
- The conceptual models used and justification why they are representative or conservative of actual field conditions at the site. The conceptual models will identify the physical domains and geometries simulated including the tailings cell design and construction, all boundary and initial conditions assigned in the models, and the shallow aquifer locations where future potential contaminant concentrations have been predicted.
- How the infiltration and contaminant transport problem has been conceptualized, planned, and executed to demonstrate compliance with the requirements of Part I.D.8 of the Permit.

- Model results, model calibration, steady state conditions, sensitivity analyses, post-model audit plan.

Additionally, Part I.D.8 (Closed Cell Performance Requirements) of the Permit presents requirements regarding performance requirements for closed cells at the facility, which impacts both actual infiltration at the site as well as how this infiltration will be modeled, as follows:

- Before reclamation and closure of any tailings disposal cell, the Permittee shall ensure that the final design, construction, and operation of the cover system at each tailings cell will comply with all requirements of an approved Reclamation Plan, and will for a period of not less than 200 years meet the following minimum performance requirements:
 - Minimize infiltration of precipitation or other surface water into the tailings, including, but not limited to the radon barrier.
 - Prevent the accumulation of leachate head within the tailings waste layer that could rise above or over-top the maximum flexible membrane liner (FML) elevation internal to any disposal cell, i.e., create a “bathtub effect”.
 - Ensure the groundwater quality at the compliance monitoring wells does not exceed the Ground Water Quality Standards (GWQS’s) or Ground Water Compliance Limits (GWCL’s) specified in Part I.C.1 and Table 2 of the Permit.

Further, Part I.C.1 (Permit Limits) of the Permit includes the following:

- The Permittee shall comply with the following GWCL’s – contaminant concentrations measured in each monitoring well shall not exceed the GWCL’s defined in Table 2 of the Permit. Groundwater quality at the site must at all times meet all the applicable GWQS’s and the ad hoc GWQS’s

defined in R317-6 even though the Permit does not require monitoring for each specific contaminant.

Part I.H.2.f also states that “Upon Executive Secretary approval of the final infiltration and contaminant transport report, the Reclamation Plan may be modified to accommodate necessary changes to protect public health and the environment.”

The infiltration and contaminant transport modeling report has been prepared to comply with the Permit as described above.

1.3 GENERAL MODELING APPROACH TO ADDRESS PERMIT REQUIREMENTS

The Permit specifically states that the purpose of the infiltration modeling is to evaluate the closed-cell cover system performance. To evaluate performance of the cover system, a model of the cover system was constructed to predict potential infiltration of water through the cover to the tailings. Several cover designs were tested with the cover system infiltration model including the currently permitted rock cover design and a proposed monolithic evapotranspiration (ET) cover (and several variations). Minimizing infiltration through the cover and preventing build-up of leachate head within the tailings are required for compliance with Part I.D.8 of the Permit.

An additional requirement of Part I.D.8 is that the final design construction and operation of the cover system will ensure that the groundwater quality at the compliance monitoring wells does not exceed the GWQS's or GWCL's. However, the cover system infiltration model cannot evaluate impacts to groundwater quality. To evaluate potential impacts to groundwater, a vadose zone model was constructed to predict potential flow and contaminant transport through the bedrock vadose zone beneath the tailings cells. To address specific requests of the DRC, the operational and dewatering phases of the tailings cells were included in the modeling in addition to the 200-year regulatory timeframe after the cells are closed (with the cover in place). For these simulations, potential water flux rates through the liners were estimated for the operational phase, dewatering phase, and post-closure steady state based on water levels estimated in the

tailings cells. The bedrock vadose zone model evaluates the potential impacts of the tailings cell system as a whole (liner system, dewatering system, and cover system) on groundwater for the project lifecycle, including the operational phase (without cell cover system), the dewatering phase (with an interim cover only), and the 200-year regulatory post-closure period (with complete cover system, but with some limited water remaining in the tailings). For the 240-year period modeled, the potential flux rate and contaminant transport through the underlying bedrock vadose zone is dominated by the effect of the operational phase when the cells were not covered. As a result, the bedrock vadose zone model including the operational phase is not a reliable indicator of performance of the closed-cell cover system. However, even with the operational phase, model-predicted contaminant concentrations in vadose zone pore water entering the perched aquifer did not exceed the GWQS's or GWCL's for any downgradient monitoring wells, thus demonstrating compliance with Part I.D.8 of the Permit.

Other modeling and calculations were performed to support initial conditions and boundary conditions used in the cover system infiltration model and the bedrock vadose zone flow and transport models. Specific details of the modeling are presented throughout the remainder of this report with supporting information provided in the appendices.

1.4 INFILTRATION AND CONTAMINANT TRANSPORT MODELING REPORT HISTORY

The original Permit specified that a work plan must be submitted and approved before the ICTM report could be prepared. Denison submitted a work plan to the DRC in a letter dated 3 September 2005. However, the DRC did not review this work plan and removed this requirement from the Permit as stated in a letter from the Executive Secretary to Denison dated 3 November 2006.

The ICTM report was submitted to the DRC for Executive Security approval on 21 November 2007. The DRC reviewed the report and submitted review comments and a request for additional information in a letter to Denison dated 2 February 2009. To facilitate discussion and provide clarification regarding the DRC's comments, a meeting

was held between the DRC, Denison, and MWH on 31 March 2009 at the DRC's office in Salt Lake City, Utah. A follow-up meeting was held on 2 September 2009 also at the DRC's office in Salt Lake City. Meeting minutes for these two meetings were prepared and approved by the DRC. On 1 December 2009, Denison submitted a memorandum prepared by MWH that provided preliminary responses to the DRC's comments and request for additional information. Subsequently, a deadline of 31 March 2010 was established for submittal of the revised ICTM report. The revised ICTM report, and supporting documentation contained within the appendices, is submitted here in its entirety. The 2010 ICTM report submitted here supersedes the 2007 ICTM report.

1.5 DOCUMENT ORGANIZATION

The remainder of this report includes the following sections:

- Section 2.0 – Site Background; descriptions of the site including tailings cell cover and liner designs, as well as tailings chemical and physical characteristics, site geology and hydrogeology, conceptual model of water flow (infiltration) through the tailings cell cover, and conceptual model of water flow and potential contaminant transport through the vadose zone
- Section 3.0 – Methodology; descriptions of the tailings cell cover infiltration model, vadose zone flow and transport model, tailings cell dewatering model, input parameters and boundary conditions, and modeling assumptions
- Section 4.0 – Results; descriptions of the results of the tailings cell cover infiltration model, vadose zone flow and transport model, tailings cell dewatering model, and sensitivity analysis
- Section 5.0 – Conclusions; summary of the conclusions of the tailings cell cover infiltration model, and bedrock vadose zone flow and transport model, along with recommendations for a post-audit monitoring plan
- Section 6.0 – References

- Appendix A – Laboratory reports with results of vadose zone mineralogical testing and properties of stockpiled soil
- Appendix B – Laboratory report with unsaturated and saturated hydraulic properties of the bedrock core samples
- Appendix C – Bedrock sampling to characterize hydraulic and geochemical properties of the vadose zone
- Appendix D – Vegetation evaluation for the evapotranspiration cover
- Appendix E – Comparison of cover designs based on infiltration modeling
- Appendix F – Evaluation of the effects of storm intensity on infiltration through evapotranspiration cover
- Appendix G – Sensitivity analysis comparing infiltration rates through the evapotranspiration cover based on cover vegetation, biointrusion, and precipitation
- Appendix H – Radon emanation modeling for the evapotranspiration cover
- Appendix I – Tailings hydraulic conductivity evaluation
- Appendix J – Tailings cell dewatering modeling
- Appendix K – Statistical evaluation of tailings pore water chemistry and identification of source term concentrations
- Appendix L – Evaluation of potential water flow through the tailings cell liners
- Appendix M – Geochemical model and reactive transport modeling of flow and transport through the vadose zone
- Appendix N – Predictive simulation input and output files in electronic format only (on CD).

2.0 BACKGROUND

This section provides information on the:

- Site background including descriptions of the White Mesa Mill facility, proposed tailings cell cover design, tailings cell liner systems, and tailings chemical and physical characteristics;
- Site characteristics including descriptions of climate, geology, hydrogeology of the perched aquifer system, groundwater quality of the perched aquifer system, and vadose zone hydrogeology and geochemistry of the unsaturated bedrock;
- Conceptual model of water flow (infiltration) through the tailings cell cover; and
- Conceptual model of water flow and potential contaminant transport through the vadose zone.

Site-specific studies and reports reviewed to prepare this modeling report included:

- *Engineering Report, Tailings Management System, White Mesa Uranium Project, Blanding, Utah* (D'Appolonia Consulting Engineers, Inc., 1979)
- *Construction Report, Initial Phase – Tailings Management System, White Mesa Uranium Project, Blanding, Utah* (D'Appolonia Consulting Engineers, Inc., 1982)
- *Cell 4A Lining System Design Report for the White Mesa Mill, Blanding, Utah* (Geosyntec Consultants, 2006a)
- *Stockpile Evaluation Tailings Cell 4A, White Mesa Mill - Technical Memo submitted to International Uranium (USA) Corporation* (Geosyntec Consultants, 2006b)

- *Cell 4B Design Report, White Mesa Mill, Blanding, Utah* (Geosyntec Consultants, 2007a)
- *Revised Construction Drawings, DMC White Mesa Mill, Cell 4A Lining System* (Geosyntec Consultants, 2007b)
- *Analysis of Slimes Drains for White Mesa Mill, Cell 4A* (Geosyntec Consultants, 2007c)
- *Hydraulic Testing at the White Mesa Uranium Mill Site, near Blanding, Utah during July 2002* (Hydro Geo Chem, Inc., 2002)
- *Site Hydrogeology and Estimation of Groundwater Pore Velocities in the Perched Zone, White Mesa Uranium Mill Site near Blanding, Utah* (Hydro Geo Chem, Inc., 2009)
- *Revised Background Groundwater Quality Report: Existing Wells for Denison Mines (USA) Corp.'s White Mesa Mill Site, San Juan County, Utah* (INTERA, Inc., 2007a)
- *Revised Addendum Evaluation of Available Pre-Operational and Regional Background Data Background Groundwater Quality Report: Existing Wells for Denison Mines (USA) Corp.'s White Mesa Mill Site, San Juan County, Utah* (INTERA, Inc., 2007b)
- *Revised Addendum Background Groundwater Quality Report: New Wells for Denison Mines (USA) Corp.'s White Mesa Mill Site, San Juan County, Utah* (INTERA, Inc., 2008)
- *Summary of Work Completed, Data Results, Interpretations, and Recommendations for the July 2007 Sampling Event at the Denison Mines, USA, White Mesa Uranium Mill, near Blanding, Utah* (Hurst and Solomon, 2008)
- *Reclamation Plan, White Mesa Mill, Blanding, Utah, Source Material License No. SUA-1358, Docket No. 40-8681, Revision 3.0* (IUC, 2000)

- *Reclamation Plan, White Mesa Mill, Blanding, Utah, Radioactive Materials License No. UT1900479, Revision 4.0* (Denison, 2009)
- *Hydrogeological Evaluation of White Mesa Uranium Mill* (TITAN Environmental Corporation, 1994)
- *Tailings Cover Design, White Mesa Mill, Blanding Utah* (TITAN Environmental Corporation, 1996).

Complete citations for these and other sources cited throughout this document are provided in the References section.

2.1 SITE OVERVIEW

2.1.1 Facility Description

The White Mesa Mill is located in southeastern Utah, approximately six miles south of Blanding, Utah. The Mill includes a mill facility and tailings cells located south of the Mill (see Figure 2-1). The focus of this report is the tailings cells; for information concerning site history or milling operations, see the *Reclamation Plan* (IUC, 2000; Denison, 2009).

The tailings cells comprise the following:

- Cell 1 – 55 acres, used for the evaporation of process solutions
- Cell 2 – 65 acres, used for storage of barren tailings sands
- Cell 3 – 70 acres, used for storage of barren tailings sands and evaporation of process solutions
- Cell 4A – 40 acres, used for storage of barren tailings sands and evaporation of process solutions

- Cell 4B – currently being permitted (approximately 40 acres to be used for storage of barren tailings sands and evaporation of process solutions).

The tailings cells generally were excavated into the underlying Dakota Sandstone and are separated by dikes composed of compacted earthen materials. The tailings cells are lined as described in Section 2.1.3. In the vicinity of the tailings cells, the perched water table is approximately 75 to 115 ft below ground surface, which is 40 to 90 ft below the bottom of the tailings cells.

The White Mesa Mill is a zero-discharge facility, thus all liquids must be eliminated through evaporation. Currently, Denison is actively evaporating process waters from Cell 1, Cell 3, and Cell 4A. Cell 1 is currently used as an evaporation pond only and will not be used to hold solid tailings. During site closure the solution in the Cell 1 pond will be evaporated dry and the evaporite crystals, sediment, geomembrane liner, and any contaminated underlay (foundation) material will be relocated to another cell. Disposal of the decommissioning material in Cell 1 is identified as a contingency in case other cells (e.g., Cell 4B) do not have adequate storage for such material. The cover system constructed above Cell 1 would be identical to the design proposed for the other tailings cells.

Cell 2 is no longer receiving tailings and has been covered with approximately three feet of soil. Cell 3 is near to being full of tailings and is in the process of being covered. The interim soil cover is placed to facilitate site closure and will be used as platform fill to achieve sufficient grading and provide a stable working surface. Water removed from Cells 2 & 3 by the dewatering systems will be discharged to Cell 1 and subsequently evaporated. Cell 4A is currently receiving tailings and will eventually be filled with tailings and covered during site reclamation. Cell 4B is currently being permitted and would be operated in a manner similar to Cell 4A. Descriptions of the proposed tailings cover system and constructed liner systems are provided in the sections below. The proposed cover system would be constructed across all of the tailings cells.

2.1.2 Proposed Tailings Cover Design

The construction of a monolithic evapotranspiration (ET) cover is proposed as part of this ICTM report to cap the entirety of all tailings cells. The proposed 2.84-m (9.3-ft) thick monolithic ET cover design (see Figure 2-2) would consist of (from top to bottom):

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil (sandy clayey silt) placed at 85% of Standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer
- 162 cm (5.3 ft) of random fill soil (sandy clayey silt) composed of 2.8 feet of random fill compacted to 95% of Standard Proctor dry density over 2.5 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

A monolithic ET cover is the preferred design to minimize infiltration and meet the radon attenuation standard. The proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon flux.

Details regarding the short-term establishment and long-term sustainability of the vegetative component of the ET cover are summarized in Appendix D. Empirical data regarding the ecological characteristics of the species mix (rooting depth and root distribution) and established plant community (percent cover) were summarized from the literature and nearby lysimeter studies to develop a conceptual model of the vegetative component for the ET cover system. The empirical data were then used to parameterize the infiltration model and predict the ET cover's performance over the long term (see Appendices E and G).

The monolithic ET cover was tested with the infiltration model as described in Sections 3.0 and 4.0. A sensitivity analysis was performed to test variations in the ET cover design and the proposed design and variations demonstrated significantly improved performance over the currently permitted rock cover design (see Appendix E for details of this comparison). Results of modeling the emanation of radon-222 from the top surface of the monolithic ET cover are presented in Appendix H. The proposed cover design replaces the top surface of the cover; the side slope design may include rock armoring, as in the original design (TITAN Environmental, 1996).

2.1.3 Tailings Cell Liner Systems

Cells 2 & 3. The tailings liner systems for Cells 2 & 3 are identical and consist of a slimes drain collection system overlying a single liner (see Figure 2-2). The design consists of (from top to bottom):

- slimes drain system (cell bottom only)
- liner protective blanket
- 30-mil (0.03-inch) poly vinyl chloride (PVC) flexible membrane liner (FML)
- 6-inch compacted bedding material
- prepared subgrade with limited leak detection system (i.e., a single pipe at the toe of the southern dike).

Cells 4A & 4B. The tailings liner system for Cell 4A is double lined, and consists of a slimes drain collection system overlying a primary liner, leak detection system, and composite secondary liner (see Figure 2-2). A composite liner is defined as a geomembrane liner underlain by a low-permeability soil (e.g., naturally compacted soil or geosynthetic clay layer). The design for Cell 4B is currently under review, but preliminary drawings indicate a design identical to that of Cell 4A, with minor deviations. The design consists of (from top to bottom):

- slimes drain system (cell bottom only)
- 60-mil (0.06-inch) high-density polyethylene (HDPE) geomembrane (primary liner)
- geonet drainage layer (leak detection system)
- 60-mil (0.06-inch) HDPE geomembrane (secondary liner)
- geosynthetic clay liner (GCL)
- prepared subgrade.

Slimes drain systems are installed in Cells 2, 3, 4A, and 4B. The slimes drains in Cells 2 & 3 include both 1.5-inch and 3-inch diameter slotted PVC pipe installed in a 1-ft thick clean sand layer above the protective blanket. These lateral drains are installed on 50-ft centers parallel to the southern edge of the tailings cells and cover an area that is approximately 400 ft (north-south) by 600 ft (east-west). The slimes drains in Cells 4A & 4B are on 50-ft centers and are located beneath the entirety of the cells. Leak detection systems are installed under the cells and are monitored weekly. Details of the liner systems are provided in D'Appolonia Consulting Engineers (1982) for Cells 2 & 3, in Geosyntec Consultants (2006a) for Cell 4A, and in Geosyntec Consultants (2007) for Cell 4B.

There is strong evidence to suggest that no significant leakage has occurred through the liner systems beneath Cells 2 & 3 over the past 30 years. Evidence that Cells 2 & 3 are not leaking includes:

- No significant leakage indicated by the leak detection systems
- No leakage indicated by the perched aquifer water table surface elevations

- No observations of contamination (e.g., acid leaching, dissolution of carbonates, gypsum precipitation, staining) were recorded during drilling of monitoring wells installed between and adjacent to the cells during spring 2005
- Total uranium was detected at background levels in bedrock core samples collected while drilling monitoring wells between and adjacent to the cells (see Appendix A)
- No contaminants detected in groundwater at levels above natural background concentrations (INTERA, Inc., 2007a; 2007b; 2008), which is corroborated by the finding that the groundwater age beneath the tailings cells is dominated by water that is at least 50 years old (Hurst and Solomon, 2008)
- No contaminants detected in groundwater as evaluated through stable isotopes (Hurst and Solomon, 2008).

2.1.4 Characteristics of Tailings

The tailings are generally silty sand but heterogeneous due to the placement process. Based on grain-size analyses performed on the tailings, sand-sized particles are dominant (57 percent on average) with the remainder being silt- and clay-sized particles. Grain size distribution data for the White Mesa Mill tailings are compared to data collected at other uranium mill tailings facilities (see Appendix I). The saturated hydraulic conductivity of the tailings assumed for White Mesa was based on measured values reported for the Cotter Corporation's Canon City Mill tailings impoundment (see Appendix I). The mill tailings at Canon City are considered to be representative of the mill tailings at White Mesa because the average grain-size distributions between the two sites are similar.

The tailings are initially saturated when placed but are dewatered through evaporation and pumping from the slimes drains system. The solution chemistry of the tailings pore water, as represented by samples collected from the Cell 2 slimes drain, was assumed to

be identical for all of the cells (see Appendix K). Tailings pore water in the slimes drains (i.e., immediately above the tailing cell liners) is considered to be more representative of solutions that would remain in the tailings cells during operations and at closure given that these solutions would have had sufficient time to equilibrate with the tailings. Furthermore, water extracted from the slimes drains, as opposed to samples grabbed from surface ponds, is not affected as much by evaporation/evapoconcentration and addition/recirculation of mill process water; evaporation and recirculation of mill process water would tend to create a variable source-term solution chemistry that is dissimilar to and not representative of the long-term pore water chemistry in the tailings.

2.2 SITE CHARACTERISTICS

2.2.1 Climate

The climate of the Blanding area is semiarid with average annual precipitation of 13.3 inches (Utah Climate Center, 2007). Most precipitation falls in the form of rain, with about one-quarter of the precipitation falling as snow. There are two separate rainfall seasons in the area: a late summer season when monsoonal moisture from the Gulf of Mexico leads to thunderstorms and a winter season related to fronts from the Pacific. The average annual Class A pan evaporation rate is 68 inches.

Climatological data are available for the weather station near Blanding, Utah (420738), located approximately six miles north of the White Mesa Mill at an elevation of 6,040 ft above mean sea level (ft above MSL). The White Mesa Mill is located at an elevation of 5,600 ft above MSL. Data are available for the period December 1904 through December 2006; however, large gaps in the dataset (i.e., missing precipitation and/or air-temperature measurements) occurred during 1905, 1910 to 1912, 1915, 1916, 1917, 1927, 1929, 1931, 1989, and 2005. Data for the period between 1932 and 1988 are nearly continuous.

The long-term average annual precipitation at the Blanding weather station was 13.3 inches with a standard deviation of 3.9 inches. Annual precipitation for the period 1905 through 2005 is presented in Figure 2-3. The greatest annual precipitation was

measured in 1909 (24.5 inches), but other years that exceeded 20 inches include 1906 (23.6 inches), 1957 (22.4 inches), 1941 (21.5 inches), 1908 (20.2 inches), 1997 (20.2 inches), and 1965 (20.1 inches). Daily precipitation for the period 1905 through 2005 is presented in Figure 2-4. The largest daily precipitation event was 4.48 inches, which occurred on 1 August 1968.

The mean annual temperature for Blanding, Utah is 52°F, based on the period 1971-2000. January is typically the coldest month, with a mean monthly temperature of about 30°F. July is generally the warmest month, with a mean monthly temperature of 76°F. Daily ranges in temperatures are typically large.

Winds are generally light to moderate (less than 15 miles per hour) at the site during all seasons, with winds prevailing from the south. Strong winds are associated with summer thunderstorms and frontal activity during the late winter and spring.

2.2.2 Summary of Site Geology

The White Mesa Mill is located within the Blanding Basin of the Colorado Plateau physiographic province. The average elevation at the site is 5,600 ft above MSL. The site is underlain by unconsolidated alluvium overlying sedimentary bedrock consisting primarily of sandstone and shale. The unconsolidated deposits are primarily aeolian silt and sand and range from 1 to 30 ft thick (these deposits have been removed where the tailings cells are located). The bedrock underlying the site is relatively undeformed and horizontal (generally dips are less than 3 degrees). Cretaceous Dakota Sandstone and Burro Canyon Formation are at or near the surface; these sandstone units have a combined thickness of 100 to 140 ft at the site. Beneath the Burro Canyon Formation is the Morrison Formation, which is primarily shale. The Brushy Basin Member is the uppermost member of the Morrison Formation and is composed primarily of bentonitic mudstones, siltstones, and claystones. The contact between the Burro Canyon Formation and Brushy Basin Member dips slightly to the south. Beneath the Brushy Basin Member are the Westwater Canyon, Recapture, and Salt Wash members of the Morrison Formation. Beneath the Morrison Formation are the Summerville Formation, Entrada

Sandstone, and Navajo Sandstone. For more detailed descriptions of the geologic setting see the *Reclamation Plan* (IUC, 2000; Denison 2009).

2.2.3 Hydrogeology of the Perched Aquifer System

Groundwater beneath the site is first encountered as a perched zone within the Burro Canyon Formation. The low-permeability Brushy Basin Member of the Morrison Formation acts as an aquitard and forms the base of the perched aquifer. Monitoring wells at the site are screened across the saturated portion of the Burro Canyon Formation and generally extend down to the contact with the Brushy Basin Member. The saturated thickness of the perched zone ranges from less than 5 to as much as 82 ft beneath the site, assuming the base of the Burro Canyon Formation is the base of the perched aquifer. The water table of the perched aquifer was 13 to 116 ft below ground surface (bgs) at the facility in 2007. The perched water table is shallowest near the wildlife ponds (13 ft in piezometer P-2), east of the Mill and tailings cells. Groundwater within the perched zone generally flows south to southwest beneath the site (see Figure 2-5). Recharge to the perched aquifer is primarily from areal recharge due to infiltration of precipitation and seepage from the wildlife ponds on the eastern margin of the site. Discharge from the perched aquifer is believed to be to springs and seeps along Westwater Creek Canyon and Cottonwood Wash to the west-southwest and along Corral Canyon to the east of the site. The discharge point located most directly downgradient of the tailings cells is believed to be Ruin Spring in Westwater Creek Canyon, a tributary to Cottonwood Wash, approximately two miles from the tailings cells.

The horizontal hydraulic gradient in the perched aquifer downgradient and in the vicinity of the tailings cells ranges from approximately 0.01 to 0.04 feet per foot (ft/ft) and is generally to the south and southwest with local variations in magnitude and direction (see Figure 2-5). Recharge from the wildlife ponds causes localized mounding of the water table.

The hydraulic conductivity of the perched aquifer (generally within the Burro Canyon Formation) has been characterized through aquifer pumping tests, slug tests, packer tests, and laboratory analysis of core samples. Based on tests performed in perched zone

monitoring wells downgradient of the tailings cells (MW-3, MW-5, MW-11, MW-12, MW-14, MW-15, MW-17, MW-20, MW-22, and MW-25), the geometric mean horizontal hydraulic conductivity in this area ranges (based on several analysis methods) from 0.064 to 0.12 ft/day (2.3×10^{-5} to 4.3×10^{-5} cm/sec) (Hydro Geo Chem, 2009). Based on these hydraulic conductivities, a porosity of 18 percent, and an average hydraulic gradient of 0.013 ft/ft, the average linear velocity of groundwater downgradient of the tailings cells was calculated to be 0.005 to 0.009 ft/day (1.7 to 3.2 ft/year) (Hydro Geo Chem, 2009).

Beneath and immediately upgradient of the tailing cells, the geometric mean hydraulic conductivity (based on tests from wells MW-23, MW-25, MW-27, MW-28, MW-29, MW-30, MW-31, MW-32, TW4-20, TW4-21, and TW4-22) was 0.08 ft/day (3×10^{-5} cm/sec). Based on gradients in the vicinity of each well, the hydraulic conductivity at each well, and the estimated effective porosity of 18 percent, the geometric mean linear velocity of groundwater was calculated to be 0.012 ft/day (4.5 ft/year) (Hydro Geo Chem, 2009).

The vertical hydraulic conductivity of the underlying Brushy Basin Member of the Morrison Formation is significantly lower and demonstrates that it acts as a perching layer. Cores from the Brushy Basin Member had vertical hydraulic conductivities of 2.1×10^{-7} to 25.4 ft/day (7.3×10^{-11} to 5.9×10^{-4} cm/sec) with a geometric mean of 3.4×10^{-5} ft/day 1.2×10^{-8} cm/sec (IUC, 2000).

2.2.4 Groundwater Quality of the Perched Aquifer System

Groundwater quality in existing and new wells completed in the perched aquifer has been used to establish background concentrations and determine GWCLs. For additional details regarding groundwater quality and the determination of GWCLs, see the *Revised Background Groundwater Quality Report: Existing Wells for Denison Mines (USA) Corp.'s White Mesa Mill Site, San Juan County, Utah* (INTERA, Inc., 2007a); *Revised Addendum Evaluation of Available Pre-Operational and Regional Background Data Background Groundwater Quality Report: Existing Wells* (INTERA, Inc., 2007b); and

Revised Addendum Background Groundwater Quality Report: New Wells (INTERA, Inc., 2008).

2.2.5 Vadose Zone Hydrogeology and Geochemistry of the Unsaturated Bedrock

The vadose zone is the zone between the ground surface and the perched water table. The vadose zone beneath the White Mesa Mill is within the unconsolidated deposits (removed during construction of the tailings cells), the Dakota Sandstone, and Burro Canyon Formation. The vadose zone thickness was calculated by taking the difference between the elevation of the cell bottom and the distance to the water table (see Appendix C). The minimum vadose zone thicknesses beneath Cells 2 & 3 and Cell 4A are approximately 42 ft and 40 ft, respectively. As a comparison, the average vadose zone thicknesses beneath Cell 2, Cell 3, and Cell 4A are 63 ft, 66 ft, and 56 ft. For the vadose zone transport models, the vadose zone thickness beneath Cells 2 & 3 and Cells 4A & 4B was assumed to be 42 ft (12.8 m).

Samples of bedrock from the vadose zone between and immediately adjacent to the White Mesa Mill tailings cells were collected and characterized for hydraulic and geochemical properties. The original laboratory reports are included in Appendix A and B and statistical analyses of the data and identification of hydrogeochemical units are included in Appendix C. Hydraulic properties are used to predict the flow of water through the vadose zone, while geochemical properties are used to predict water/rock chemical reactions as the tailings pore water potentially migrates beneath the tailings cells. Geochemical properties tested include mass concentrations of hydrous ferric oxide (HFO) and acid neutralization potential (ANP). The mass of ANP is used in the vadose zone reactive transport model to predict the consumption of alkalinity (as a neutralization front) as low-pH tailings pore water potentially migrates beneath the tailings cells, while the mass of HFO is used to predict surface complexation (adsorption) reactions. Soil water retention and unsaturated hydraulic conductivity curves are presented and used to identify hydrologic units, while a statistical analysis of the geochemical data is presented and used to identify geochemical units. Lithologic data combined with the hydrologic

and geochemical data form the basis for assigning hydrogeochemical stratigraphic units within the vadose zone (see Appendix C).

2.3 CONCEPTUAL MODEL OF WATER FLOW (INFILTRATION) THROUGH THE TAILINGS CELL COVER AND POTENTIAL CONTAMINANT TRANSPORT THROUGH THE VADOSE ZONE

This section presents the conceptual model for water flow (infiltration) through the tailings cell cover and potential contaminant transport through the vadose zone. Details of the implementation of the conceptual model into the numerical model as well as parameter values, boundary conditions, and initial conditions used in the modeling are described in detail in Section 3.0. Results of the numerical modeling are presented in Section 4.0.

2.3.1 Unsaturated Flow

Unsaturated Flow Governing Equation. Unsaturated flow through the vadose zone can be described with a modified form of the Richards Equation. The Richards Equation is derived by combining the Darcy-Buckingham equation with the mass continuity equation. The governing flow equation for one-dimensional vertical isothermal flow of liquid water (as an incompressible fluid) in a variably saturated rigid porous medium, assuming that the air phase plays an insignificant role in the liquid flow process, is given by the following modified form of the Richards Equation (Simunek et al., 2009):

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z} \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right] - S(h)$$

where:

θ = volumetric water content [L^3L^{-3}]

h = pressure head of soil water [L]

- S = sink term, volume of water removed from a unit volume of soil per unit time (e.g., uptake by plants) [T⁻¹]
- z = spatial coordinate in the vertical direction [L]
- t = time [T]
- K = unsaturated hydraulic conductivity [LT⁻¹].

The unsaturated hydraulic conductivity (K) is a function of the volumetric water content (θ) and pressure head (h), and as a result can vary in both space and time. The pressure head and volumetric water content may be used interchangeably as the independent variable. Hydraulic properties of unsaturated porous media (i.e., $\theta(h)$ and $K(h)$) are nonlinear functions of the pressure head (h), and a solution to the Richards Equation is commonly solved numerically with a computer program.

Unsaturated Hydraulic Conductivity. To solve the above equation, it is necessary to specify the relationships of unsaturated hydraulic conductivity (K) versus the effective water saturation (S_e), and of pressure head (h) versus volumetric water content (θ).

The relationship of unsaturated hydraulic conductivity versus effective water saturation, assuming the pore-size-distribution model presented in Mualem (1976), is described by the following equation (van Genuchten, 1980):

$$K(h) = K_s S_e^l \left[1 - (1 - S_e^{1/m})^m \right]^2$$

where:

K = unsaturated hydraulic conductivity [LT⁻¹]

K_s = saturated hydraulic conductivity [LT⁻¹]

S_e = effective saturation [dimensionless].

l = empirical pore connectivity parameter [dimensionless]

m = empirical shape parameter [dimensionless].

The effective saturation is equal to:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

where:

S_e = effective saturation [dimensionless]

θ = volumetric water content [L^3L^{-3}]

θ_r = residual volumetric water content [L^3L^{-3}]

θ_s = saturated volumetric water content [L^3L^{-3}].

Soil Water Retention. The relationship of pressure head (h) to water content (θ), assuming the pore-size-distribution model presented in Mualem (1976), is described by the following equation (van Genuchten, 1980):

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

where:

θ = volumetric water content [L^3L^{-3}]

θ_r = residual volumetric water content [L^3L^{-3}]

θ_s = saturated volumetric water content [L^3L^{-3}]

h = pressure head of soil water [L]

α = empirical fitting parameter [L^{-1}]

n = empirical fitting parameter [dimensionless]

m = empirical shape parameter [dimensionless].

The fitting parameters (α , n , and m) are considered to be empirical coefficients that affect the shape of the hydraulic functions used to describe variations in water content and hydraulic conductivity for different soil water pressures. For unsaturated porous media,

the pressure head of soil pore water is negative (i.e., less than atmospheric pressure) and is commonly referred to as matric potential or soil-water tension (negative). The unsaturated hydraulic conductivity is a function of the saturated hydraulic conductivity, pressure head, and moisture content. As a result, the unsaturated hydraulic conductivity in the vadose zone can vary through time. In an unsaturated system, the advective velocity is largely controlled by variations in soil moisture content because the unsaturated hydraulic conductivity and effective porosity varies through time as moisture contents vary. The saturated and unsaturated hydraulic properties are listed in Section 3.0 and Appendix C.

Plant-Water Uptake. The sink term in the Richards Equation is defined as the volume of water removed from a unit volume of soil per unit time. This accounts for plant-water uptake and can be defined in terms of soil water pressure head (h) as described by the following equation (Feddes et al., 1978):

$$S(h, z) = \alpha(h)S_p$$

where:

S = sink term, volume of water removed from a unit volume of soil per unit time
(e.g., uptake by plants) [T^{-1}]

α = root water uptake water stress response function [dimensionless]

S_p = potential root water uptake rate [T^{-1}].

The root water uptake water stress response function (α) is a dimensionless function that ranges between 0 and 1, and is dependent on the soil water pressure head and vegetation type. For example, when conditions are extremely dry or extremely wet, plants cease to take up water. A plant root distribution function can also be used to account for variable plant water uptake with depth. The following equation can be used to describe conditions that involve spatially variable root density (Simunek et al., 2009):

$$S_p = b(z)T_p$$

where:

S_p = potential root water uptake rate [T^{-1}]

b = normalized root water uptake distribution (root density) [L^{-1}]

T_p = potential rate of transpiration [LT^{-1}].

The root water uptake distribution is normalized to ensure that $b(z)$ integrates to unity throughout the rooting depth (Simunek et al., 2009). Spatially variable root density has been observed for grasses, in which grass roots are usually most dense near the ground surface and decrease with depth (see Appendix D).

2.3.2 Contaminant Transport in the Unsaturated Zone

Contaminant Transport Governing Equation. Contaminant transport can be described by the advection-dispersion equation (ADE). The governing equation for unsaturated zone contaminant transport with advection, dispersion, mineral precipitation/dissolution reactions, and surface complexation reactions (sorption/retardation) of contaminants is (Jacques and Simunek, 2005):

$$\frac{\partial \theta C_i}{\partial t} = \frac{\partial}{\partial z} \left(\theta D^w \frac{\partial C_i}{\partial z} \right) - \frac{\partial q C_i}{\partial z} - R_i$$

where:

θ = volumetric water content [L^3L^{-3}]

C_i = aqueous concentration of species [ML^{-3}]

t = elapsed time [T]

z = spatial coordinates in the vertical direction [L]

D^w = hydrodynamic dispersion coefficient in the liquid phase [L^2T^{-1}]

q = Darcy flux [LT^{-1}]

R_i = general source/sink term for geochemical reactions [$ML^{-3}T^{-1}$].

Hydrodynamic Dispersion. The equation used to describe the hydrodynamic dispersion coefficient in the liquid phase is given by (Bear, 1972; Simunek et al., 2009):

$$\theta D^w = D_L |q| + \theta D_w t_w$$

where:

- θ = volumetric water content [L^3L^{-3}]
- D^w = hydrodynamic dispersion coefficient in the liquid phase [L^2T^{-1}]
- D_L = longitudinal dispersivity in the liquid phase [L]
- q = Darcy flux [LT^{-1}]
- D_w = molecular diffusion coefficient in free water [L^2T^{-1}]
- t_w = tortuosity factor in the liquid phase [dimensionless].

While the equation used to describe the tortuosity factor in the liquid phase is given by (Millington and Quirk, 1961; Simunek et al., 2009):

$$t_w = \frac{\theta^{7/3}}{\theta_s^2}$$

where:

- t_w = tortuosity factor in the liquid phase [dimensionless]
- θ = volumetric water content [L^3L^{-3}]
- θ_s = saturated volumetric water content [L^3L^{-3}].

Dispersion versus Diffusion. The hydrodynamic dispersion coefficient includes the effects from mechanical dispersion and molecular diffusion. These two processes act to dilute and spread contamination as it is transported by advection. For saturated systems, mechanical dispersion tends to dominate over molecular diffusion because advective velocities are high; as a result, effects due to diffusive transport of mass may be ignored in a saturated system with high velocities. Conversely, for unsaturated systems, molecular diffusion tends to dominate over dispersion because advective velocities are

low; as a result, effects due to mechanical dispersion of mass may be ignored in an unsaturated system with low velocities (Bear and Verruijt, 1987; Fetter, 1998).

The relative contribution of mechanical dispersion to diffusive transport of mass can be evaluated by calculating the dimensionless Peclet number within the vadose zone. The Peclet number is given by the following equation (Bear and Verruijt, 1987; Fetter, 1998):

$$Pe = \frac{vd}{D_w}$$

where:

Pe = Peclet number [dimensionless]

v = velocity [LT⁻¹] [Darcy flux divided by volumetric water content]

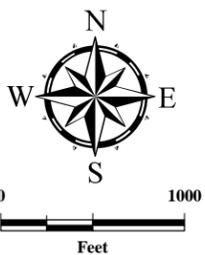
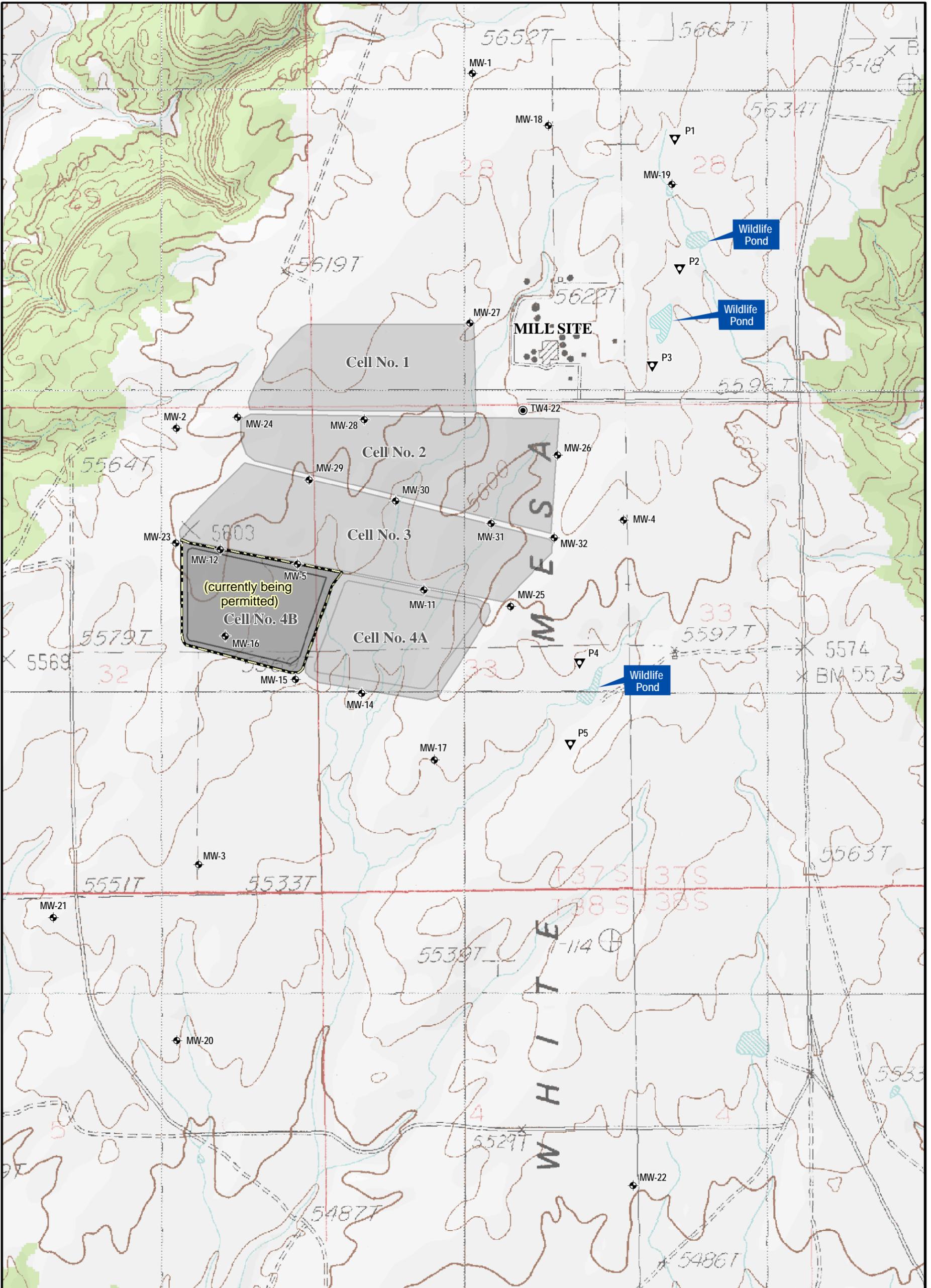
d = average grain size diameter of vadose zone material [L]

D_w = molecular diffusion coefficient in free water [L²T⁻¹].

Diffusion tends to dominate over dispersion for Peclet numbers less than 0.4 (Bear and Verruijt, 1987; Fetter, 1998). For the White Mesa Mill vadose zone, the following assumptions were considered in calculating a Peclet number: (1) the water flux is assumed to equal the highest potential water flux rate calculated to migrate through the tailing cell liners (5 x 10⁻³ cm/day; see Appendix L); (2) the volumetric water content in the vadose zone was assumed to be at 75 percent saturation (0.14; see Appendix C); (3) the average grain size diameter was assumed to equal 0.05 cm, which is characteristic of fine- to medium-size sand grains (see Appendix C); and (4) the molecular diffusion coefficient for chloride was assumed to equal 1.75 cm²/day (Li and Gregory, 1974). The calculated Peclet number, assuming these values as input, is equal to 0.001, which indicates that diffusive transport of mass is going to dominate, and the effects of mechanical dispersion can be ignored because of the low mass transport velocities.

Sorption and Retardation. Chemical reactions between dissolved constituents in vadose zone pore water (e.g., metals and radionuclides) and the vadose zone bedrock (Dakota Sandstone and Burro Canyon Formation) often dictate spatial and temporal variations in contaminant-plume transport and mobility in the subsurface by controlling

the degree of adsorption-desorption of aqueous complexes to surface assemblages and mineral precipitation-dissolution reactions. The amount of HFO and ANP in the vadose zone is used to determine surface complexation and acid neutralization reactions (see Appendix C). The geochemical model and reactive transport modeling of flow and transport through the vadose zone are described in Appendix M. The geochemical and solute transport properties are listed in Section 3.0 and Appendix C and M.



Base map adapted from USGS 7.5 Minute Topographic maps of Black Mesa Butte, Blanding South, No-Mans Island, and Big Bench, Utah Quadrangles.

Coordinates are UTM Zone 12, NAD 1927 meters.

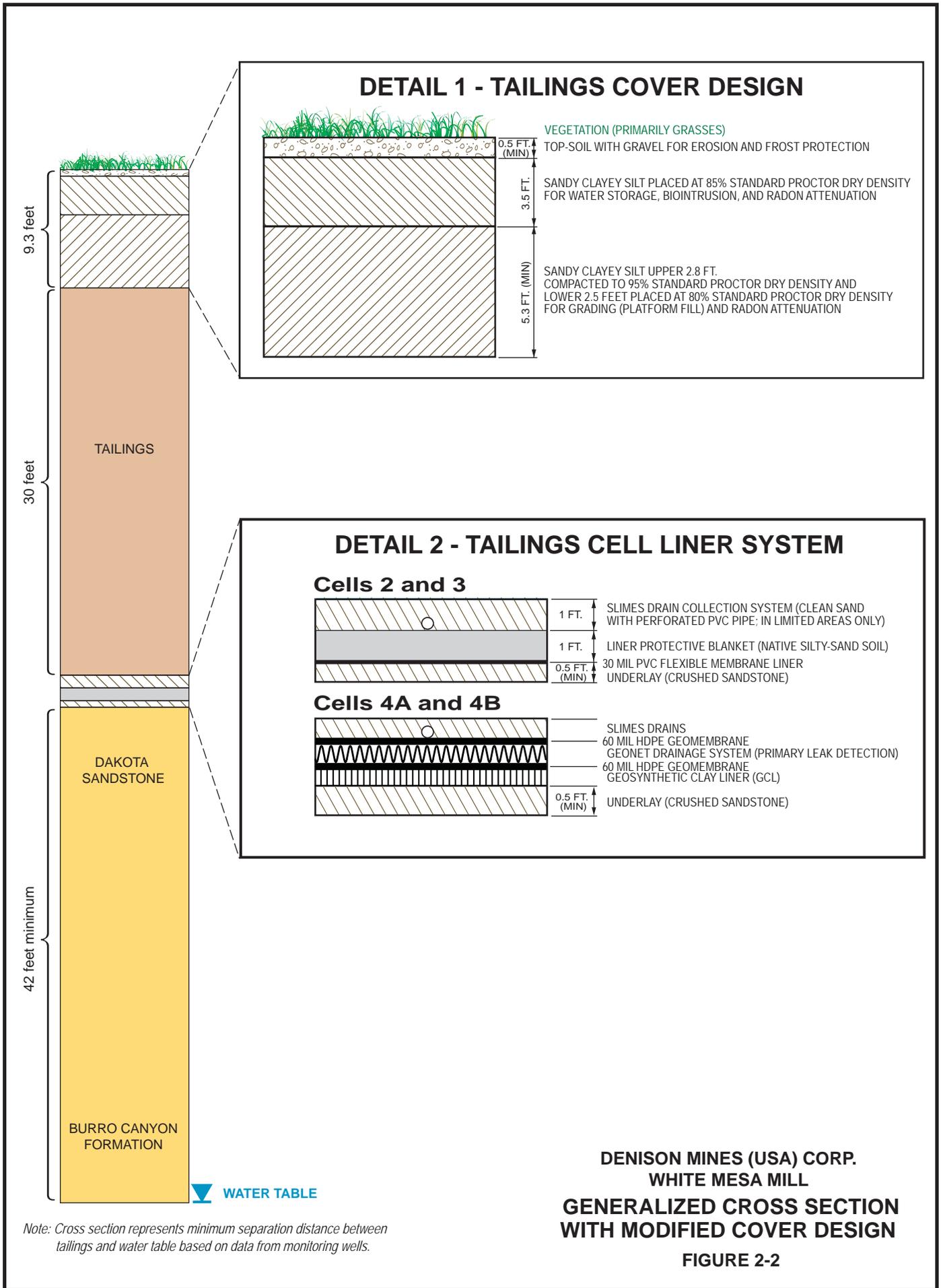
EXPLANATION

- Test well
- ◆ Monitoring well
- ▼ Piezometer

**DENISON MINES (USA) CORP.
WHITE MESA MILL**

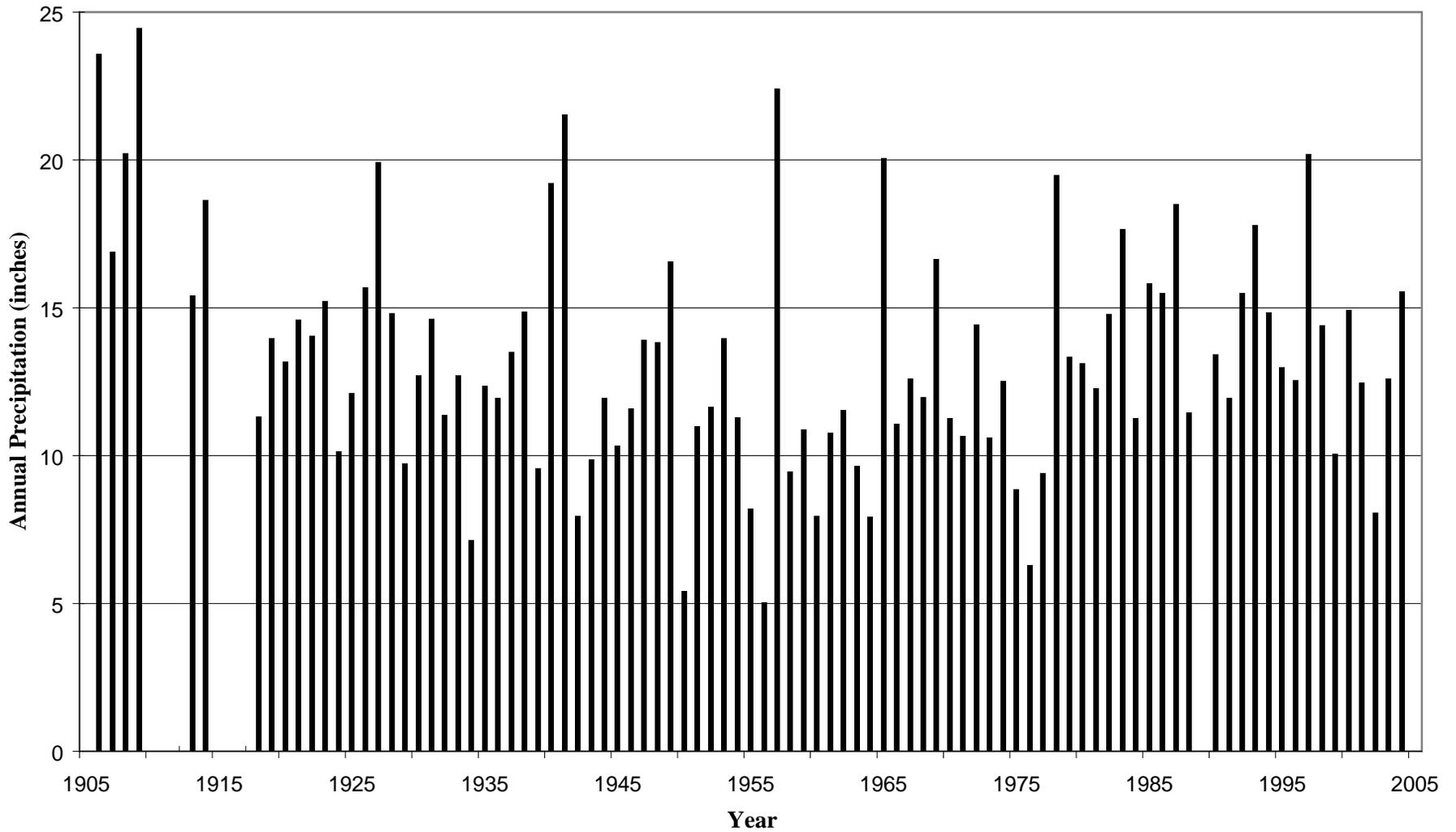
SITE MAP

FIGURE 2-1



Note: Cross section represents minimum separation distance between tailings and water table based on data from monitoring wells.

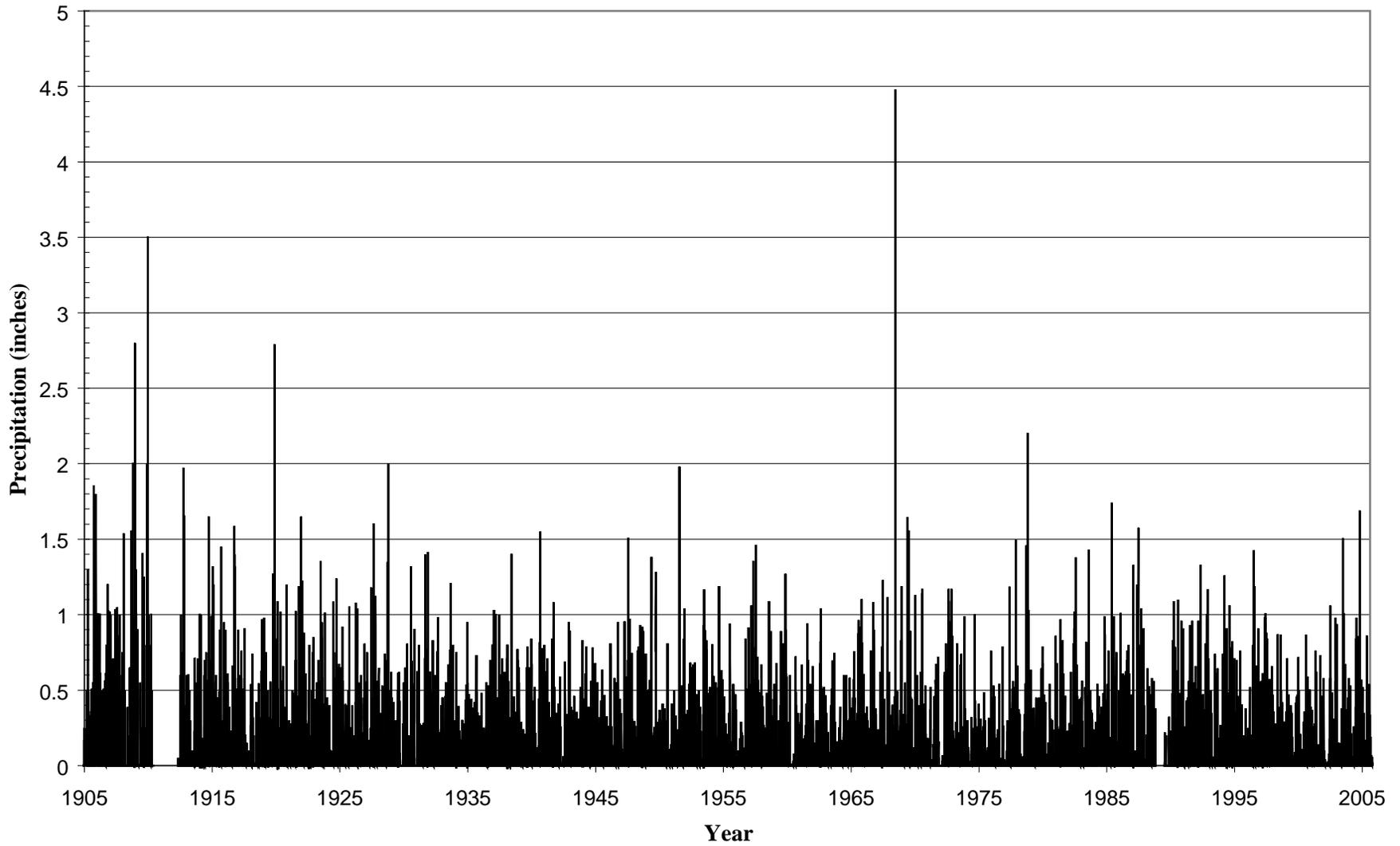
DENISON MINES (USA) CORP.
 WHITE MESA MILL
**GENERALIZED CROSS SECTION
 WITH MODIFIED COVER DESIGN**
 FIGURE 2-2



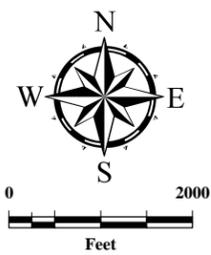
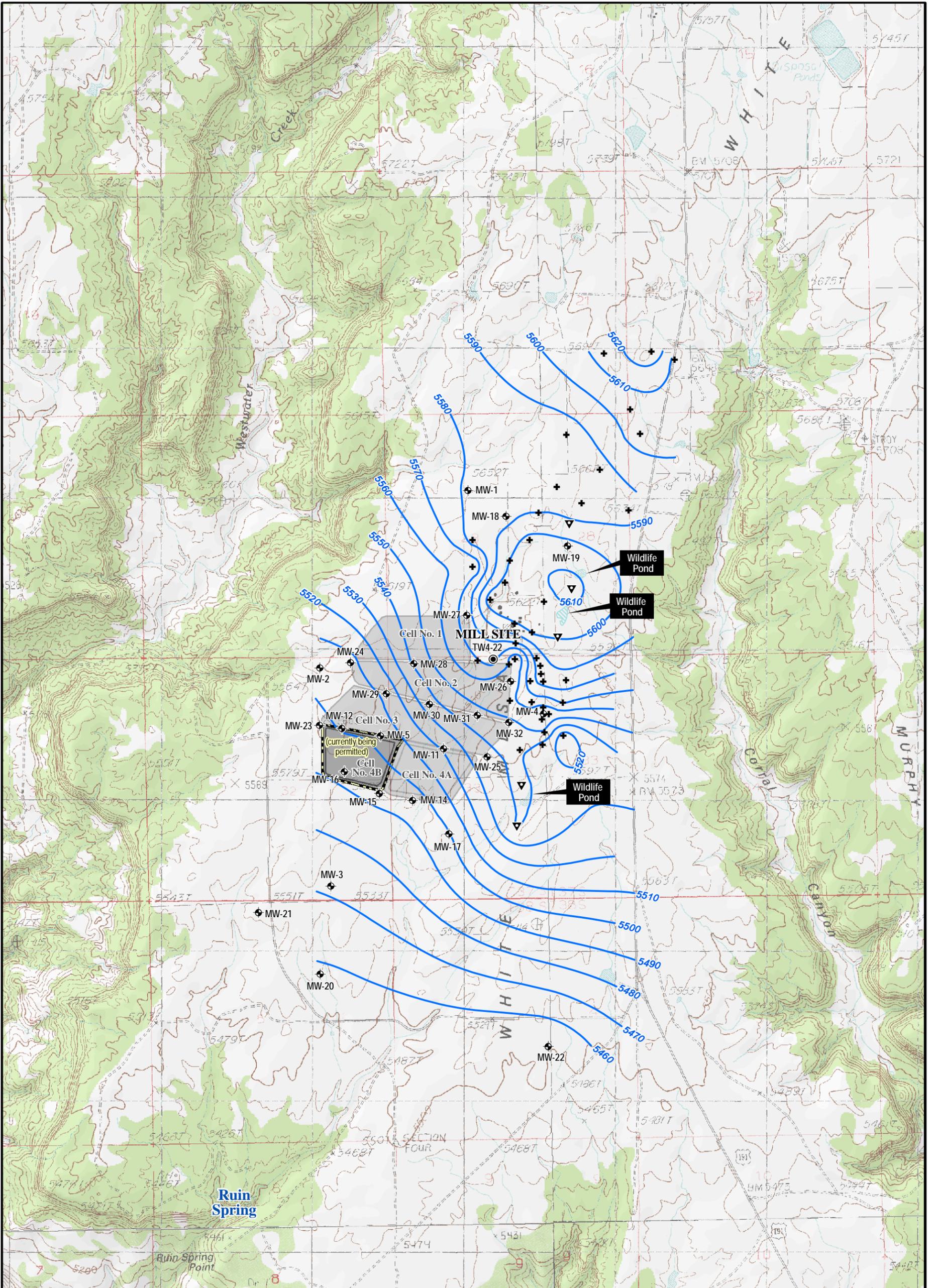
DENISON MINES (USA) CORP.
WHITE MESA MILL
ANNUAL PRECIPITATION AT BLANDING, UTAH
(1905 TO 2005)

FIGURE 2-3

Note: years with incomplete data not shown.



DENISON MINES (USA) CORP.
WHITE MESA MILL
DAILY PRECIPITATION AT BLANDING, UTAH
(1905 TO 2005)
FIGURE 2-4



Note: Water level contours from Hydro Geo Chem, Inc. (2009)
 Base map adapted from USGS 7.5 Minute Topographic maps of Black Mesa Butte, Blanding South, No-Mans Island, and Big Bench, Utah Quadrangles.
 Coordinates are UTM Zone 12, NAD 1927 meters.

EXPLANATION

-  Water level contour line, dashed where uncertain
-  Test well
-  Monitoring well
-  Piezometer
-  Temporary monitoring well

**DENISON MINES (USA) CORP.
 WHITE MESA MILL
 PIEZOMETRIC SURFACE CONTOURS
 PERCHED AQUIFER
 (DECEMBER 2009)**

FIGURE 2-5

3.0 METHODOLOGY

This section provides information regarding the conceptual and mathematical models used to:

- Predict potential infiltration rates through the tailings cell cover
- Predict potential flow and contaminant transport from the tailings cells through the underlying vadose zone to the perched groundwater.

Detailed descriptions of the modeling effort are provided in the remainder of this section. The overall modeling approach is described in Section 3.1. The HYDRUS-1D and HP1 codes are described in Section 3.2. The methodology for modeling potential infiltration through the cover is described in Section 3.3. The methodology for modeling potential flow and contaminant transport through the bedrock vadose zone to the underlying perched groundwater is described in Section 3.4.

3.1 OVERALL MODELING APPROACH

Following conceptual-model development, numerical modeling was completed with the following two basic models (see Figure 3-1 for model domains):

1. Cover Model: Infiltration modeling with HYDRUS-1D of the tailings cell cover system with daily precipitation and evapotranspiration to estimate potential long-term average infiltration rates to the tailings.
2. Bedrock Vadose Zone Model: Vadose zone flow and potential contaminant transport modeling with HP1/HYDRUS-1D through the bedrock vadose zone to the underlying perched aquifer during the operational phase, dewatering phase, and 200-year regulatory post-closure steady-state timeframes. HYDRUS-1D was used to confirm the results for flow and transport of a conservative solute (chloride) predicted by HP1.

To evaluate the potential “worst case” for build-up of water in the tailings (“bathtub effect”), the model-predicted long-term average water flux rate through the tailings cell cover system was used to estimate the total amount of water entering the tailings during the 200-year regulatory timeframe. By assuming a completely impermeable liner system (i.e., no water flow through the liners; all water that infiltrated through the cover was accumulated in the cells), the total amount of water entering the tailings through the cover would be accumulated in the cell. By dividing this total water flux by the tailings porosity, the potential rise in water levels in the tailings was calculated for this worst-case scenario. Under this scenario, there would be no impacts to groundwater, because no water would be leaving the cells.

3.2 HYDRUS-1D AND HP1 COMPUTER CODES

The computer code HYDRUS-1D was used to predict potential infiltration through the proposed tailings cell cover, while the computer code HP1 (HYDRUS-1D coupled with the geochemical program PHREEQC) was used to predict potential flow and contaminant transport through the bedrock vadose zone beneath the tailings cells. HYDRUS is a finite-element model that simulates water flow and solute transport in unsaturated/saturated porous media, and was developed by the U.S. Salinity Laboratory in collaboration with the Department of Environmental Sciences at the University of California at Riverside (Simunek et al., 1998; Simunek et al., 2005; Simunek et al., 2009). HYDRUS-1D was selected because it is capable of simulating the dominant processes affecting infiltration and contaminant transport given the semiarid conditions and multiple hydrogeologic layers that must be simulated at the site. HP1 (Jacques and Simunek, 2005) is a reactive transport code that combines the infiltration, unsaturated flow, and multicomponent contaminant transport modeling capabilities of HYDRUS-1D (Simunek et al., 2005) with the equilibrium geochemical model PHREEQC (Parkhurst and Appelo, 1999). HP1 was selected because it has the capabilities of HYDRUS-1D, but can also model geochemical (water-rock) interactions necessary to predict the transport of nonconservative solutes that may participate in surface complexation (adsorption) and mineral precipitation/dissolution reactions.

3.2.1 HYDRUS-1D

The program can be used to analyze water and solute movement in unsaturated, partially-saturated, or saturated porous media. HYDRUS allows for spatial and temporal variation in soil properties, allowing for simulation of a heterogeneous soil profile under variably-saturated, unsteady-flow conditions. HYDRUS can simulate one-dimensional advection, dispersion, retardation (sorption), and degradation of contaminants. HYDRUS-1D is one of the few, commercially available, frequently tested models that can simulate both unsaturated flow and contaminant transport in the vadose zone (including layered stratigraphy) with a variety of initial and boundary conditions. Consideration of discontinuities in capillary and unsaturated hydraulic conductivity is very important for layered systems because travel times and storage of water and contaminants in the vadose zone is complex (due to potential capillary-barrier effects). The model provides accurate results when appropriate spatial discretization for the finite-element domain is established.

HYDRUS has been used to simulate deep percolation beneath final-closure designs for radioactive-waste management at the Nevada Test Site, flow around nuclear-subsidence craters at the Nevada Test Site, and influences of a capillary barrier at the Texas low-level radioactive waste disposal site. A comparison of HYDRUS to other codes (CHAIN, MULTIMED-DP, FECTUZ, and CHAIN 2D) was prepared by the U.S. Environmental Protection Agency to evaluate each code's ability to predict radionuclide fate and transport in the unsaturated zone (Chen et al., 2002). Of the codes evaluated by Chen et al. (2002), HYDRUS was the most comprehensive, containing the greatest number of physical processes. Scanlon et al. (2002) performed a comparison of codes for simulation of landfill covers in semiarid environments. In addition to HYDRUS, the evaluation by Scanlon et al. (2002) included the codes HELP, Soil-Cover, SHAW, SWIM, UNSAT-H, and VS2DT1. This evaluation indicated that Richards-Equation-based codes such as HYDRUS-1D are more appropriate for simulating near surface water balance than those using a water-balance approach such as HELP. Only HYDRUS-1D, SWIM, and VS2DT1 could simulate a seepage face. Of these VS2DT1, did not simulate the upper atmospheric boundary conditions as well as HYDRUS-1D.

The HYDRUS-1D program numerically solves the Richards Equation for saturated/unsaturated water flow and the Fickian-based advection-dispersion equation for heat and solute transport. HYDRUS-1D incorporates unsaturated soil-hydraulic properties using the van Genuchten (1980), Brooks and Corey (1964), or modified van Genuchten-type (Vogel and Cislérova, 1988) analytical functions. The water flow portion of the model can incorporate (constant or time-varying) prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions. Soil surface boundary conditions may change during the simulation from prescribed flux to prescribed head-type conditions. The code also allows for internal sinks such as plant-water uptake. The solute transport portion of the model can incorporate (constant and time-varying) prescribed concentration and concentration flux boundaries. The dispersion tensor includes a term reflecting the effects of molecular diffusion and tortuosity. The transport equation is coupled to the flow equation through the velocity term.

3.2.2 HP1

The HP1 model was developed by the Belgian Nuclear Research Centre (SCK•CEN) in collaboration with the U.S. Salinity Laboratory and Department of Environmental Sciences at the University of California at Riverside. HP1 couples the HYDRUS-1D variably-saturated water flow and multicomponent contaminant transport model with the PHREEQC geochemical code. The HP1 code retains all of the features documented in HYDRUS (as described above) but incorporates additional modules capable of simulating a broad range of low-temperature geochemical reactions in water, soil, and groundwater systems. HP1 can simulate multicomponent reactive transport under mixed equilibrium/kinetic geochemical reactions, including interactions with minerals, gases, exchangers, and sorption surfaces, based on thermodynamic equilibrium, kinetics, or mixed equilibrium-kinetic reactions. Neutralization of the infiltrating tailings porewaters, sorption of solutes, and mineral precipitation/dissolution reactions within the bedrock vadose zone were determined using HP1.

3.3 INFILTRATION MODEL OF TAILINGS CELL COVER

3.3.1 Domain

The tailings cell cover model consisted of a one-dimensional conceptual representation of the planned cover design and was 284 cm (9.3 ft) thick extending from the cover surface to the top of the tailings (see Figure 2-2 and Figure 3-1).

3.3.2 Finite Element Node Spacing

The finite-element nodes were discretized in the vertical direction to simulate layers in the tailings cell cover system. Construction of the finite-element mesh is dependent on surface and bottom boundary conditions and represented heterogeneities due to layering (Simunek et al., 2009). As a result, node spacing was finer than the tailings cell cover layers to simulate steep hydraulic gradients which result from transient wetting (precipitation and infiltration) and drying (evapotranspiration) fronts. Fine-grid spacing is necessary to accurately simulate water flow (infiltration) through the unsaturated cover system because hydraulic properties (soil water retention and unsaturated hydraulic conductivity) may change very rapidly during very short timeframes in a nonlinear manner. Because hydraulic properties vary much faster and on a finer scale near the land surface due to rapid changes in atmospheric conditions (daily variations in precipitation and evapotranspiration were modeled), the node spacing varied between 0.1 and 1 cm near the top of the cover model domain representing the tailings cell cover system. To reduce errors due to numerical dispersion, the ratio between neighboring elements did not exceed 1.5 (Simunek et al., 2009).

3.3.3 Boundary Conditions

An atmospheric upper boundary condition was applied across the top of the model representing the tailings cell cover to simulate meteorological conditions and was a function of precipitation and potential evapotranspiration, as described in the paragraphs that follow. Free drainage (i.e., unit gradient) was assumed for the lower boundary condition of the model representing the tailings cell cover. Because of the one-

dimensional nature of the model, the sides of the domain are implicitly assumed to be zero-flux boundaries.

Atmospheric Boundary Condition. Daily precipitation and air-temperature measurements were obtained for the Blanding weather station and used as inputs to the model to determine boundary conditions (Utah Climate Center, 2007). Given the flat nature of the cover (0.2 percent slope), no runoff- or runoff-based processes were assumed to occur. As a result, precipitation applied to the upper boundary was removed through evaporation or transpiration, retained in the soil profile as storage, or transmitted downward as infiltration (potential recharge or drainage to the tailings). The 57-year period between 1932 and 1988 was selected for use in the vadose zone model because it contained (see Figure 2-3 and Figure 2-4):

- a nearly continuous time series
- a mixture of the largest annual and daily precipitation events
- consecutive wet years.

The third and fourth wettest years on record (1957 and 1941; 22.4 and 21.5 inches, respectively) are within the time series selected, and are approximately 9% and 14% less than the maximum annual precipitation of 24.5 inches recorded during 1909. The largest daily precipitation event of 4.48 inches, which occurred on 1 August 1968, is represented in the time series selected. Also, the climate record included the period 1978-1987, which is a 10-year timeframe characterized by above-average amounts of annual (15.2 inches) and winter precipitation. Increased precipitation was modeled as part of the sensitivity analysis.

Some interpolation was necessary to construct a continuous time series between 1932 and 1988. Missing precipitation measurements were left blank but accounted for only a small subset of the population (10 days out of 20,820 days). Air-temperature measurements were interpolated between missing data points, but overall accounted for a small subset (55 days out of 20,820 days) of the time series.

A combination temperature-based and solar-radiation-based approach was used to calculate daily potential evapotranspirative (PET) fluxes using the Hargreave's Equation. This approach was selected because long-term meteorological data (e.g., wind speed) were not available, and the Hargreave's Equation can be used as a substitute for the Penman-Monteith Equation. The calculations assume a hypothetical grass reference crop with sufficient access to water such that the amount of PET is controlled by site-specific climatic conditions (e.g., air temperature, day of year, solar declination). PET was calculated for each day from measured maximum and minimum air temperatures in addition to estimated radiative fluxes following the methodology outlined in the work of Allen et al. (1998). The average annual PET between 1932 and 1988 was 46.5 inches. Potential evaporation (PE) from the soil surface and potential transpiration (PT) from roots were partitioned from the PET assuming 40% vegetative cover; and the winter months that included December, January, and February were assigned a transpiration rate of zero, and only evaporation was simulated in the HYDRUS-1D model (see Appendix D). The percent of vegetative cover was varied as part of the sensitivity analysis.

Transpiration. Root water uptake will vary as a function of the soil water pressure head within the rooting zone, the normalized plant root distribution function (i.e., density of roots), and the rate of potential transpiration. The rate of potential transpiration is assigned as part of the atmospheric upper boundary condition for the cover model, which HYDRUS then uses to compute the actual transpiration (AT) as a function of time and space within the rooting zone. For example, when conditions are extremely dry (i.e., less than the wilting point) or extremely wet (i.e., near saturation) plants cease to uptake water, and the actual transpiration would be zero. At intermediate soil water conditions, the actual transpiration would be a fraction of the potential transpiration. The water stress response function for grass was selected from the default database in HYDRUS. The database does not distinguish between different species of grass.

The model assumed an anticipated scenario with a maximum rooting depth of 107-cm and an anticipated root density distribution (see Appendix D details). For grasses, roots are usually denser near the ground surface and decrease with depth. A nonlinear decrease

in root density with depth was assumed for the root-water-uptake function (i.e., assumes vegetation removes more water near the ground surface and less with depth). The maximum rooting depth and root density distribution was varied as part of the sensitivity analysis. The root-water-uptake function is a dimensionless number proportional to the root distribution or root density. The Feddes et al. (1978) water-uptake model with water-response functions for grass was selected from the default database in HYDRUS. The database does not distinguish between different species of grass. The assumed wilting point pressure was varied as part of the sensitivity analysis.

Evaporation. The rate of potential evaporation is also assigned as part of the atmospheric input file. In HYDRUS, the potential evaporation rate is reduced to an actual evaporation (AE) rate if a specified pressure head is reached at the surface. The pressure head at which this occurs is controlled by equilibrium conditions between soil water and atmospheric water vapor. The model assumed a minimum surface pressure head of -15,000 cm, which is the recommended value by the program. When the pressure head at the surface reaches -15,000 cm the program calculates a reduced, actual evaporation rate. The minimum surface pressure head at the upper boundary was varied as part of the sensitivity analysis.

Climate Record. The 57-year climate record comprised of measured precipitation and calculated potential evaporation and potential transpiration was repeated to establish a synthetic atmospheric record for greater durations. Generation of a concatenated atmospheric record assumes that historic meteorological conditions are considered representative for the future.

3.3.4 Input Parameters

Hydraulic properties required for the cover model include vertical saturated hydraulic conductivity, residual soil water content, saturated soil water content, and the soil water retention empirical curve-fitting parameters. Unsaturated hydraulic properties for the tailings cell cover materials were estimated using grain-size and geotechnical data for these materials with the soil-properties database in HYDRUS (details regarding derivation of hydraulic properties are provided in Appendix E). Hydraulic properties

used in the model are presented in Table 3-1. The van Genuchten-Mualem single-porosity soil hydraulic property model was selected to characterize the soil hydraulic properties.

3.3.5 Initial Conditions

Initial conditions for the infiltration model were determined by evaluating a long-term simulation that used the concatenated atmospheric input file as an upper boundary condition (i.e., the 57-year climate record repeated twice). The pressure head distribution for the final time step of the 114-year simulation was used as the initial condition for the transient simulations used to predict water infiltration rates through the cover. The methodology implemented to establish the initial conditions for the site is a commonly accepted approach for solving hydrogeologic modeling problems. For all HYDRUS-1D simulations, initial conditions were prescribed as pressure heads (as opposed to water content) to facilitate model convergence.

3.3.6 Duration of Simulations and Time Steps

Climatological data for the 57-year period 1932 through 1988 were repeated to generate the necessary duration of input data. Climatic data were input on a daily basis for the tailings cell cover model.

The minimum and maximum time-step lengths were 1×10^{-6} day (0.09 seconds) and 0.5 days for the HYDRUS-1D models. The maximum number of iterations per time step was 40. In HYDRUS-1D, solution efficiency is maximized by incorporating adaptive time-step adjustments based on criteria described in Simunek et al. (2009).

3.3.7 Sensitivity Analysis

To test the importance of simulating reduced performance of the vegetative component of the cover system, and how increased precipitation could influence the transport of water through the monolithic ET cover, the HYDRUS-1D infiltration model was run using different assumptions aimed at characterizing a lower bound, base case, and upper bound

scenario. Rates of model-predicted water flux entering the tailings cells were compared between simulations using different input assumptions. The effects on moisture content by the parameters used to assess establishment of vegetation and root water uptake were also evaluated to determine whether moisture contents that were input into the radon model are conservative. Input variables incorporated into the sensitivity analysis included percent vegetative cover, maximum rooting depth and root density, wilting point pressure head, minimum surface pressure head, and precipitation. A complete description regarding the sensitivity analysis and comparison of infiltration rates through the cover based on cover vegetation, biointrusion, and precipitation is included in Appendix G.

3.4 FLOW AND CONTAMINANT TRANSPORT MODEL OF THE BEDROCK VADOSE ZONE

Solute transport models were developed for the bedrock vadose zone beneath Cell 1 (contingency cell identified for the potential disposal of decommissioning and deconstruction debris), Cells 2 & 3, and Cells 4A & 4B.

3.4.1 Domain

The bedrock vadose zone model extended from the base of the tailings cell liner systems through the Dakota Sandstone and Burro Canyon Formation to the perched water table surface (see Figure 3-1). The vadose zone thickness was calculated by taking the difference between the bottom elevation of the cell and the distance to the water table for individual monitoring wells. The minimum vadose zone thickness beneath Cells 2 & 3 and Cell 4A was approximately 12.8 m (42 ft) and 12.2 m (40 ft), respectively (based on 2007 water level data). As a comparison, the average vadose zone thickness beneath Cell 2, Cell 3, and Cell 4A are 19.2 m (63 ft), 20.1 m (66 ft), and 17.1 m (56 ft). A minimum vadose zone thickness of 12.8 meters (42 feet) was assumed for all of the simulations of solute transport beneath the cells (see Appendix C for a discussion of vadose zone thicknesses and a summary table of vadose zone thickness beneath the tailings cells).

3.4.2 Finite Element Node Spacing

The finite-element nodes were discretized in the vertical direction to simulate layers in the bedrock vadose zone. The bedrock vadose zone model had a uniform node spacing of 5 cm. In order to reduce numerical errors due to discretization, grid spacing was based on recommendations provided by Jacques et al. (2006).

3.4.3 Boundary Conditions

Variable specified mass flux rates (flux multiplied by the concentration) were applied to the upper boundary of the bedrock vadose zone.

Cell 1. For Cell 1, which was assumed to contain no saturated materials, the average long-term water flux rate through the ET cover (predicted with the infiltration model) was used as an upper boundary condition (constant flux) to represent the post-closure steady-state period. The bottom of Cell 1 (if constructed) will contain a soil liner compacted to achieve low permeability, but this layer was not included in the modeling, which yields conservative estimates of chloride transport through the vadose zone.

Cells 2 & 3. Potential water flux rates through the liner systems for Cells 2 & 3 were calculated using the Giroud-Bonaparte Equation (Giroud and Bonaparte, 1989; Giroud, et al., 1992) as described in Appendix L. The predicted saturated thickness of the tailings during the operational phase, during active dewatering, and during post-closure steady state was used in the Giroud-Bonaparte Equation to calculate the potential flux rate through the liner for use as an upper boundary condition in the flow and contaminant transport model of the bedrock vadose zone. Groundwater flow modeling with MODFLOW of Cells 2 & 3 was performed to estimate tailings-dewatering rates through time and average water levels (saturated thickness) that will remain in the tailings after dewatering (described in Appendix J). In addition to the maximum saturated thickness of the tailings during operations, the number of potential liner defects, and their impacts on potential water flux through the liners, were evaluated as part of the sensitivity analysis (see Appendix L for details).

Cells 4A & 4B. Potential flux through the liner for Cells 4A & 4B was calculated using the Giroud-Bonaparte Equation as described in Geosyntec Consultants (2006a; 2007a). Dewatering predictions for Cells 4A & 4B used in the Giroud-Bonaparte Equation to calculate the potential flux through the liner for Cells 4A & 4B were from Geosyntec Consultants (2006a; 2007a).

The average solute concentrations used as inputs represented the source term solution chemistry of the tailings pore water and were also varied as part of the sensitivity analysis (see Appendix K for a discussion of source term chemistries). The lower boundary at the base of the domain was assumed to be fully saturated (i.e., water table conditions with a constant pressure head equal to 0 cm [atmospheric pressure]), representing the water-table surface of the perched aquifer. A zero concentration gradient was specified at the lower boundary for solute transport. Because of the one-dimensional nature of the model, the sides of the domain are implicitly assumed to be zero-flux boundaries.

3.4.4 Input Parameters

Water Flow. Hydraulic properties required for the vadose zone flow model include vertical saturated hydraulic conductivity, residual soil water content, saturated soil water content, and the soil water retention empirical curve-fitting parameters. The saturated and unsaturated hydraulic properties were measured for cores from the Dakota Sandstone and Burro Canyon Formation (see Appendix B for original laboratory report). Bedrock core sample collection methodologies, presentation of soil water retention and unsaturated hydraulic conductivity curves, and selection of hydrologic units are discussed in Appendix C. Hydraulic properties used in the model are presented in Table 3-1.

The vadose zone model assumed a single set of hydraulic properties consistent with the test results reported for the Dakota Sandstone. This assumption is considered appropriate because the saturated and unsaturated hydraulic properties of the samples are quite similar to one another (see Appendix C). Assignment of a single set of hydrogeologic properties should not significantly affect the model results given the similarity in unsaturated hydraulic properties [$\theta(h)$] and [$K(h)$] for all samples (i.e., there were no

large differences in soil water retention curves or unsaturated hydraulic conductivity curves for the materials tested). The hydraulic properties (and dry bulk density) from MW-23 (55.5-56.0 ft) were used as input to the model because the hydraulic functions are intermediate as compared to the other samples. Unsaturated hydraulic conductivity of the vadose zone was not included in the sensitivity analysis because the unsaturated hydraulic conductivities vary to match flux rates under a unit hydraulic gradient.

Contaminants Modeled. The contaminants modeled included pH, major cations and anions necessary to achieve charge balance (aluminum, calcium, carbonate, chloride, magnesium, potassium, sodium, and sulfate), and selected trace elements (arsenic, cadmium, copper, iron, nickel, uranium, vanadium, and zinc). Trace elements included in the model were based on their elevated concentrations in the tailings slimes drains as compared to the GWCLs. Aluminum was included and used to obtain charge balance. These solutes are the most dependable indicators of site water quality and of potential cell failure due to their predominance (uranium and sulfate) and predominance and mobility (chloride). In particular, chloride will migrate unretarded and act as a conservative tracer and thus would be expected to be detected before all other site contaminants. Uranium was included because it is one of the primary contaminants of concern.

Source Term Concentrations. The average solute concentrations were used as input to represent the source term solution chemistry of the tailings pore water (see Appendix K for a discussion of source term chemistries). The average concentration of chloride, sulfate, and uranium were 3,221 milligrams per liter (mg/L), 62,847 mg/L, and 24.3 mg/L, respectively. No source degradation, treatment, or dilution was assumed: that is concentrations were held constant through time. As part of the sensitivity analysis, the initial solute concentrations were varied: with the maximum reported values used for an upper bound and the mean minus one-half standard deviation used for the lower bound.

Geochemistry. Geochemical properties of the vadose zone included the amount of acid neutralization potential (ANP) and mass of hydrous ferric oxide (HFO) present in the bedrock vadose zone. The amount of ANP and HFO were based on measured values obtained from core. The sampling methodology, results, and statistical analysis of the

data, in addition to a discussion regarding the selection of hydrogeochemical units, are summarized in Appendix C while the original laboratory data are contained in Appendix A. As part of the sensitivity analysis, the amount of ANP was varied with the geometric mean plus one geometric standard deviation used for an upper bound and the geometric mean minus one geometric standard deviation used for the lower bound. The amount of HFO did not vary significantly within the bedrock vadose zone and was not included in the sensitivity analysis.

The partial pressure of oxygen was fixed in the model assuming a dissolved oxygen concentration in vadose zone porewater equal to 2 mg/L. The partial pressure of carbon dioxide was fixed in the model assuming $10^{-2.0}$ atmospheres of pressure, but was varied as part of the sensitivity analysis to $10^{-1.0}$ atmospheres of pressure used for an upper bound and $10^{-3.0}$ atmospheres of pressure used for the lower bound. Redox conditions were controlled by the oxygen couple. The following minerals were allowed to participate or dissolve, depending on their saturation indices: gypsum, calcite (ANP), amorphous aluminum hydroxide, and amorphous iron hydroxide (ferrihydrite or HFO). The mass of HFO allowed to participate in surface complexation reactions was fixed according to measured values in bedrock (geometric mean), and HFO that precipitated from solution did not add to the available sorption sites. The number of available sorption sites was based on assumptions implicit with the Dzombak and Morel (1990) diffuse layer model database. Additional details regarding the geochemical and reactive transport model are summarized in Appendix M.

Diffusion. Tortuosity, and its effect on molecular diffusion, was explicitly modeled during contaminant transport modeling by incorporation of a tortuosity factor for the liquid phase (Simunek et al., 2009). Given the extremely low advective velocity, mechanical dispersion was assumed to be negligible relative to molecular diffusion (see Section 2.0).

Degradation and Production. No degradation or production of chloride, sulfate, uranium, or other trace elements was assumed. Radioactive decay of uranium is considered to be relatively minor due to the slow processes involved (e.g., the half-life

for natural uranium, which is predominantly U-238 [$\sim 99.3\%$], is 4.5×10^9 years). Although uranium and other trace elements can be removed from solution through microbial processes, to yield more conservative model predictions, these processes were not simulated.

3.4.5 Initial Conditions

Water Flow. Initial soil water pressure heads within the bedrock vadose zone were estimated by applying a constant flux boundary using $\sim 1\%$ of average annual amount of precipitation. For all HP1 simulations, initial conditions were prescribed as pressure heads (as opposed to water content) to facilitate model convergence.

Geochemistry. Solution concentrations in the bedrock vadose were estimated by assuming equilibrium of calcite with the HFO surface. Only calcium and carbonate were included as aqueous species. The modeling assumed no initial concentrations of other solutes in the vadose zone for simplicity.

3.4.6 Duration of Simulations and Time Steps

Simulations were run to evaluate solute transport during the operational phase, dewatering phase, and post-closure steady-state timeframes equal to a total duration simulation of 240 years. The operational and dewatering phases (see Appendix L for details) were followed by 200 years following closure as required by the Permit.

The minimum and maximum time-step lengths were 1.04×10^{-2} day (900 seconds) and 180 days for the HP1 model. The maximum number of iterations per time step was 40. In HP1, solution efficiency is maximized by incorporating adaptive time-step adjustments based on criteria described in Simunek et al. (2009).

3.4.7 Sensitivity Analysis

A sensitivity analysis was performed to quantify the model-prediction uncertainty due to estimating solute transport input parameters. Three values were selected for each input

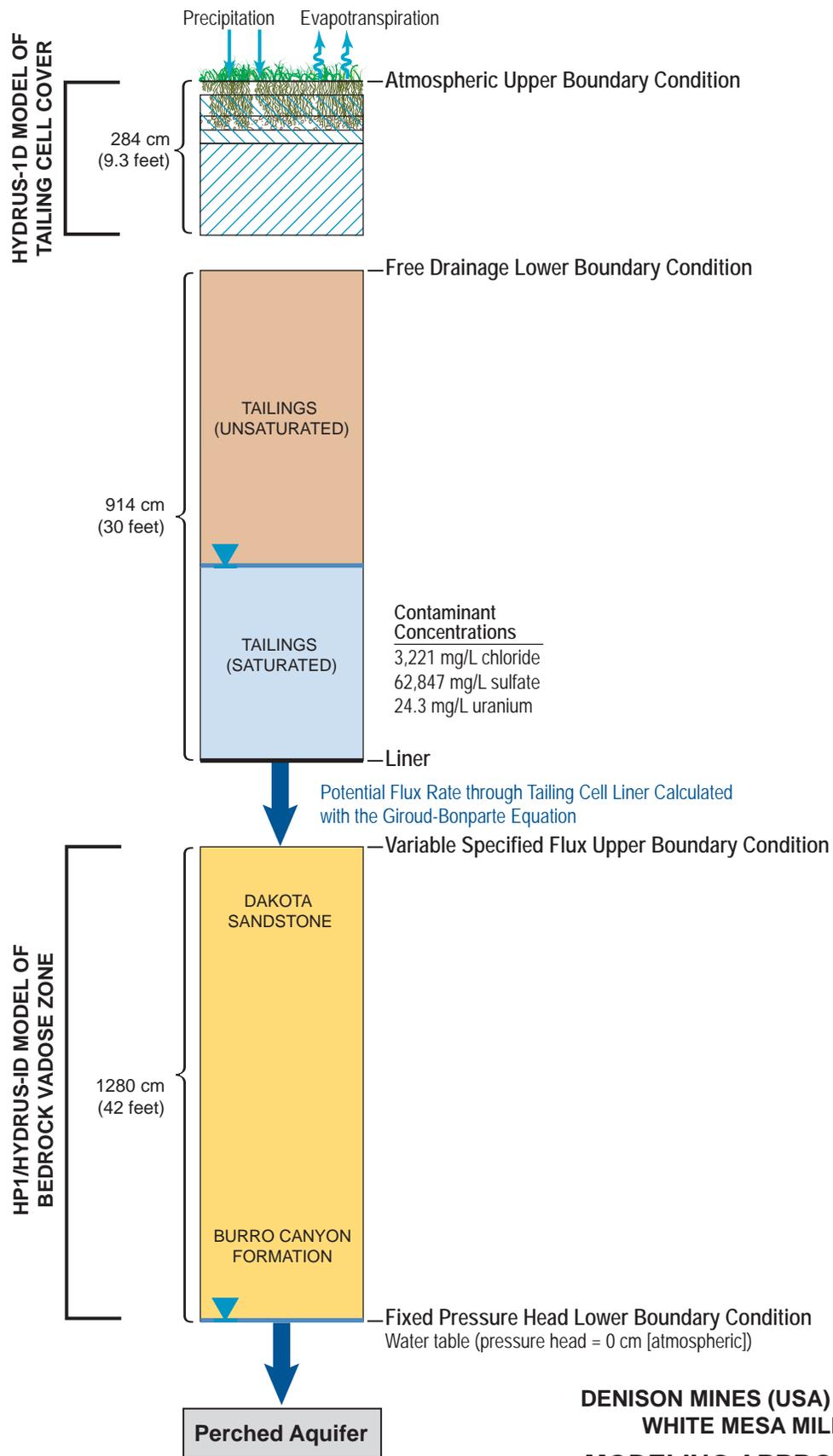
parameter, representing three different scenarios corresponding to a lower bound, base case, and upper bound. Input variables incorporated into the sensitivity analysis included source term solution chemistry of the tailings (see Appendix K for details), maximum tailings saturated thickness during operations (see Appendix J for details), number of potential liner defects (see Appendix L for details), ANP of the bedrock vadose zone (see Appendix C for details), and partial pressure of carbon dioxide gas within the bedrock vadose zone (see Appendix M for details). Because neither tailings saturated thickness nor the number of potential liner defects are explicitly simulated in the bedrock vadose zone model, variability in these parameters was incorporated in the sensitivity analysis by varying the potential flux rates through the liner.

TABLE 3-1

**SATURATED AND UNSATURATED HYDRAULIC PROPERTIES
OF THE WHITE MESA MILL TAILINGS CELL COVER INFILTRATION MODEL AND BEDROCK VADOSE ZONE CONTAMINANT TRANSPORT MODEL**

Model Layer	Purpose	Thickness z (ft)	Thickness z (cm)	Residual Soil Water Content θ_r (-)	Saturated Soil Water Content θ_s (-)	Curve Fitting Parameters in the Soil Water Retention Function		Saturated Hydraulic Conductivity K_s (cm/d)
						α (cm ⁻¹)	n (-)	
Monolithic ET Cover								
1	erosion protection and frost penetration	0.5	15	0.045	0.254	0.0145	1.406	5.6
2	water storage, biointrusion, and radon attenuation	3.5	107	0.055	0.404	0.0145	1.406	7.4
3	grading and radon attenuation	2.8	86	0.046	0.334	0.0229	1.261	3.6
4	grading and radon attenuation	2.5	76	0.059	0.439	0.0125	1.461	10.4
Bedrock Vadose Zone								
1	-	42	1280	0.003	0.184	0.0103	1.386	9.37

Note: Derivation of hydraulic properties for the cover are described in Appendix E. Derivation of hydraulic properties of the bedrock vadose zone are described in Appendix C.



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WHITE MESA MILL
MODELING APPROACH,
MODEL DOMAIN
AND BOUNDARY CONDITIONS
FIGURE 3-1**

4.0 RESULTS

This section presents the results from the tailings cell cover infiltration model and bedrock vadose zone flow and contaminant transport model. The HYDRUS-1D infiltration model was used to predict potential water fluxes through the tailings cell cover system, the results of which are presented in Section 4.1. The HP1 bedrock vadose zone contaminant transport model was used to predict the potential flow and transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace elements) solutes through the bedrock vadose zone to the perched aquifer, the results of which are presented in Section 4.2. A sensitivity analysis was performed to evaluate the impacts that uncertainty in parameter input values have on model results. The results of the sensitivity analysis for the tailings cell cover infiltration model and bedrock vadose zone contaminant transport model are described in each section separately. Key modeling assumptions and model uncertainty are discussed in Section 4.3. For all HYDRUS-1D and HP1 simulations the water and mass balance errors did not exceed 1%. As a general rule-of-thumb, mass balance errors that do not exceed 3% are considered acceptable.

4.1 TAILINGS CELL COVER SYSTEM INFILTRATION MODELING

The HYDRUS-1D infiltration model was used to predict potential water fluxes through the proposed monolithic ET cover system assuming atmospheric boundary conditions and a cover design as presented in Figure 2-2. The construction of a monolithic ET cover is proposed as part of this ICTM report to cap the entirety of all tailings cells. As described in Section 3.0, the model did not include runoff and 100% of the precipitation was allowed to evaporate or infiltrate into the top layer of the cover; no runoff was assumed to occur. Water not removed through evapotranspiration, or stored within the cover system, was transported downward as drainage that could potentially recharge the tailings cells. The modeling approach, model domain, and boundary conditions are described in Figure 3-1.

4.1.1 Model-Predicted Water Flux Rate

The model-predicted water flux rate through the tailings cell cover during the anticipated 57-year climate record (between 1932 and 1988) is shown on Figure 4-1. The model-predicted water flux rate varies during the 57-year period from a minimum rate of 0.17 millimeters per year (mm/yr) to a maximum rate of 1.1 mm/yr, with an average long-term flux rate through the cover system of 0.45 mm/yr. The average long-term water flux rate corresponds to approximately 0.1% of the average annual amount of precipitation recorded at the Blanding weather station. The average long-term infiltration rate predicted to enter the top of the tailings cells was reduced from 34 mm/yr for the currently permitted rock cover design to 0.45 mm/yr for the proposed monolithic ET cover design (see Appendix E for details of this comparison). The increased performance and reduction of infiltration for the proposed ET cover, relative to the original rock cover design, is attributed to the presence of vegetation and associated root water uptake via transpiration.

The model-predicted water flux rate through the monolithic ET cover indicates that the available storage capacity of the cover should be sufficient to significantly reduce infiltration, and the ET cover should function properly as designed. The transport of water below the rooting zone and into the tailings material would occur when the storage capacity of the overlying soil materials is exceeded; for example, during multi-consecutive years, or longer, that receive above average amounts of annual or winter precipitation. Breakthrough of water through the bottom of the cover (i.e., drainage), beginning at about year 48 (see Figure 4-1), results from the occurrence of three consecutive years that received above average amounts of winter precipitation followed by another seven years that received above average amounts of annual precipitation.

The model-predicted infiltration rates for the monolithic ET cover are consistent with data reported from lysimeter and infiltration modeling studies of other vegetated ET covers (e.g., Albright et al., 2004; Bolen et al., 2001; Fayer and Gee, 2006; Gee et al 1994; Scanlon et al., 2005). Furthermore, results from the nearby uranium mill tailings lysimeter at Monticello (Waugh et al., 2008) also agree with model predictions for the

proposed cover system at White Mesa. For example, the average infiltration rate measured at Monticello during a seven year monitoring period was approximately 0.6 mm/yr, which corresponds to approximately 0.2% of the average annual amount of precipitation (recorded at the Monticello weather station) occurring as recharge. At Monticello, nearly all of the measured drainage occurred during an exceptionally wet winter-spring season and no drainage was measured during the first four years of the monitoring period (Waugh et al., 2008). Overall, the comparison between model predictions for the proposed ET cover system at White Mesa, with results reported for lysimeter studies constructed with similar cover system designs and located in similar semiarid climates, suggests that only a fraction of the average annual amount of precipitation (e.g., less than 0.5%) can be expected to occur as recharge to the underlying tailings.

In summary, a monolithic ET cover is the preferred design to minimize infiltration necessary to meet the Permit (Part I.D.8) and meet the radon attenuation standard. The material thicknesses for the different cover layers were based on the results of radon attenuation modeling to achieve the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). The results of modeling the emanation of radon-222 from the top surface of the monolithic ET cover are presented in Appendix H. Furthermore, the proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration and biointrusion, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon flux.

4.1.2 Evaluation of Build-up of Water in Tailings

To evaluate the potential for build-up of water in the tailings ("bathtub effect"), the long-term average water flux rate through the tailings cell cover system (predicted with the infiltration model) was used to calculate the amount of water entering the tailings during the 200-year regulatory timeframe specified by the Permit. The amount of water expected to migrate through the cover and enter the tailings cells (i.e., assuming all recharge to the tailings can act to increase the amount of head on the liner) was then used

to calculate the maximum potential rise in water levels in the tailings assuming no water flow through the liners (i.e., all water that infiltrated through the cover was accumulated in the cells). The assumptions for evaluating the “bathtub effect” result in an end-member scenario expected to produce a conservative estimate of closed-cell cover system performance.

The amount of water calculated to enter the tailings after 200 years is equal to 90 millimeters (0.3 feet) of water. Assuming a tailings porosity of 57%, the calculated water-level rise on the liner is approximately 160 millimeters (0.53 feet). Consequently, a significant build-up of water (“bathtub effect”) within the cells is not anticipated. Therefore, the proposed cover design will prevent the accumulation of leachate head within the tailings that could rise above or over-top the maximum liner elevation (which is typically greater than 20 feet above the bottom of the cell), meeting the requirement of the Permit (Part I.D.8).

4.1.3 Sensitivity Analysis

To test the importance of simulating reduced performance of the vegetative component of the cover system, and how increased precipitation could influence the transport of water through the monolithic ET cover, the HYDRUS-1D infiltration model was run using different assumptions to evaluate the effects of lower bound, and upper bound scenarios, in addition to the base case. Rates of model-predicted water flux entering the tailings cells were compared between simulations using different input assumptions. The effects on moisture content by the parameters used to assess establishment of vegetation and root water uptake were also evaluated to determine whether moisture contents input into the radon model are conservative. Input variables incorporated into the sensitivity analysis included percent vegetative cover, maximum rooting depth and root density, wilting point pressure head, and precipitation. A complete description regarding the sensitivity analysis and comparison of infiltration rates through the cover based on cover vegetation, biointrusion, and precipitation is included in Appendix G.

The lower bound, anticipated, and upper bound long-term average water flux rates entering the tailings were 0.19 mm/yr, 0.45 mm/yr (see Section 4.1.1), and 2.4 mm/yr,

respectively, which would result in a total of approximately 38 mm (0.12 ft), 90 mm (0.3 ft), and 480 mm (1.6 ft) of water entering the tailings during the 200-year regulatory timeframe, respectively, and corresponding to an increase in saturated tailings thickness of 67 mm (0.21 ft), 160 mm (0.53 ft), and 840 mm (2.8 ft), respectively.

The results of the sensitivity analysis demonstrate that the design and construction of a monolithic ET cover will be sufficient to minimize infiltration into the tailings and prevent the formation of a bathtub effect for a broad range of conditions used to represent the establishment of vegetation, root water uptake by vegetation, and amount of precipitation that may occur at the site, thereby meeting closed cell performance requirements specified in the Permit (Part I.D.8.a and Part I.D.8.b). The results of the sensitivity analysis for the broad range of conditions described above, also demonstrate that the monolithic ET cover will have sufficient long-term moisture to attenuate radon fluxes thereby achieving the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Overall, all of the simulations, including the simulation with the lowest average flux rates, demonstrate that the amount of moisture predicted with the infiltration model exceeds the amount of moisture used in the radon attenuation model, which indicates that the predictions of radon emanation at the surface are conservative.

4.2 BEDROCK VADOSE ZONE FLOW AND CONTAMINANT TRANSPORT MODELING

The bedrock vadose zone flow and contaminant transport model was used to predict potential flow rates and contaminant transport rates through the bedrock vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. The modeling approach, model domain, and boundary conditions were described in Figure 3-1. Solute transport models were developed for the bedrock vadose zone beneath Cell 1 (contingency cell identified for the potential disposal of decommissioning and deconstruction debris), Cells 2 & 3, and Cells 4A & 4B. For simplicity, a vadose zone thickness of 12.8 meters (42 feet) was assumed for all of the simulations (see Appendix C for discussion of vadose zone thicknesses). This is a

conservative assumption given that the average vadose zone thicknesses beneath Cell 2, Cell 3, and Cell 4A are 19.2 m (63 ft), 20.1 m (66 ft), and 17.1 m (56 ft). HP1 was used to simulate potential solute transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace element) solutes through the vadose zone beneath the tailings cells. Conservative and nonconservative solute transport was predicted for the vadose zone beneath Cells 2 & 3. Because of the difference in potential mass transport rates (discussed below), only the transport of conservative solutes (chloride) was predicted for Cells 4A & 4B and Cell 1.

Potential water flux rates through the primary liner installed beneath Cells 2 & 3 and the secondary liner installed beneath Cells 4A & 4B were calculated using the Giroud-Bonaparte Equation (see Appendix L for equations used and list of assumptions). Conservative estimates of potential water flux rates through the liners were used as an upper boundary condition (time-dependent flux) for the HP1 model used to predict flow and solute transport through the vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. The average long-term water flux rate through the ET cover (predicted with the infiltration model) was used as an upper boundary condition (constant flux) for Cell 1 to represent the post-closure steady-state period. The bottom of Cell 1 (if constructed) will contain a soil liner compacted to achieve low permeability, but this layer was not included in the modeling, which yields conservative estimates of transport through the vadose zone.

The calculated potential water flux rates through the liners were multiplied by the average solute concentrations to yield a time-dependent mass flux rate applied as an upper boundary condition. The average solute concentrations were used as input to represent the source term solution chemistry of the tailings pore water (see Appendix K for a discussion of source term chemistries).

4.2.1 Cells 2 & 3

Head on Liner. The head above the single liner beneath Cells 2 & 3 was used as input to calculate the potential rate of fluid migration through the liners into the underlying vadose zone. For Cells 2 & 3, operational data (see Appendix L for details) and

predictions with the MODFLOW dewatering model (see Appendix J for details) were used to estimate the saturated thickness of the tailings through time. For simplicity, the average operational period for Cells 2 & 3 (23 years) was used in the flux calculations. For modeling purposes, the head on the liner was assumed to increase linearly for 13 years from approximately zero to fully saturated conditions. The average saturated thickness across the entirety of the cell when the cell was entirely full, 5.82 m (19.1 ft), was used as the maximum head during operations. Then the cells were assumed to remain fully saturated for an additional 10 years for a total operational period of 23 years, at which point active dewatering was assumed to be initiated. The MODFLOW dewatering model predicted that, as a result of dewatering activities, that the tailings would draindown nonlinearly through time reaching an average saturated thickness of 1.07 m (3.5 ft) after 10 years (i.e., total operational phase plus dewatering phase equal to 33 years). The saturated tailings thickness (head on liner) assumed in the model during the operational, dewatering, and post-closure steady-state timeframes is plotted in Figure 4-2.

Model-Predicted Water Flux Rate. The model-predicted water flux rate at the bottom of the vadose zone (immediately above the perched aquifer) at various times during the operational, dewatering, and post-closure steady-state timeframes are plotted on Figure 4-3. The potential flux rate predicted to enter the perched aquifer closely resembles the flux rate assumed to enter the top of the bedrock vadose zone with some minor differences that result from equilibration of initial conditions and storage of moisture within the bedrock. The flux rate predicted at the water table reaches a maximum value of approximately 7.5 mm/yr (compared to the 8.3 mm/yr maximum flux rate applied at the upper boundary) after 25 years of operations. The flux rate then rapidly declines in response to decreased head (saturated thickness) that occur in the tailings during the dewatering phase (see Figure 4-2), ultimately reaching a long-term steady state value of approximately 0.7 mm/yr (see Figure 4-3).

Model-Predicted Volumetric Moisture Content. The model-predicted volumetric water content throughout the vadose zone beneath Cells 2 & 3 during the operational, dewatering, and post-closure steady-state timeframes is plotted in Figure 4-4. The

volumetric water contents represent synoptic timeframes after 13 years (beginning of maximum head conditions in Cells 2 & 3), 23 years (at the end of maximum head conditions), 33 years (at the end of dewatering of Cells 2 & 3), and 100 & 240 years (post-closure steady-state). The volumetric water content profiles after 100 and 240 years are identical, indicating that steady state flow conditions have developed in the bedrock vadose zone.

Model-Predicted Chloride Concentration. The model-predicted chloride concentration at the bottom of the vadose zone beneath Cells 2 & 3 after 240 years (including operational, dewatering, and post-closure periods) of transport is 0.01 mg/L. The chloride concentration at the bottom of the vadose zone represents the model-predicted addition of chloride as a result of the potential flux from the tailings cells. While there is naturally-occurring chloride in the vadose zone initially, the modeling assumed no initial chloride for simplicity, and because there is a lack of data concerning background chloride and distribution of chloride within the vadose zone. Furthermore, the predicted chloride concentration is the solute concentration in vadose zone pore water that will reach the perched aquifer; however, the predicted concentration is not equal to the concentration in groundwater. The chloride mass flux (water flux multiplied by the concentration) entering the perched aquifer system will mix with groundwater resulting in a reduced concentration compared to the value predicted to occur at the bottom of the vadose zone. A model was not constructed to determine the actual (diluted) concentration in groundwater because the chloride concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL, which is 10 mg/L for chloride. The minimum GWCL (for chloride and all other solutes modeled) was selected from the list of monitoring wells located immediately downgradient from the tailings cells (i.e., monitoring wells MW-5, MW-11, MW-12, MW-14, MW-15, MW-23, MW-24, MW-28, MW-29, MW-30, and MW-31; GWCL's for these wells are specified in the Permit) (see Figure 2-5). Chloride transport predicted with HP1 was confirmed with HYDRUS-1D.

Model-Predicted Sulfate Concentration. The model-predicted sulfate concentration at the bottom of the vadose zone beneath Cells 2 & 3 after 240 years of transport is

0.014 mg/L. The distribution of sulfate within the bedrock vadose zone is controlled by the amount of gypsum that may precipitate from solution. The sulfate concentration at the bottom of the vadose zone represents the model-predicted addition of sulfate as a result of the potential flux from the tailings cells. While there is naturally-occurring sulfate in the vadose zone initially, the modeling assumed no initial sulfate for simplicity. Furthermore, the predicted sulfate concentration is the solute concentration in vadose zone pore water that will reach the perched aquifer; however, the predicted concentration is not equal to the concentration in groundwater, which will be diluted. The sulfate mass flux entering the perched aquifer system will mix with groundwater resulting in a reduced concentration compared to the value predicted to occur at the bottom of the vadose zone. A model was not constructed to determine the actual (diluted) concentration in groundwater because the sulfate concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL, which is 532 mg/L.

Model-Predicted Uranium Concentration. Uranium does not reach the bottom of the vadose zone beneath Cells 2 & 3 during the 240-year transport timeframe. Adsorption of uranium onto the surface of HFO present in the bedrock vadose zone limits the transport distance below the liner. The depth at which the uranium concentration is approximately equal to the minimum GWCL (0.0049 mg/L) is 2.3 meters (8 feet) below the liner system; a minimum of 10.5 meters (34 feet) above the perched water table. The uranium concentration within the vadose zone represents the model-predicted addition of uranium as a result of the potential flux from the tailings cells. While there is naturally-occurring uranium in the vadose zone initially, the modeling assumed no initial uranium for simplicity.

Model-Predicted Concentration of Other Trace Elements. The sorption of uranium was competitive because additional trace elements were modeled. Solutes included in the model were based on their elevated concentrations in the tailings pore water as compared to the GWCLs. Transport of the following trace elements was modeled: arsenic, cadmium, copper, nickel, vanadium, and zinc. Similar to uranium, these solutes were predicted to migrate a limited distance below the liner (e.g., a few meters).

4.2.2 Cells 4A & 4B

Head on Secondary Liner. The head within the leak detection system above the secondary liner beneath Cells 4A & 4B was used as input to calculate the potential rate of fluid migration through the secondary liner into the underlying vadose zone. For Cells 4A & 4B, operational data (see Appendix L for details) and dewatering predictions (Geosyntec Consultants, 2007a; 2007c) were used to determine the length of the operational and dewatering timeframes. For simplicity, the average operational period (6 years) and dewatering period (6 years) for Cells 4A & 4B was used in the flux calculations. The maximum head on the secondary liner during operations is assumed to equal 0.004 m (0.01 ft) for Cells 4A & 4B (Geosyntec Consultants, 2007a; 2007c). Significantly reduced head on the secondary liner for Cells 4A & 4B, as compared to Cells 2 & 3, is due to a more extensive slimes drain collection system, the upper primary liner, and pumping of the leak detection system, thus reducing the head on the secondary liner. The maximum head on the secondary liner was assumed to remain constant throughout the operational and dewatering periods (total of 12 years). The actual head on the secondary liner during the majority of the operational and dewatering periods is expected to be less than 0.004 m.

Model-Predicted Water Flux Rate. The calculated flux of water through the secondary liner beneath Cells 4A & 4B for the maximum head within the leak detection system during the operational and dewatering periods is approximately 8×10^{-5} mm/yr. The potential flux rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state because the increase in water levels is anticipated to be minor (see Section 4.1). Therefore, the model-predicted water flux rate at the bottom of the vadose zone (immediately above the perched aquifer) during post-closure steady-state is 8×10^{-5} mm/yr.

Model-Predicted Volumetric Moisture Content. The model-predicted volumetric water contents throughout the vadose zone beneath Cells 4A & 4B at various times throughout the operational, dewatering, and post-closure periods are nearly identical to

the long-term steady-state profile (at 100 and 240 years) beneath Cells 2 & 3 as shown on Figure 4-4.

Model-Predicted Chloride Concentration. For all practical purposes, chloride is not predicted to reach the bottom of the vadose zone during the 12-year operational and 200-year post-closure periods (chloride concentration predicted to reach the water table at 212 years was 5×10^{-14} mg/L). The chloride concentration is not predicted to exceed the 10 mg/L minimum GWCL anywhere in the vadose zone because of the diminutive chloride mass flux rate entering the vadose zone.

Model-Predicted Concentration of Other Solutes. Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the fact that the model predictions demonstrate nearly zero impact, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was not considered necessary.

4.2.3 Cell 1

Head on Compacted Soil Liner. The bottom of Cell 1 (if constructed) will contain a soil liner compacted to achieve low permeability. The compacted soil liner was not included in the bedrock vadose zone model as a simplification. Furthermore, if necessary Cell 1 would be constructed to contain demolition debris generated during decommissioning and deconstruction (D & D) of the mill, and all debris would be dry in an unsaturated state (negative soil water pressure head). Therefore, the build-up of head on the compacted soil liner is not anticipated.

Model-Predicted Water Flux Rate. If Cell 1 is constructed for D & D disposal, it will be covered with the monolithic ET cover design. The design will be the same as the cover proposed for the other cells (see Figure 2-2). Consequently, the long-term average infiltration rate would be equivalent to the value presented for the other cells (see Section 4.1 and Figure 4-1). Therefore, the model-predicted water flux rate at the bottom of the vadose zone (immediately above the perched aquifer) during the 200-year post-closure steady-state is predicted to be approximately 0.5 mm/yr.

Model-Predicted Volumetric Moisture Content. The model-predicted volumetric water content throughout the vadose zone during long-term steady conditions beneath Cell 1 is nearly identical to the long-term steady state profile beneath Cells 2 & 3 (at 100 and 240 years) plotted in Figure 4-4.

Model-Predicted Chloride Concentration. The source term of the D & D debris is assumed to equal the concentrations assigned to the tailings pore water, which is anticipated to lead to conservative predictions that over predict the potential impacts. For all practical purposes, chloride is not predicted to reach the bottom of the vadose zone during the 200-year transport timeframe (chloride concentration predicted to reach the water table at 200 years was 7×10^{-9} mg/L). The bedrock vadose zone depth at which the chloride concentration is approximately equal to the minimum GWCL (10 mg/L) is 4.65 meters (15.3 feet), approximately 8.1 meters (26.7 feet) above the water table.

Model-Predicted Concentration of Other Solutes. Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the diminutive transport distance, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was not considered necessary.

4.2.4 Evaluation of Closed-Cell Cover System Performance (Potential Impacts to Groundwater)

To evaluate the potential impacts to groundwater as a result of closed cell cover system performance, all infiltration migrating through the cover to the tailings was assumed to pass through the tailings and the liner system into the underlying bedrock vadose zone. Model predictions of chloride, sulfate, uranium, and other trace elements (arsenic, cadmium, copper, nickel, vanadium, and zinc) at the bottom of the vadose zone do not exceed the GWCLs for monitoring wells located immediately downgradient from the tailings cells (i.e., MW-5, MW-11, MW-12, MW-14, MW-15, MW-23, MW-24, MW-28, MW-29, MW-30, and MW-31) (see Figure 2-5). Therefore, the proposed cover design will be protective of groundwater quality; contaminant concentrations are not predicted to

exceed the GWCS's or GWCL's at the compliance monitoring wells specified in the Permit, thus demonstrating compliance with the Permit (Part I.D.8).

4.2.5 Sensitivity Analysis

A sensitivity analysis was performed to quantify the model-prediction uncertainty due to estimating model input parameters. Three values were selected for each input parameter, representing three different scenarios corresponding to a lower bound, base case, and upper bound. Input variables incorporated into the sensitivity analysis included source term solution chemistry of the tailings pore water (see Appendix K for details), maximum tailings saturated thickness during operations (see Appendix J for details), number of potential liner defects (see Appendix L for details), acid neutralization potential of the bedrock (ANP) vadose zone (see Appendix C for details), and partial pressure of carbon dioxide gas within the bedrock vadose zone (see Appendix M for details). A complete description regarding the sensitivity analysis and results for the bedrock zone contaminant transport modeling is included in Appendix M. Based on the results for conservative transport of chloride (i.e., limited transport distance) within the bedrock vadose zone beneath Cells 4A & 4B and Cell 1, the sensitivity analysis was only evaluated for Cells 2 & 3.

For the transport of conservative solutes, rates of model-predicted chloride concentrations at the bottom of the vadose zone (entering the perched aquifer) are presented; for nonconservative solutes, rates of model-predicted sulfate concentrations at the bottom of the vadose zone (entering the perched aquifer) are presented, while for uranium, bedrock vadose zone depths at which uranium concentrations approximately equal the minimum GWCL are presented. Results between simulations using different input assumptions are compared to evaluate the effect of parameter uncertainty on predictions of contaminant transport through the bedrock vadose zone.

Chloride. The model-predicted chloride concentrations at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years of transport are summarized in Table 4-1 for the seven model simulations. The sensitivity analysis assessing the range in chloride concentrations predicted to occur at the bottom of the bedrock vadose zone considered a

range in solute concentrations, maximum tailings saturated thickness, and number of potential liner defects. The input variables including ANP and partial pressure of carbon dioxide gas within the bedrock vadose zone were not included because these parameters would only affect the transport of nonconservative solutes. The results for the base case scenario were described in Section 4.2.1. The upper bound model-predicted chloride concentration at the bottom of the vadose zone was 18 mg/L, which is slightly greater than the minimum GWCL of 10 mg/L. However, mixing of vadose zone pore water with groundwater in the perched aquifer system would dilute this concentration below the minimum GWCL. The lower bound model-predicted chloride concentration at the bottom of the vadose zone was essentially zero (9.1×10^{-6} mg/L). Assuming all other variables are equal, the model-predicted chloride concentrations are least sensitive to the source term chemistry and most sensitive to the number of potential liner defects (which affects the potential liner flux rate), while the maximum tailing saturated thickness during operations has an intermediate effect (see Table 4-1, response variable statistic column).

Sulfate. The model-predicted sulfate concentrations at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years of transport are summarized in Table 4-2 for the nine model simulations. The sensitivity analysis assessing the range in sulfate concentrations predicted to occur at the bottom of the bedrock vadose zone considered a range in solute concentrations, number of potential liner defects, ANP within the bedrock vadose zone, and partial pressure of carbon dioxide gas within the bedrock vadose zone. Based on the results for chloride transport discussed above, the maximum tailings saturated thickness was excluded from the sensitivity analysis assessing nonconservative solute transport. The results for the base case scenario were described in Section 4.2.1. The upper bound model-predicted sulfate concentration at the bottom of the vadose zone was 45 mg/L, which is less than the minimum GWCL of 532 mg/L. The lower bound model-predicted sulfate concentration at the bottom of the vadose zone was essentially zero (1.0×10^{-5} mg/L). The distribution of sulfate within the bedrock vadose zone is controlled by the amount of gypsum that may precipitate from solution (see Appendix M). Assuming all other variables are equal, the model-predicted sulfate concentrations are least sensitive to the ANP of the bedrock vadose zone and most sensitive to the number of potential liner defects (which affects the potential liner flux

rate), while the source term chemistry and partial pressure of carbon dioxide gas within the bedrock vadose zone have an intermediate effect (see Table 4-2, response variable statistic column).

Uranium. The model-predicted bedrock vadose zone depth at which the uranium concentration approximately equals the minimum GWCL (0.0049 mg/L) after 240 years of transport beneath Cells 2 & 3 is summarized in Table 4-3 for the nine model simulations. The sensitivity analysis assessing the range in uranium concentrations predicted to occur within the bedrock vadose zone used the same input variables as for sulfate. The upper bound model-predicted depth at which uranium approximately equaled the minimum GWCL was 3.9 meters. The base case scenario was described in Section 4.2.1. The lower bound model-predicted depth at which uranium approximately equaled the minimum GWCL was 1.3 meters. None of the sensitivity runs predicted that uranium, or other trace elements (arsenic, cadmium, copper, nickel, vanadium, and zinc; see Appendix M) would reach the perched aquifer in the 240 year period simulated.

Assuming all other variables are equal, the model-predicted uranium transport depths are least sensitive to the source term chemistry and most sensitive to the number of potential liner defects, while the ANP and partial pressure of carbon dioxide gas within the bedrock vadose zone have an intermediate effect (see Table 4-3, response variable statistic column). The distribution of uranium is controlled by sorption onto the surfaces of HFO within the bedrock vadose zone. Factors that influence the transport and sorption potential of uranium are discussed in Appendix M.

For the broad range of input values of different geochemical variables, model-predicted concentrations of chloride, sulfate, uranium, and other trace elements (arsenic, cadmium, copper, nickel, vanadium, and zinc; see Appendix M) in the perched aquifer are not predicted to exceed the GWCLs for monitoring wells located immediately downgradient from the tailings cells (i.e., MW-5, MW-11, MW-12, MW-14, MW-15, MW-23, MW-24, MW-28, MW-29, MW-30, and MW-31) (see Figure 2-5). Therefore, the proposed cover design will be protective of groundwater quality; contaminant concentrations are not

predicted to exceed the GWCSs or GWCLs at the compliance monitoring wells specified in the Permit, thus meeting the permit requirements (Part I.C.1 and Table 2; Part I.D.8.c).

4.3 UNCERTAINTY AND ASSUMPTIONS

The numerical modeling presented in this report was based on fundamental biological, ecological, physical, and geochemical assumptions concerning the mechanisms controlling infiltration through the tailings cell cover model and contaminant transport in the bedrock vadose zone. However, as with all numerical models, the model only replicates the actual physical system to the extent that it is based on an accurate conceptual model that describes the site hydrogeology, boundary conditions, and initial conditions. The goal of the conceptual model is to describe these conditions (e.g., vegetation, stratigraphy, hydraulic properties, transport mechanisms, and boundary conditions) with a sufficient level of detail to address the objectives of the study. Because the subsurface environment is heterogeneous, simplifying assumptions are required so that the characteristics of the system can be quantified and incorporated into the numerical model.

Some of the simplifications include assuming the bedrock vadose zone thickness is equal to the minimum separation distance between the bottom of the tailings cells and the top of the perched aquifer. In the model, the vadose zone (distance between the liner beneath the cells and the perched aquifer water table) was assumed to be 12.8 meters (42 feet) for all of the cells. This vadose-zone thickness is the minimum depth to the water table (measured in nearby monitoring wells), which only occurs in one small area. The depth from the bottom of the cells to the perched aquifer water table is up to 27 meters (90 feet) in some areas. The assumption of a minimum bedrock vadose zone thickness is conservative as it results in shorter travel times for contamination to reach the water table. Actual travel times are likely to be much greater than predicted, particularly for transport beneath the western half of Cells 2 & 3 where the vadose zone thickness is much greater than 12.8 meters.

There is considerable evidence that the cells are not leaking. However, potential flux rates through the tailings cell liner systems were calculated using empirical equations and

assumptions developed for landfills. In reality, the tailings may limit the transmission of water, thus actual flow rates for a given hole size would be less than the calculated flow rates through the liners. Leakage rates computed for a tailings facility are expected to be less than the measured leakage rates for landfills because tailings are likely to have a limited capacity to transmit all available water. Consolidation of fine-grained tailings and deposition of tailing slimes, coupled with the chemical nature of the pore water (e.g., precipitation of gypsum), is anticipated to essentially seal some of the defects, which would act to decrease the potential flux rates through the liners.

A significant amount of gypsum, amorphous aluminum hydroxide, and amorphous iron hydroxide (ferrihydrite or HFO) was predicted to precipitate within the shallow bedrock vadose zone, which would be expected to modify liquid phase saturation and effective porosities, resulting in decreased water flux rates. It is likely that a layer of mineral precipitates would act to seal any holes in the liners, further reducing contaminant transport mobilities and transport distances.

Leakage from the unlined wildlife ponds have resulted in significant impacts to the perched water table surface (see Figure 2-5), which is not evident beneath the tailings cells. Considering the significantly larger footprint of the tailings cells, compared to the wildlife ponds, combined with the fact that the tailings cells have contained tailings at nearly fully-saturated conditions for long periods of time, if leakage were significant, it is likely that evidence would have appeared at this point.

The vadose-zone model assumed no lateral flow, only vertical flow. This ignores the impacts that horizontal heterogeneities may have on migration in the vadose zone. Because there is little information concerning vadose-zone heterogeneities, a two- or three-dimensional model was not constructed. However, given that hydraulic gradients in the vadose zone are strongly vertical, flow is primarily vertical, and thus a one-dimensional model is adequate for vadose zone flow and transport.

The bedrock vadose zone flow component of the contaminant transport model cannot be calibrated because there are no moisture content or pressure head data available for the vadose zone. Quantifying moisture fluxes through desert vadose zones is very difficult

due to the small magnitude of fluxes and the very long response times (Walvoord et al., 2002). The bedrock vadose zone modeling does not account for vapor transport. Under natural conditions, water transport in thick desert vadose zones is dominated by upward vapor transport over very long time periods (Walvoord et al., 2002). Modeling performed by Walvoord et al. (2002) indicates that most thick desert vadose zones are in a slow drying process that is on the order of tens of thousands of years. Upward vapor transport would act to slow downward contaminant migration.

The assumptions used to construct the numerical models to predict infiltration through the cover and potential impacts to the perched groundwater system, generally were either conservative or based on anticipated conditions. As a result, the predictions are considered to be conservative.

TABLE 4-1

MODEL-PREDICTED CHLORIDE CONCENTRATIONS
AT THE BOTTOM OF THE BEDROCK VADOSE ZONE AFTER 240 YEARS FOR CELLS 2 AND 3 EVALUATED AS PART OF THE SENSITIVITY ANALYSIS

Model Run ^a	Input Parameter Varied			Response Variable Evaluated	Response Variable Statistic
	Chloride Concentration ^b	Maximum Tailings Saturated Thickness During Operations ^c	Number of Potential Liner Defects ^d	Chloride Concentration at the Bottom of the Bedrock Vadose Zone at 240 yr (mg/L)	Change in Chloride Concentration at the Bottom of the Bedrock Vadose Zone at 240 yr (mg/L)
1	Base Case	Base Case	Base Case	0.0096	0
2	Upper Bound	Base Case	Base Case	0.012	0.0024
3	Lower Bound	Base Case	Base Case	0.0087	-0.00090
4	Base Case	Upper Bound	Base Case	0.25	0.24
5	Base Case	Lower Bound	Base Case	0.00030	-0.0093
6	Base Case	Base Case	Upper Bound	18	18
7	Base Case	Base Case	Lower Bound	0.000091	-0.010

^a Model run 1 is the base case scenario.

^b The base case assumed the mean concentration, while the upper bound assumed the maximum concentration and the lower bound assumed the mean minus one-half standard deviation.

^c The base case assumed the average saturated thickness, while the upper bound assumed the maximum saturated thickness and the lower bound assumed the the average value minus the difference between the upper bound and base case saturated thicknesses.

^d The base case assumed one small hole and one large hole defect per acre, while the upper bound assumed one small hole and three large hole defects per acre and the lower bound assumed one small hole defect per acre.

TABLE 4-2

**MODEL-PREDICTED SULFATE CONCENTRATIONS
AT THE BOTTOM OF THE BEDROCK VADOSE ZONE AFTER 240 YEARS OF TRANSPORT FOR CELLS 2 AND 3 EVALUATED AS PART OF THE SENSITIVITY ANALYSIS**

Model Run ^a	Input Parameter Varied				Response Variable Evaluated	Response Variable Statistic
	Sulfate Concentration ^b	Partial Pressure of Carbon Dioxide Gas ^c	Number of Potential Liner Defects ^d	Acid Neutralization Potential (ANP) ^e	Sulfate Concentration at the Bottom of the Bedrock Vadose Zone at 240 yr (mg/L)	Change in Sulfate Concentration at the Bottom of the Bedrock Vadose Zone at 240 yr (mg/L)
1	Base Case	Base Case	Base Case	Base Case	0.014	0
2	Upper Bound	Base Case	Base Case	Base Case	0.017	0.0030
3	Lower Bound	Base Case	Base Case	Base Case	0.012	-0.0020
4	Base Case	Upper Bound	Base Case	Base Case	0.034	0.020
5	Base Case	Lower Bound	Base Case	Base Case	0.0085	-0.0055
6	Base Case	Base Case	Upper Bound	Base Case	45	45
7	Base Case	Base Case	Lower Bound	Base Case	0.000010	-0.014
8	Base Case	Base Case	Base Case	Upper Bound	0.014	0
9	Base Case	Base Case	Base Case	Lower Bound	0.015	0.0010

^a Model run 1 is the base case scenario.

^b The base case assumed the mean concentration, while the upper bound assumed the maximum concentration and the lower bound assumed the mean minus one-half standard deviation.

^c The base case assumed a partial pressure of $10^{-2.0}$ atmospheres, while the upper bound assumed a partial pressure of $10^{-1.0}$ atmospheres and the lower bound assumed a partial pressure of $10^{-3.0}$ atmospheres.

^d The base case assumed one small hole and one large hole defect per acre, while the upper bound assumed one small hole and three large hole defects per acre and the lower bound assumed one small hole defect per acre.

^e The base case assumed the geometric mean, while the upper bound assumed the geometric mean plus one geometric standard deviation and the lower bound assumed the geometric mean minus one geometric standard deviation.

TABLE 4-3

MODEL-PREDICTED DEPTH WITHIN THE BEDROCK VADOSE ZONE AT WHICH URANIUM CONCENTRATION IS EQUAL TO THE MINIMUM GROUNDWATER COMPLIANCE LIMIT AFTER 240 YEARS FOR CELLS 2 AND 3 EVALUATED AS PART OF THE SENSITIVITY ANALYSIS

Model Run ^a	Input Parameter Varied				Response Variable Evaluated	Response Variable Statistic
	Uranium Concentration ^b	Partial Pressure of Carbon Dioxide Gas ^c	Number of Potential Liner Defects ^d	Acid Neutralization Potential (ANP) ^e	Bedrock Vadose Zone Depth at Which Uranium Concentration Equals the Minimum GWCL at 240 yr (meters)	Change in Depth at Which Uranium Concentration Equals the Minimum GWCL at 240 yr (meters)
1	Base Case	Base Case	Base Case	Base Case	2.30	0
2	Upper Bound	Base Case	Base Case	Base Case	2.50	0.20
3	Lower Bound	Base Case	Base Case	Base Case	2.15	-0.15
4	Base Case	Upper Bound	Base Case	Base Case	3.90	1.60
5	Base Case	Lower Bound	Base Case	Base Case	2.15	-0.15
6	Base Case	Base Case	Upper Bound	Base Case	3.70	1.40
7	Base Case	Base Case	Lower Bound	Base Case	1.30	-1.00
8	Base Case	Base Case	Base Case	Upper Bound	2.20	-0.10
9	Base Case	Base Case	Base Case	Lower Bound	1.55	-0.75

GWCL = groundwater compliance limit

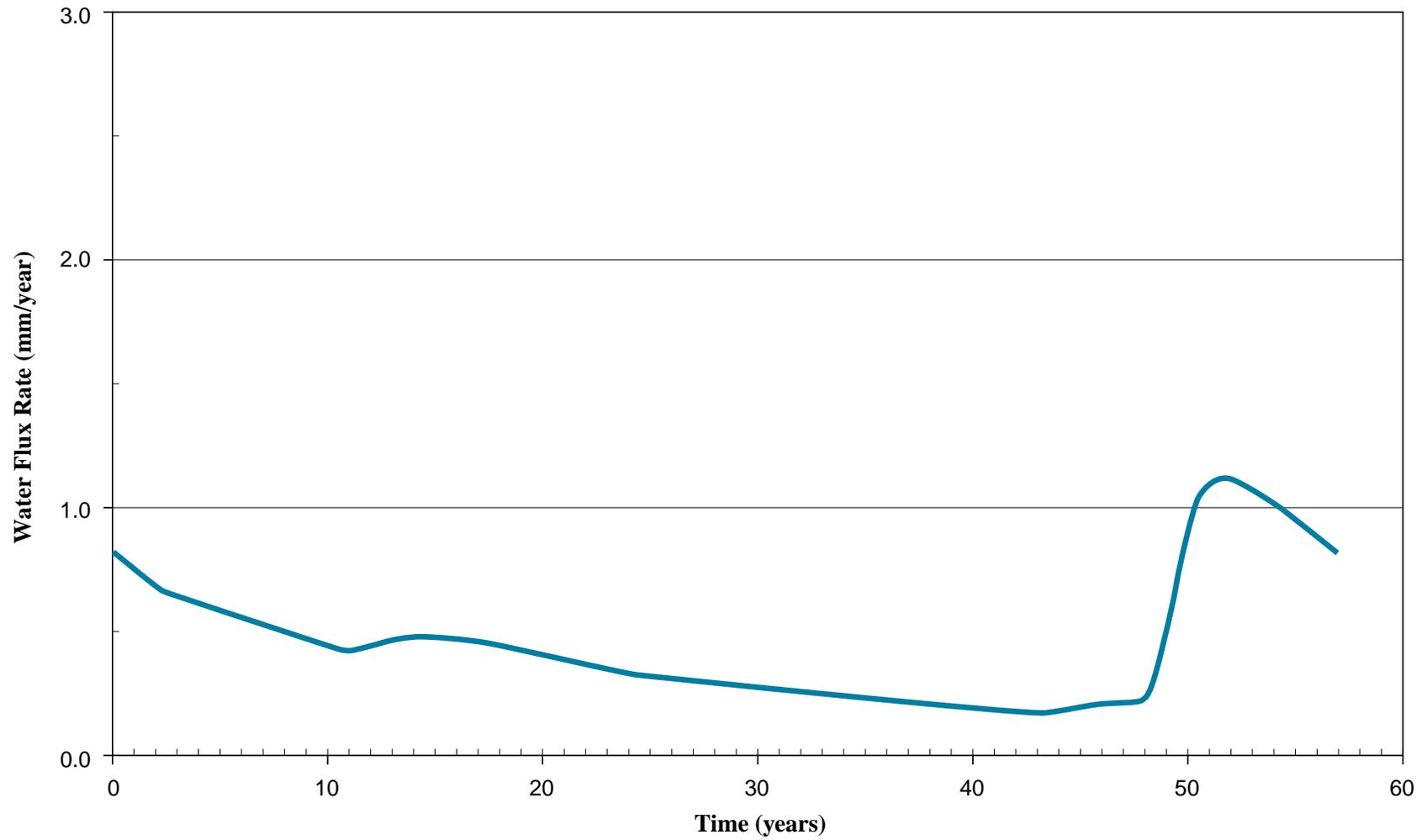
^a Model run 1 is the base case scenario.

^b The base case assumed the mean concentration, while the upper bound assumed the maximum concentration and the lower bound assumed the mean minus one-half standard deviation.

^c The base case assumed a partial pressure of $10^{-2.0}$ atmospheres, while the upper bound assumed a partial pressure of $10^{-1.0}$ atmospheres and the lower bound assumed a partial pressure of $10^{-3.0}$ atmospheres.

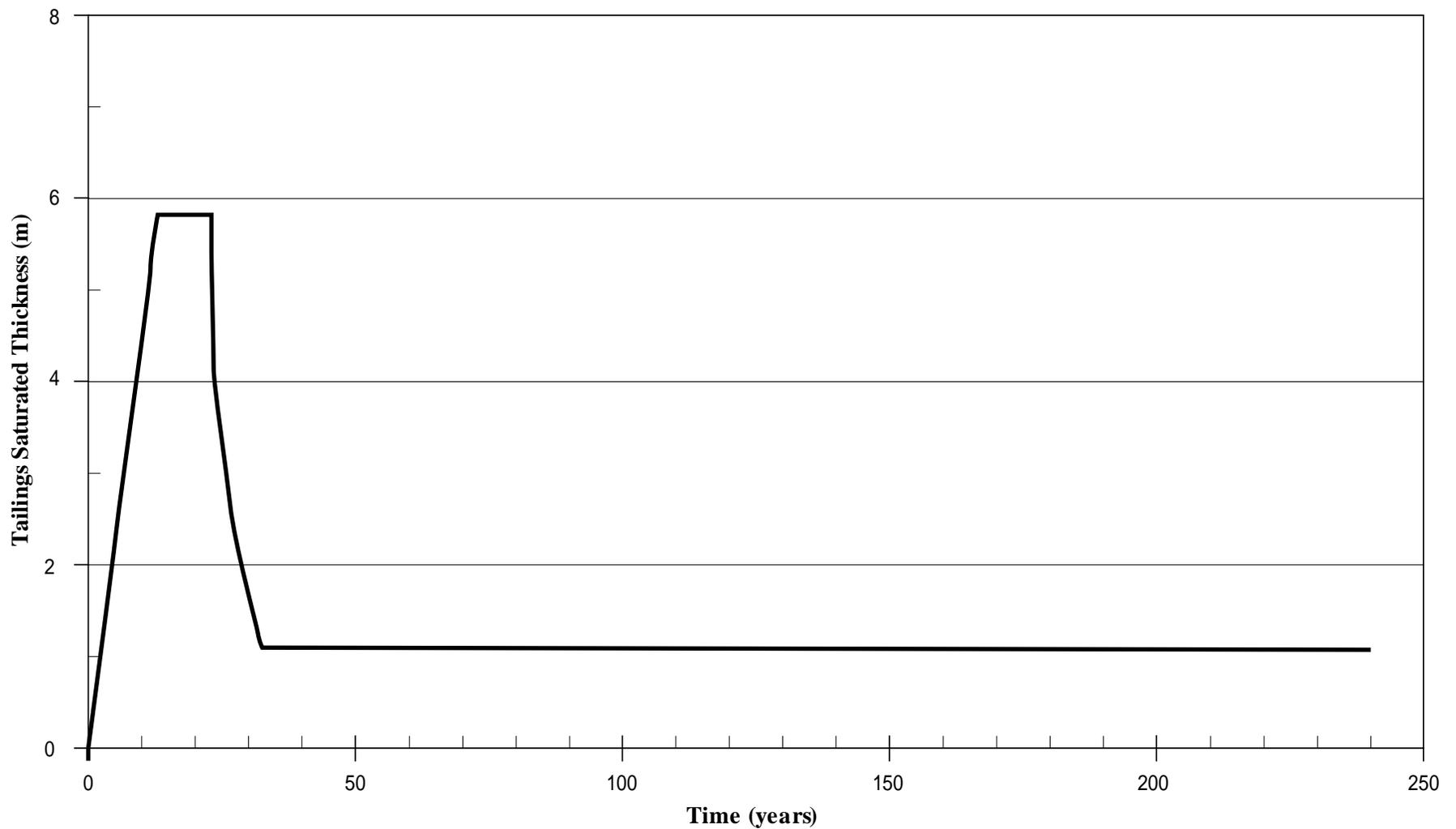
^d The base case assumed one small hole and one large hole defect per acre, while the upper bound assumed one small hole and three large hole defects per acre and the lower bound assumed one small hole defect per acre.

^e The base case assumed the geometric mean, while the upper bound assumed the geometric mean plus one geometric standard deviation and the lower bound assumed the geometric mean minus one geometric standard deviation.



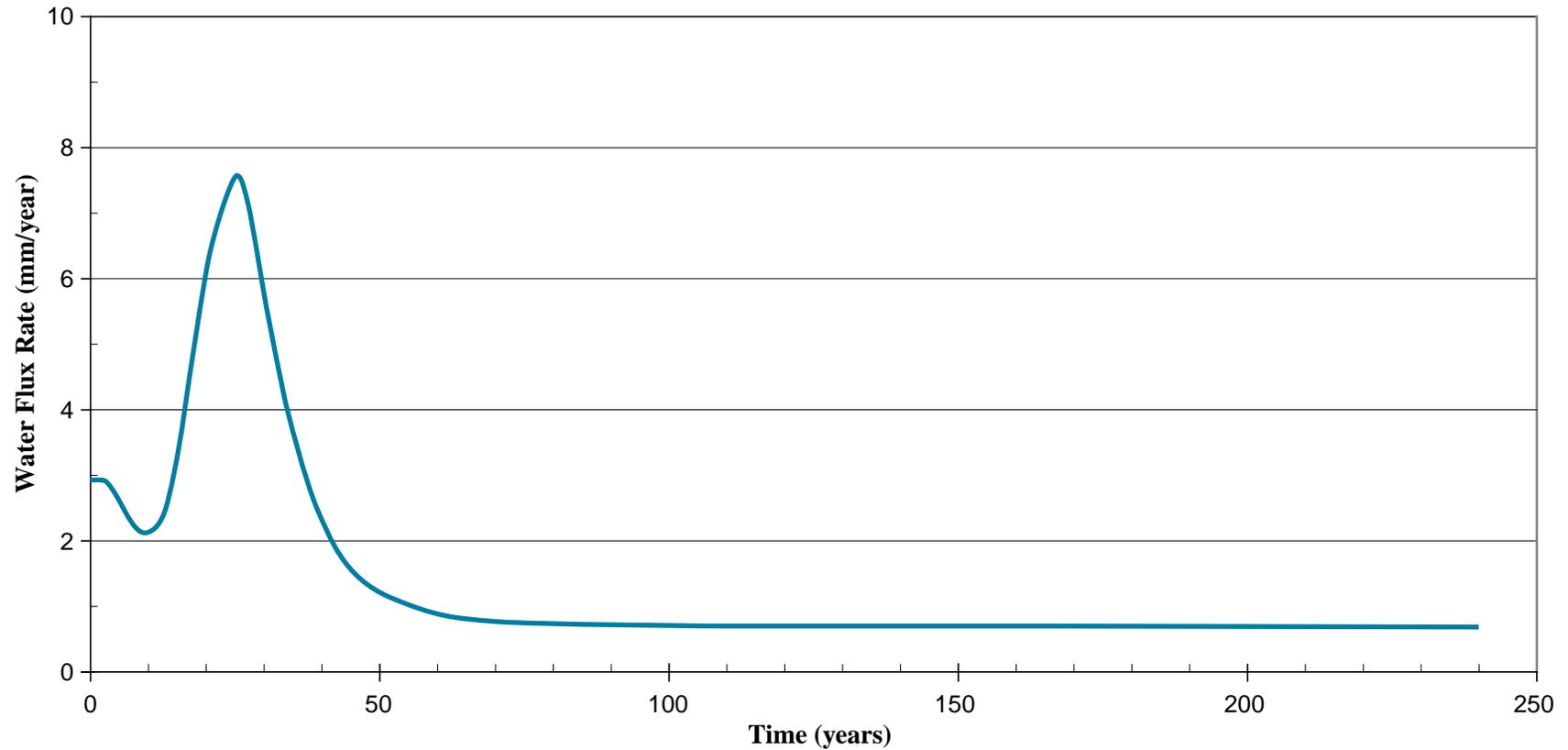
DENISON MINES (USA) CORP.
WHITE MESA MILL
MODEL-PREDICTED WATER FLUX RATE
THROUGH TAILINGS CELL COVER
(TYPICAL 57-YEAR PERIOD)

FIGURE 4-1



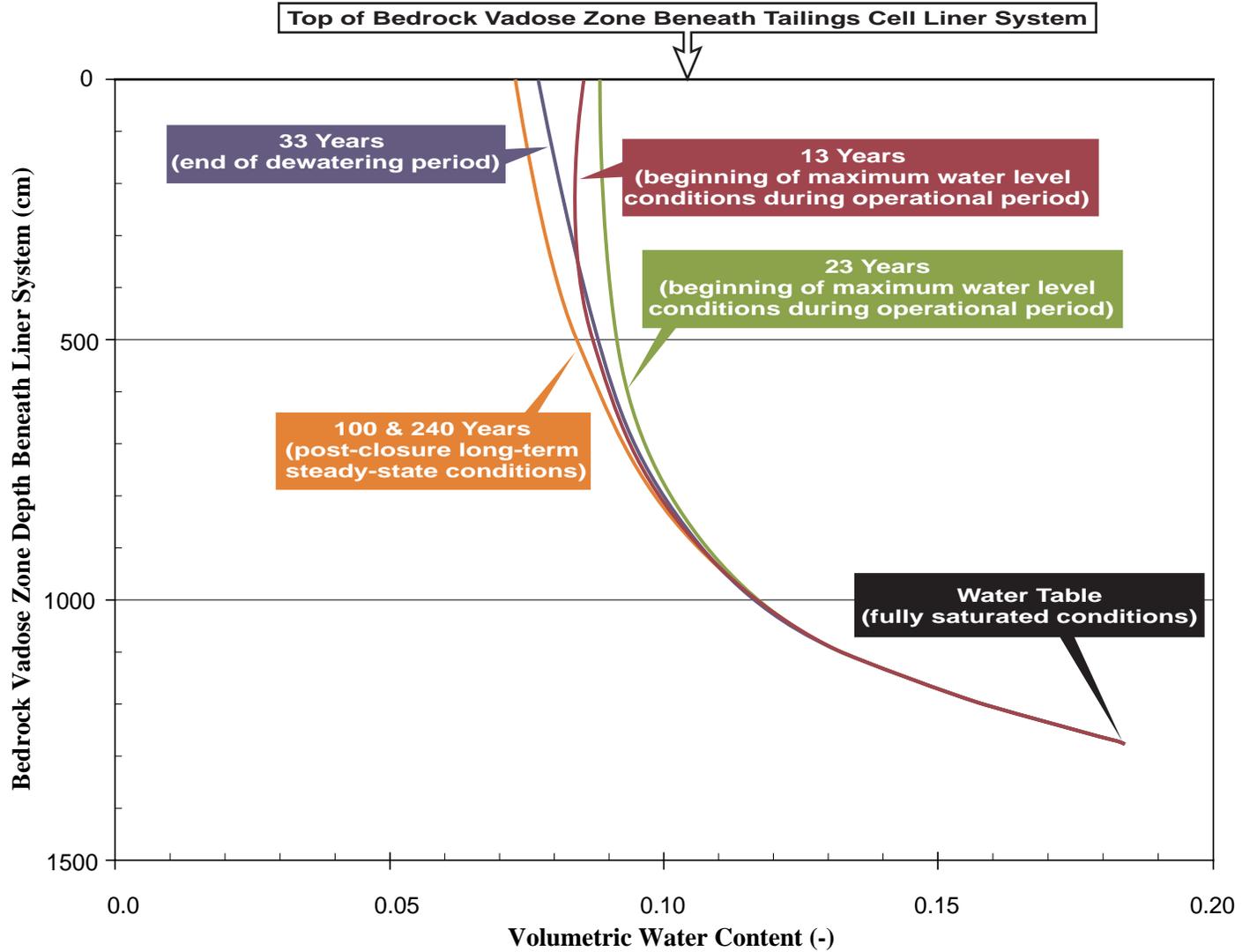
DENISON MINES (USA) CORP.
WHITE MESA MILL
TAILINGS SATURATED THICKNESS (HEAD ON LINER) DURING
THE OPERATIONAL, DEWATERING, AND POST-CLOSURE
STEADY-STATE TIMEFRAMES FOR CELLS 2 & 3

FIGURE 4-2



DENISON MINES (USA) CORP.
WHITE MESA MILL
MODEL-PREDICTED WATER FLUX RATE AT THE BOTTOM OF
THE BEDROCK VADOSE ZONE (ENTERING THE PERCHED AQUIFER)
DURING THE OPERATIONAL, DEWATERING, AND POST-CLOSURE
STEADY-STATE TIMEFRAMES FOR CELLS 2 & 3

FIGURE 4-3



DENISON MINES (USA) CORP.
WHITE MESA MILL
MODEL-PREDICTED VOLUMETRIC WATER CONTENT
THROUGHOUT THE BEDROCK VADOSE ZONE
DURING THE OPERATIONAL, DEWATERING, AND
POST-CLOSURE STEADY-STATE TIMEFRAMES FOR CELLS 2 & 3

FIGURE 4-4

5.0 CONCLUSIONS AND POST-AUDIT MONITORING PLAN

This section summarizes the results of infiltration and contaminant transport modeling performed to support Denison's Ground Water Discharge Permit for the White Mesa uranium milling and tailings disposal facility and provides recommendations for a post-audit monitoring plan.

5.1 CONCLUSIONS

The HYDRUS-1D infiltration model was used to predict potential water fluxes through the tailings cell cover system. The HP1 bedrock vadose zone contaminant transport model was used to predict the potential flow and transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace elements) solutes through the bedrock vadose zone to the perched aquifer. Sensitivity analyses were performed to evaluate the impacts that uncertainty in parameter input values have on model results.

5.1.1 Model-Predicted Water Flux Rate for Tailings Cell Cover System

The model-predicted average long-term water flux rate through the proposed monolithic ET tailings cell cover, assuming a historical climate record (based on climatic data recorded between 1932 and 1988), was 0.45 mm/yr. The average long-term water flux rate corresponds to approximately 0.1% of the average annual amount of precipitation recorded at the Blanding weather station. This is in contrast to an average long-term infiltration rate of 34 mm/yr predicted for the currently permitted rock cover design. The increased performance, and reduction of infiltration for the ET cover relative to the original rock cover design, is attributed to the presence of vegetation and associated root water uptake via transpiration. The model-predicted water flux rate through the monolithic ET cover indicates that the available storage capacity of the cover should be sufficient to significantly reduce infiltration, and the ET cover should function properly as designed.

A monolithic ET cover is the preferred design to minimize infiltration necessary to meet the Permit requirements (Part I.D.8) and meet the radon attenuation standard. The material thicknesses for the different cover layers were based on the results of radon attenuation modeling to achieve the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Furthermore, the proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration and biointrusion, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon flux.

5.1.2 Evaluation of Build-up of Water in Tailings

To evaluate the potential for build-up of water in the tailings (“bathtub effect”), the long-term average water flux rate through the tailings cell cover system (predicted with the infiltration model) was used to calculate the amount of water entering the tailings during the 200-year regulatory timeframe specified by the Permit. The amount of water expected to migrate through the cover and enter the tailings cells (i.e., assuming all recharge to the tailings can act to increase the amount of head on the liner) was then used to calculate the maximum potential rise in water levels in the tailings assuming no water flow through the liners (i.e., all water that infiltrated through the cover was accumulated in the cells). The assumptions for evaluating the “bathtub effect” result in an end-member scenario expected to produce a conservative estimate of closed-cell cover system performance.

The amount of water calculated to enter the tailings after 200 years is equal to 90 millimeters (0.3 feet) of water. Assuming a tailings porosity of 57%, the calculated water-level rise on the liner is approximately 160 millimeters (0.53 feet). Consequently, a significant build-up of water (“bathtub effect”) within the cells is not anticipated and the leachate head within the tailings is not predicted to rise above or over-top the maximum liner elevation (which typically is greater than 20 feet above the bottom of the cell), meeting the requirement of the Permit (Part I.D.8).

5.1.3 Bedrock Vadose Zone Flow and Contaminant Transport Modeling

The bedrock vadose zone flow and contaminant transport model was used to predict potential flow rates and contaminant transport rates through the bedrock vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. Solute transport models were developed for the bedrock vadose zone beneath Cell 1 (contingency cell identified for the potential disposal of decommissioning and deconstruction debris), Cells 2 & 3, and Cells 4A & 4B. For simplicity, a vadose zone thickness of 12.8 meters (42 feet) was assumed for all of the simulations. This is a conservative assumption given that the average vadose zone thicknesses beneath Cell 2, Cell 3, and Cell 4A are 19.2 m (63 ft), 20.1 m (66 ft), and 17.1 m (56 ft). HP1 was used to simulate potential solute transport of conservative (chloride) and nonconservative (sulfate, uranium, and other trace elements) solutes through the bedrock vadose zone beneath the tailings cells.

Potential water flux rates through the primary liner installed beneath Cells 2 & 3 and the secondary liner installed beneath Cells 4A & 4B were calculated using the Giroud-Bonaparte Equation. Estimates of potential water flux rates through the liners were used as an upper boundary condition (time-dependent flux) for the HP1 model used to predict flow and solute transport through the bedrock vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes. The average long-term water flux rate through the ET cover (predicted with the infiltration model) was used as an upper boundary condition (constant flux) for Cell 1 to represent the post-closure steady-state period. The bottom of Cell 1 (if constructed) will contain a soil liner compacted to achieve low permeability, but this layer was not included in the modeling, which yields conservative estimates of solute transport through the bedrock vadose zone.

The calculated potential water flux rates through the liners were multiplied by the average solute concentrations measured in the tailings slimes drains to yield a time-dependent mass flux rate applied as an upper boundary condition to the top of the bedrock vadose zone. The average solute concentrations were used as input to represent the source term solution chemistry of the tailings pore water.

Cells 2 & 3 Model-Predicted Water Flux Rate. The potential water flux rate at the bottom of the bedrock vadose zone (immediately above the perched aquifer) is predicted to reach a maximum value of approximately 7.5 mm/yr after 25 years of tailings cell operation (note that tailings cells are not covered during this period). The potential flux rate is then predicted to rapidly decline in response to decreased head (saturated thickness) that occur in the tailings during the dewatering phase, ultimately reaching a long-term steady state value of approximately 0.7 mm/yr during the 200-year regulatory post-closure period. The calculations used to determine the potential flux rates through the liners were based on conservative assumptions, and there is considerable evidence that the cells are not leaking. Furthermore, consolidation of fine-grained tailings and deposition of tailing slimes, coupled with the chemical nature of the pore water (e.g., precipitation of gypsum and amorphous mineral phases), is anticipated to essentially seal some of the defects, which would act to decrease the potential flux rates through the liners.

Cells 2 & 3 Model-Predicted Chloride Concentration. The model-predicted increase in chloride concentrations at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years (including operational, dewatering, and post-closure periods) of transport is 0.01 mg/L. The chloride concentration at the bottom of the vadose zone represents the model-predicted addition of chloride as a result of the potential flux from the tailings cells. While there is naturally-occurring chloride in the vadose zone, the modeling assumed no initial chloride for simplicity, and because there is a lack of data concerning background chloride concentrations and the distribution of chloride within the vadose zone. Furthermore, the model-predicted chloride concentration is the solute concentration in vadose zone pore water that will reach the perched aquifer; however, the predicted concentration is not equal to the concentration in groundwater. A model was not constructed to determine the actual (diluted) concentration in groundwater because the chloride concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL for chloride, which is 10 mg/L. The minimum GWCL (for chloride and all other solutes modeled) was selected from the list of monitoring wells located immediately downgradient from the tailings cells (i.e.,

monitoring wells MW-5, MW-11, MW-12, MW-14, MW-15, MW-23, MW-24, MW-28, MW-29, MW-30, and MW-31; GWCL's for these wells are specified in the Permit).

Cells 2 & 3 Model-Predicted Sulfate Concentration. The model-predicted sulfate concentration at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years of transport is 0.014 mg/L. The distribution of sulfate within the bedrock vadose zone is controlled by the amount of gypsum that may precipitate from solution. The sulfate concentration at the bottom of the bedrock vadose zone represents the model-predicted addition of sulfate as a result of the potential flux from the tailings cells. A model was not constructed to determine the actual (diluted) concentration in groundwater because the sulfate concentration predicted at the bottom of the vadose zone was orders of magnitude less than the minimum GWCL for sulfate, which is 532 mg/L for monitoring wells located immediately downgradient from the tailings cells.

Cells 2 & 3 Model-Predicted Uranium Concentration. Uranium is not predicted to reach the bottom of the bedrock vadose zone beneath Cells 2 & 3 during the 240-year timeframe. Adsorption of uranium onto the surface of hydrous ferric oxide (HFO) present in the bedrock vadose zone limits the transport distance below the liner. The depth at which the model-predicted uranium concentration is approximately equal to the minimum GWCL (0.0049 mg/L) after 240 years is 2.3 meters (8 feet) below the tailing cell liner system; a minimum of 10.5 meters (34 feet) above the perched water table. The uranium concentration within the bedrock vadose zone represents the model-predicted addition of uranium as a result of the potential flux from the tailings cells. HFO is the only solid phase that serves as a potential sorption site of uranium and other trace elements, which is a conservative assumption because other phases (e.g., hematite, quartz, clays, etc.) also participate in surface complexation reactions.

Cells 2 & 3 Model-Predicted Concentration of Other Trace Elements. The sorption of uranium was competitive because additional trace elements were modeled. Solutes included in the model were based on their elevated concentrations in the tailings pore water as compared to the GWCLs. Transport of the following trace elements was modeled: arsenic, cadmium, copper, nickel, vanadium, and zinc. Similar to uranium,

these solutes were predicted to migrate a limited distance below the liner (e.g., a few meters).

Cells 4A & 4B Model-Predicted Water Flux Rate. The calculated potential flux of water through the secondary liner beneath Cells 4A & 4B for the maximum head within the leak detection system during the operational and dewatering periods is approximately 8×10^{-5} mm/yr. The potential flux rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state because the increase in water levels is anticipated to be minor. Therefore, the model-predicted water flux rate at the bottom of the bedrock vadose zone (immediately above the perched aquifer) during post-closure steady-state is 8×10^{-5} mm/yr.

Cells 4A & 4B Model-Predicted Concentrations. For all practical purposes, chloride is not predicted to reach the bottom of the bedrock vadose zone during the 12-year operational and 200-year post-closure periods (The chloride concentration predicted to reach the water table at 212 years was 5×10^{-14} mg/L.). The chloride concentration is not predicted to exceed the 10 mg/L minimum GWCL anywhere in the vadose zone because of the diminutive chloride mass flux rate entering the vadose zone. Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the fact that the model predictions demonstrate nearly zero impact, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was considered unnecessary.

Cell 1 Model-Predicted Water Flux Rate. If Cell 1 is constructed for decommissioning and deconstruction disposal, it will include a soil liner compacted to achieve low permeability and will be covered with the monolithic ET cover. The cover design will be the same as the monolithic ET cover proposed for the other cells. Consequently, the long-term average infiltration rate would be equivalent to the value presented for the other cells. The model-predicted water flux rate at the bottom of the vadose zone (immediately above the perched aquifer) during 200-year post-closure steady-state is predicted to be approximately 0.5 mm/yr.

Cell 1 Model-Predicted Concentrations. The source term of the decommissioning and deconstruction debris is assumed to equal the concentrations assigned to the tailings pore water, which is anticipated to lead to conservative predictions that over predict the potential impacts. For all practical purposes, chloride is not predicted to reach the bottom of the bedrock vadose zone during the 200-year transport timeframe (the chloride concentration predicted to reach the water table at 200 years was 7×10^{-9} mg/L). Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with the diminutive transport distance, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was considered unnecessary.

5.1.4 Summary of Closed Cell Cover System Performance

The assumptions used to construct the numerical models to predict infiltration through the cover and potential impacts to the perched groundwater system, generally were either conservative or based on anticipated conditions. As a result, the predictions are considered to be conservative.

Part I.D.8 (Closed Cell Performance Requirements) of the Permit states:

“Before reclamation and closure of any tailings disposal cell, the Permittee shall ensure that the final design, construction, and operation of the cover system at each tailings cell will comply with all requirements of an approved Reclamation Plan, and will for a period of not less than 200 years meet the following minimum performance requirements:

- *Minimize infiltration of precipitation or other surface water into the tailings, including, but not limited to the radon barrier.*
- *Prevent the accumulation of leachate head within the tailings waste layer that could rise above or over-top the maximum flexible membrane liner (FML) elevation internal to any disposal cell, i.e., create a “bathtub effect”.*

- *Ensure the groundwater quality at the compliance monitoring wells does not exceed the Ground Water Quality Standards (GWQS's) or Ground Water Compliance Limits (GWCL's) specified in Part I.C.1 and Table 2 of the Permit."*

The bedrock vadose zone model evaluates the potential impacts of the tailings cell system as a whole (liner system, dewatering system, and cover system) on groundwater for the project lifecycle, including the operational phase (without cell cover system), the dewatering phase (with an interim cover only), and the 200-year regulatory post-closure period (with complete cover system, but with some limited water remaining in the tailings). For the 240-year period modeled, the potential flux rate and contaminant transport through the underlying bedrock vadose zone is dominated by the effect of the operational phase when the cells were not covered. As a result, the bedrock vadose zone model including the operational phase is not a reliable indicator of performance of the closed-cell cover system. However, even with the operational phase, model-predicted contaminant concentrations in vadose zone pore water entering the perched aquifer did not exceed the GWQS's or GWCL's for any downgradient monitoring wells, thus demonstrating compliance with Part I.D.8 of the Permit.

Based on the model results, the proposed monolithic ET cover will minimize infiltration into the tailings, will prevent build-up of leachate head on the cell liner, and will be protective of groundwater quality; contaminant concentrations are not predicted to exceed the GWCS's or GWCL's at the compliance monitoring wells specified in the Permit, thus demonstrating compliance with Part I.D.8 of the Permit. Furthermore, the results of the radon attenuation model demonstrate that the proposed monolithic ET cover will attenuate radon fluxes thereby achieving the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24).

5.2 POST-AUDIT MONITORING PLAN

To check the accuracy of the model predictions, a post-audit can be performed, often referred to as model verification. Additional data are collected and after a specified

period, the model is rerun with new input data and the results are compared to field-measured data for the same period. Given difficulties associated with data collection and the time-scale on which processes occur in the vadose zone, a post-audit of the HYDRUS-1D and HP1 models is not practical. Given the time-scale on which the model-predicts contaminants could potentially reach the perched aquifer, post-audit monitoring should include ongoing groundwater level measurements and groundwater sampling, but at a reduced frequency and at a limited set of wells relative to that currently used to establish background levels. Sampling should focus on the closest downgradient monitoring wells.

A post audit of the MODFLOW model for the tailings cell dewatering (presented in Appendix J) is described below. For post-audit monitoring of the dewatering system, water levels in the tailings and pumping rates and volumes should be measured and recorded monthly. The model predictions should be compared to these data. If the dewatering rates predicted by the model are considerably different than actual measured rates, the MODFLOW model should be recalibrated by adjusting terms such as areal recharge, hydraulic conductivity of tailings, storage parameters, and/or slimes drain conductance to match dewatering rates and measured water levels.

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APPENDIX A

**LABORATORY REPORTS WITH RESULTS OF VADOSE ZONE
MINERALOGICAL TESTING AND PROPERTIES OF
STOCKPILED SOIL**

April 27, 2007

Report to:

Doug Oliver
MWH America's Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Bill to:

Accounts Payable
MWH America's Inc.
P.O. Box 6610
Broomfield, CO 80021

cc: Ryan Jakubowski

Project ID: 1004-A0002-87430-OM/

ACZ Project ID: L62140

Doug Oliver:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on April 20, 2007. This project has been assigned to ACZ's project number, L62140. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 11.0. The enclosed results relate only to the samples received under L62140. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after May 27, 2007. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-30 37.5-38.0ACZ Sample ID: **L62140-01**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	137		*	mg/L	0.03	0.2	04/25/07 21:09	djt
Calcium, dissolved	M200.7 ICP	53.5		*	mg/L	0.2	1	04/25/07 0:40	djt
Iron, dissolved	M200.7 ICP	295		*	mg/L	0.02	0.05	04/25/07 21:09	djt
Magnesium, dissolved	M200.7 ICP	59.6		*	mg/L	0.2	1	04/25/07 0:40	djt
Manganese, dissolved	M200.7 ICP	8.440		*	mg/L	0.005	0.03	04/25/07 0:40	djt
Uranium, dissolved	M200.8 ICP-MS	0.0156		*	mg/L	0.0001	0.0005	04/24/07 1:15	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-30 43.0-43.2ACZ Sample ID: **L62140-02**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	69.90		*	mg/L	0.03	0.2	04/25/07 21:13	djt
Calcium, dissolved	M200.7 ICP	68.4		*	mg/L	0.2	1	04/25/07 1:01	djt
Iron, dissolved	M200.7 ICP	38.30		*	mg/L	0.02	0.05	04/25/07 21:13	djt
Magnesium, dissolved	M200.7 ICP	32.5		*	mg/L	0.2	1	04/25/07 1:01	djt
Manganese, dissolved	M200.7 ICP	0.057		*	mg/L	0.005	0.03	04/25/07 1:01	djt
Uranium, dissolved	M200.8 ICP-MS	0.0109		*	mg/L	0.0001	0.0005	04/24/07 1:21	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-30 43.2-43.5ACZ Sample ID: **L62140-03**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	58.30		*	mg/L	0.03	0.2	04/25/07 21:18	djt
Calcium, dissolved	M200.7 ICP	53.5		*	mg/L	0.2	1	04/25/07 1:05	djt
Iron, dissolved	M200.7 ICP	25.30		*	mg/L	0.02	0.05	04/25/07 21:18	djt
Magnesium, dissolved	M200.7 ICP	26.1		*	mg/L	0.2	1	04/25/07 1:05	djt
Manganese, dissolved	M200.7 ICP	0.070		*	mg/L	0.005	0.03	04/25/07 1:05	djt
Uranium, dissolved	M200.8 ICP-MS	0.0078		*	mg/L	0.0002	0.001	04/24/07 1:27	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 53.0-53.5ACZ Sample ID: **L62140-04**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	176		*	mg/L	0.03	0.2	04/25/07 21:30	djt
Calcium, dissolved	M200.7 ICP	76.5		*	mg/L	0.2	1	04/25/07 1:09	djt
Iron, dissolved	M200.7 ICP	304		*	mg/L	0.02	0.05	04/25/07 21:30	djt
Magnesium, dissolved	M200.7 ICP	106		*	mg/L	0.2	1	04/25/07 1:09	djt
Manganese, dissolved	M200.7 ICP	4.370		*	mg/L	0.005	0.03	04/25/07 1:09	djt
Uranium, dissolved	M200.8 ICP-MS	0.0156		*	mg/L	0.0001	0.0005	04/24/07 1:45	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 74.0-74.3ACZ Sample ID: **L62140-05**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	40.70		*	mg/L	0.03	0.2	04/25/07 21:43	djt
Calcium, dissolved	M200.7 ICP	24.7		*	mg/L	0.2	1	04/25/07 1:14	djt
Iron, dissolved	M200.7 ICP	19.10		*	mg/L	0.02	0.05	04/25/07 21:43	djt
Magnesium, dissolved	M200.7 ICP	28.4		*	mg/L	0.2	1	04/25/07 1:14	djt
Manganese, dissolved	M200.7 ICP	0.069		*	mg/L	0.005	0.03	04/25/07 1:14	djt
Uranium, dissolved	M200.8 ICP-MS	0.0112		*	mg/L	0.0001	0.0005	04/24/07 1:50	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 82.5-82.7ACZ Sample ID: **L62140-06**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	15.20		*	mg/L	0.03	0.2	04/25/07 21:48	djt
Calcium, dissolved	M200.7 ICP	11.3		*	mg/L	0.2	1	04/25/07 1:18	djt
Iron, dissolved	M200.7 ICP	14.50		*	mg/L	0.02	0.05	04/25/07 21:48	djt
Magnesium, dissolved	M200.7 ICP	12.7		*	mg/L	0.2	1	04/25/07 1:18	djt
Manganese, dissolved	M200.7 ICP	0.049		*	mg/L	0.005	0.03	04/25/07 1:18	djt
Uranium, dissolved	M200.8 ICP-MS	0.0122		*	mg/L	0.0001	0.0005	04/24/07 1:56	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 99.8-100.0ACZ Sample ID: **L62140-07**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	29.50		*	mg/L	0.03	0.2	04/25/07 21:52	djt
Calcium, dissolved	M200.7 ICP	19.1		*	mg/L	0.2	1	04/25/07 1:22	djt
Iron, dissolved	M200.7 ICP	74.60		*	mg/L	0.02	0.05	04/25/07 21:52	djt
Magnesium, dissolved	M200.7 ICP	9.0		*	mg/L	0.2	1	04/25/07 1:22	djt
Manganese, dissolved	M200.7 ICP	0.222		*	mg/L	0.005	0.03	04/25/07 1:22	djt
Uranium, dissolved	M200.8 ICP-MS	0.0147		*	mg/L	0.0001	0.0005	04/24/07 2:14	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 103.0-103.3ACZ Sample ID: **L62140-08**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	24.50		*	mg/L	0.03	0.2	04/25/07 21:56	djt
Calcium, dissolved	M200.7 ICP	14.4		*	mg/L	0.2	1	04/25/07 1:26	djt
Iron, dissolved	M200.7 ICP	15.50		*	mg/L	0.02	0.05	04/25/07 21:56	djt
Magnesium, dissolved	M200.7 ICP	9.8		*	mg/L	0.2	1	04/25/07 1:26	djt
Manganese, dissolved	M200.7 ICP	0.229		*	mg/L	0.005	0.03	04/25/07 1:26	djt
Uranium, dissolved	M200.8 ICP-MS	0.0105		*	mg/L	0.0001	0.0005	04/24/07 2:19	scp

MWH America's Inc.

Project ID: 1004-A0002-87430-OM/
Sample ID: MW-23 103.0-103.3DUP

ACZ Sample ID: **L62140-09**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	23.50		*	mg/L	0.03	0.2	04/26/07 6:12	djt
Calcium, dissolved	M200.7 ICP	12.7		*	mg/L	0.2	1	04/26/07 6:12	djt
Iron, dissolved	M200.7 ICP	15.20		*	mg/L	0.02	0.05	04/26/07 6:12	djt
Magnesium, dissolved	M200.7 ICP	9.4		*	mg/L	0.2	1	04/26/07 6:12	djt
Manganese, dissolved	M200.7 ICP	0.224		*	mg/L	0.005	0.03	04/26/07 6:12	djt
Uranium, dissolved	M200.8 ICP-MS	0.0105		*	mg/L	0.0001	0.0005	04/24/07 2:25	scp

MWH America's Inc.Project ID: 1004-A0002-87430-OM/
Sample ID: PBSACZ Sample ID: **L62140-10**
Date Sampled: 04/20/07 00:00
Date Received: 04/20/07
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Aluminum, dissolved	M200.7 ICP	0.15	B	*	mg/L	0.03	0.2	04/26/07 6:16	djt
Calcium, dissolved	M200.7 ICP	0.2	B	*	mg/L	0.2	1	04/26/07 6:16	djt
Iron, dissolved	M200.7 ICP	0.04	B	*	mg/L	0.02	0.05	04/26/07 6:16	djt
Magnesium, dissolved	M200.7 ICP		U	*	mg/L	0.2	1	04/26/07 6:16	djt
Manganese, dissolved	M200.7 ICP		U	*	mg/L	0.005	0.03	04/26/07 6:16	djt
Uranium, dissolved	M200.8 ICP-MS		U	*	mg/L	0.0001	0.0005	04/24/07 2:31	scp

Report Header Explanations

<i>Batch</i>	A distinct set of samples analyzed at a specific time
<i>Found</i>	Value of the QC Type of interest
<i>Limit</i>	Upper limit for RPD, in %.
<i>Lower</i>	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
<i>MDL</i>	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
<i>PCN/SCN</i>	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
<i>PQL</i>	Practical Quantitation Limit, typically 5 times the MDL.
<i>QC</i>	True Value of the Control Sample or the amount added to the Spike
<i>Rec</i>	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
<i>RPD</i>	Relative Percent Difference, calculation used for Duplicate QC Types
<i>Upper</i>	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
<i>Sample</i>	Value of the Sample of interest

QC Sample Types

<i>AS</i>	Analytical Spike (Post Digestion)	<i>LCSWD</i>	Laboratory Control Sample - Water Duplicate
<i>ASD</i>	Analytical Spike (Post Digestion) Duplicate	<i>LFB</i>	Laboratory Fortified Blank
<i>CCB</i>	Continuing Calibration Blank	<i>LFM</i>	Laboratory Fortified Matrix
<i>CCV</i>	Continuing Calibration Verification standard	<i>LFMD</i>	Laboratory Fortified Matrix Duplicate
<i>DUP</i>	Sample Duplicate	<i>LRB</i>	Laboratory Reagent Blank
<i>ICB</i>	Initial Calibration Blank	<i>MS</i>	Matrix Spike
<i>ICV</i>	Initial Calibration Verification standard	<i>MSD</i>	Matrix Spike Duplicate
<i>ICSAB</i>	Inter-element Correction Standard - A plus B solutions	<i>PBS</i>	Prep Blank - Soil
<i>LCSS</i>	Laboratory Control Sample - Soil	<i>PBW</i>	Prep Blank - Water
<i>LCSSD</i>	Laboratory Control Sample - Soil Duplicate	<i>PQV</i>	Practical Quantitation Verification standard
<i>LCSW</i>	Laboratory Control Sample - Water	<i>SDL</i>	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	Analyte was analyzed for but not detected at the indicated MDL

Method References

(1)	EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
(2)	EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
(3)	EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
(5)	EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
(6)	Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995.

Comments

(1)	QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
(2)	Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
(3)	Animal matrices for Inorganic analyses are reported on an "as received" basis.

MWH America's Inc.

ACZ Project ID: **L62140**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L62140-01	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-02	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-03	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-04	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-05	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-06	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.

MWH America's Inc.

ACZ Project ID: **L62140**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L62140-07	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
L62140-08	WG223639	Aluminum, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
		Iron, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.
	WG223614	Manganese, dissolved	M200.7 ICP	M3	The accuracy of the spike recovery does not apply because analyte concentration in the sample is disproportionate to the spike level. The recovery of the method control sample was acceptable.

MWH America's Inc.

ACZ Project ID: **L62140**

Metals Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Aluminum, dissolved	M200.7 ICP
Calcium, dissolved	M200.7 ICP
Iron, dissolved	M200.7 ICP
Magnesium, dissolved	M200.7 ICP
Manganese, dissolved	M200.7 ICP
Uranium, dissolved	M200.8 ICP-MS

~~4917~~ L62140
122642007

Core Samples from White Mesa near Blanding UT shipped to ACZ for Leach Testing
Contact info: Doug Oliver - MWH (801-617-3224) or Ryan Jakubowski in Steamboat (970-879-6260)
Subcontract Number: 1004-A0002-87430-OMMISA CO1

Loc ID	Depth (feet bgs)
MW-30	37.5-38.0
MW-30	43.0-43.2
MW-30	43.2-43.5
MW-23	53.0-53.5
MW-23	74.0-74.3
MW-23	82.5-82.7
MW-23	99.8-100.0
MW-23	103.0-103.3

Please contact Ryan if you need any assistance with
Sample prep. Also contact Ryan to pick up any
Unused samples

Thanks,
Doug

1226 4.9.07 11:20

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Analytical Quote

Doug Oliver
MWH America's Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Page 1 of 2
4/20/2007

Quote Number: HH-LEACHATE

Matrix: Leachate 96 Hour HH Extraction Leachates for metals

Parameter	Method	Detection Limit	Cost/Sample
Metals Analysis			
Aluminum, dissolved	M200.7 ICP	0.03 mg/L	\$8.00
Calcium, dissolved	M200.7 ICP	0.2 mg/L	\$8.00
Iron, dissolved	M200.7 ICP	0.02 mg/L	\$8.00
Magnesium, dissolved	M200.7 ICP	0.2 mg/L	\$8.00
Manganese, dissolved	M200.7 ICP	0.005 mg/L	\$8.00
Uranium, dissolved	M200.8 ICP-MS	0.0001 mg/L	\$38.00
		Cost/Sample:	\$78.00

August 10, 2007

Report to:

John Mahoney
MWH America's Inc.
1801 California Street Suite 2600
Denver, CO 80202

Bill to:

Accounts Payable
MWH America's Inc.
PO Box 6610
Broomfield, CO 80021

cc: Ryan Jakubowski

Project ID:

ACZ Project ID: L64240

John Mahoney:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on August 03, 2007. This project has been assigned to ACZ's project number, L64240. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 11.0. The enclosed results relate only to the samples received under L64240. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after September 10, 2007. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



MWH America's Inc.

Project ID:

Sample ID: L61917-01

ACZ Sample ID: **L64240-01**

Date Sampled: 08/03/07 09:55

Date Received: 08/03/07

Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	1			t CaCO3/Kt	1	5	08/08/07 16:22	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.1	B	*	%	0.1	0.5	08/04/07 9:35	lwt

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Crush and Pulverize	USDA No. 1, 1972							08/03/07 14:00	lwt

MWH America's Inc.

Project ID:

Sample ID: L61917-02

ACZ Sample ID: **L64240-02**

Date Sampled: 08/03/07 09:55

Date Received: 08/03/07

Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	1			t CaCO3/Kt	1	5	08/08/07 16:22	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.1	B	*	%	0.1	0.5	08/04/07 10:07	lwt

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Crush and Pulverize	USDA No. 1, 1972							08/03/07 14:03	lwt

MWH America's Inc.

Project ID:

Sample ID: L61917-03

ACZ Sample ID: **L64240-03**

Date Sampled: 08/03/07 09:55

Date Received: 08/03/07

Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	0			t CaCO3/Kt	1	5	08/08/07 16:22	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3		U	*	%	0.1	0.5	08/04/07 10:39	lwt

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Crush and Pulverize	USDA No. 1, 1972							08/03/07 14:07	lwt

MWH America's Inc.

Project ID:

Sample ID: L61917-04

ACZ Sample ID: **L64240-04**

Date Sampled: 08/03/07 09:55

Date Received: 08/03/07

Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	08/08/07 16:23	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	08/04/07 11:11	lwt

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Crush and Pulverize	USDA No. 1, 1972							08/03/07 14:11	lwt

MWH America's Inc.

Project ID:

Sample ID: L61917-05

ACZ Sample ID: **L64240-05**

Date Sampled: 08/03/07 09:55

Date Received: 08/03/07

Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	0			t CaCO3/Kt	1	5	08/08/07 16:23	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3		U	*	%	0.1	0.5	08/04/07 11:43	lwt

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Crush and Pulverize	USDA No. 1, 1972							08/03/07 14:15	lwt

Report Header Explanations

<i>Batch</i>	A distinct set of samples analyzed at a specific time
<i>Found</i>	Value of the QC Type of interest
<i>Limit</i>	Upper limit for RPD, in %.
<i>Lower</i>	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
<i>MDL</i>	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
<i>PCN/SCN</i>	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
<i>PQL</i>	Practical Quantitation Limit, typically 5 times the MDL.
<i>QC</i>	True Value of the Control Sample or the amount added to the Spike
<i>Rec</i>	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
<i>RPD</i>	Relative Percent Difference, calculation used for Duplicate QC Types
<i>Upper</i>	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
<i>Sample</i>	Value of the Sample of interest

QC Sample Types

<i>AS</i>	Analytical Spike (Post Digestion)	<i>LCSWD</i>	Laboratory Control Sample - Water Duplicate
<i>ASD</i>	Analytical Spike (Post Digestion) Duplicate	<i>LFB</i>	Laboratory Fortified Blank
<i>CCB</i>	Continuing Calibration Blank	<i>LFM</i>	Laboratory Fortified Matrix
<i>CCV</i>	Continuing Calibration Verification standard	<i>LFMD</i>	Laboratory Fortified Matrix Duplicate
<i>DUP</i>	Sample Duplicate	<i>LRB</i>	Laboratory Reagent Blank
<i>ICB</i>	Initial Calibration Blank	<i>MS</i>	Matrix Spike
<i>ICV</i>	Initial Calibration Verification standard	<i>MSD</i>	Matrix Spike Duplicate
<i>ICSAB</i>	Inter-element Correction Standard - A plus B solutions	<i>PBS</i>	Prep Blank - Soil
<i>LCSS</i>	Laboratory Control Sample - Soil	<i>PBW</i>	Prep Blank - Water
<i>LCSSD</i>	Laboratory Control Sample - Soil Duplicate	<i>PQV</i>	Practical Quantitation Verification standard
<i>LCSW</i>	Laboratory Control Sample - Water	<i>SDL</i>	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	Analyte was analyzed for but not detected at the indicated MDL

Method References

(1)	EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
(2)	EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
(3)	EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
(5)	EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
(6)	Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995.

Comments

(1)	QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
(2)	Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
(3)	Animal matrices for Inorganic analyses are reported on an "as received" basis.

MWH America's Inc.

ACZ Project ID: **L64240**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L64240-01	WG229660	Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L64240-02	WG229660	Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L64240-03	WG229660	Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L64240-04	WG229660	Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L64240-05	WG229660	Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH America's Inc.

ACZ Project ID: **L64240**

Soil Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Neutralization Potential as CaCO₃ M600/2-78-054 3.2.3

MWH America's Inc.

ACZ Project ID: L64240
 Date Received: 8/3/2007
 Received By:
 Date Printed: 8/3/2007

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?			X
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			
11) Are the trip blanks (VOA and/or Cyanide) present?			X
12) Are samples requiring no headspace, headspace free?			X
13) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

N/A

Contact (For any discrepancies, the client must be contacted)

N/A

Shipping Containers

Cooler Id	Temp (°C)	Rad (µR/hr)
NA4111	22.3	15

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

MWH America's Inc.

ACZ Project ID: L64240
 Date Received: 8/3/2007
 Received By:

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG < 2	B < 2	O < 2	T > 12	N/A	RAD	ID
L64240-01	L61917-01									X		<input type="checkbox"/>
L64240-02	L61917-02									X		<input type="checkbox"/>
L64240-03	L61917-03									X		<input type="checkbox"/>
L64240-04	L61917-04									X		<input type="checkbox"/>
L64240-05	L61917-05									X		<input type="checkbox"/>

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH - Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: _____



Laboratories, Inc.

LG240

CHAIN of CUSTODY

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Report to:

Name: Ryan Jakubowski
 Company: MWH
 E-mail: ryan.jakubowski@mwhglobal.com

Address:
 Telephone: 970-879-6260

Copy of Report to:

Name:
 Company:

E-mail:
 Telephone:

Invoice to:

Name: Doug Oliver
 Company:
 E-mail:

Address:
 Telephone:

If sample(s) received past holding time (HT), or if insufficient HT remains to complete analysis before expiration, shall ACZ proceed with requested short HT analyses?

YES
 NO

If "NO" then ACZ will contact client for further instruction. If neither "YES" nor "NO" is indicated, ACZ will proceed with the requested analyses, even if HT is expired, and data will be qualified.

PROJECT INFORMATION

ANALYSES REQUESTED (attach list or use quote number)

Quote #:	Project/PO #:	Reporting state for compliance testing:	Sampler's Name:	Are any samples NRC licensable material?	SAMPLE IDENTIFICATION	DATE:TIME	Matrix	# of Containers									
					L61917-01	8/3/07 9:55		1									
					-02												
					-03												
					-04												
					-05												

Matrix SW (Surface Water) · GW (Ground Water) · WW (Waste Water) · DW (Drinking Water) · SL (Sludge) · SO (Soil) · OL (Oil) · Other

REMARKS/ SAMPLE DISCLOSURES

REF L61917

PAGE
 of

Please refer to ACZ's terms & conditions located on the reverse side of this COC.

RELINQUISHED BY:	DATE:TIME	RECEIVED BY:	DATE:TIME
Ryan Jakubowski	8/3/07 9:55	[Signature]	08/03/07 09:55 hrs

June 08, 2009

Report to:

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Bill to:

Accounts Payable
MWH Americas Inc.
P.O. Box 6610
Broomfield, CO 80021

Project ID: 1004445

ACZ Project ID: L75952

Betty Van Pelt:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on May 21, 2009. This project has been assigned to ACZ's project number, L75952. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 12.0. The enclosed results relate only to the samples received under L75952. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after July 08, 2009. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



Scott Habermehl has reviewed
and approved this report.



MWH Americas Inc.Project ID: 1004445
Sample ID: MW-23 82.5-82.7ACZ Sample ID: **L75952-01**
Date Sampled: 05/18/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO ₃ /Kt	1	5	06/05/09 10:07	calc
Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 10:22	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:07	brd
Crush and Pulverize	USDA No. 1, 1972							05/26/09 14:30	bjl

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-23 99.8-100.0ACZ Sample ID: **L75952-02**
Date Sampled: 05/18/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO ₃ /Kt	1	5	06/05/09 10:07	calc
Neutralization Potential as CaCO ₃	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 11:15	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:11	brd
Crush and Pulverize	USDA No. 1, 1972							05/26/09 15:06	bjl

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 103.0-103.3

ACZ Sample ID: **L75952-03**
Date Sampled: 05/18/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/05/09 10:07	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 11:42	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:15	brd
Crush and Pulverize	USDA No. 1, 1972							05/26/09 15:42	bjl

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 103.0-103.3DUP

ACZ Sample ID: **L75952-04**
Date Sampled: 05/18/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/05/09 10:07	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 12:08	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:18	brd
Crush and Pulverize	USDA No. 1, 1972							05/26/09 16:19	bjl

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit, typically 5 times the MDL.
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
Sample	Value of the Sample of interest

QC Sample Types

AS	Analytical Spike (Post Digestion)	LCSWD	Laboratory Control Sample - Water Duplicate
ASD	Analytical Spike (Post Digestion) Duplicate	LFB	Laboratory Fortified Blank
CCB	Continuing Calibration Blank	LFM	Laboratory Fortified Matrix
CCV	Continuing Calibration Verification standard	LFMD	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate	LRB	Laboratory Reagent Blank
ICB	Initial Calibration Blank	MS	Matrix Spike
ICV	Initial Calibration Verification standard	MSD	Matrix Spike Duplicate
ICSAB	Inter-element Correction Standard - A plus B solutions	PBS	Prep Blank - Soil
LCSS	Laboratory Control Sample - Soil	PBW	Prep Blank - Water
LCSSD	Laboratory Control Sample - Soil Duplicate	PQV	Practical Quantitation Verification standard
LCSW	Laboratory Control Sample - Water	SDL	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL. The associated value is an estimated quantity.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantitation limit or the sample detection limit.

Method References

- (1) EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
- (2) EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
- (3) EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
- (5) EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
- (6) Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995 & 20th edition (1998).

Comments

- (1) QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
- (2) Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
- (3) Animal matrices for Inorganic analyses are reported on an "as received" basis.

For a complete list of ACZ's Extended Qualifiers, please click:

<http://www.acz.com/public/extquallist.pdf>

MWH Americas Inc.ACZ Project ID: **L75952**

Project ID: 1004445

Neutralization Potential as CaCO₃ M600/2-78-054 3.2.3

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264688													
WG264688LCSS	LCSS	06/04/09 9:56	PCN20880	100		112.19	%	112.2	80	120			
L75952-01DUP	DUP	06/04/09 10:49			.4	.38	%				5.1	20	RA

MWH Americas Inc.

ACZ Project ID: **L75952**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L75952-01	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L75952-02	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L75952-03	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L75952-04	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH Americas Inc.

ACZ Project ID: **L75952**

Soil Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Neutralization Potential as CaCO₃

M600/2-78-054 3.2.3

MWH Americas Inc.
 1004445

ACZ Project ID: L75952
 Date Received: 5/21/2009
 Received By:
 Date Printed: 5/21/2009

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?			X
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			X
11) Is the trip blank for Cyanide present?			X
12) Is the trip blank for VOA present?			X
13) Are samples requiring no headspace, headspace free?			X
14) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

N/A

Contact (For any discrepancies, the client must be contacted)

N/A

Shipping Containers

Cooler Id	Temp (°C)	Rad (µR/hr)
NA8445	19.7	14

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

MWH Americas Inc.
 1004445

ACZ Project ID: L75952
 Date Received: 5/21/2009
 Received By:

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG < 2	B < 2	O < 2	T > 12	N/A	RAD	ID
L75952-01	MW-23 82.5-82.7									X		<input type="checkbox"/>
L75952-02	MW-23 99.8-100.0									X		<input type="checkbox"/>
L75952-03	MW-23 103.0-103.3									X		<input type="checkbox"/>
L75952-04	MW-23 103.0-103.3DUP									X		<input type="checkbox"/>

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: _____

175950

CHAIN OF CUSTODY RECORD/LAB WORK REQUEST

Chain of Custody ID _____
 Cooler ID _____ of _____
 Page _____ of _____
 Air Bill No. _____

LABORATORY ACZ
 Contact Scott H.
 MWH
 Phone (801) 617-4200 FAX (801) 617-3200
 MWH Contact Betty van Pelt, Doug Oliver
 Project Carlson Mines White Mesa
 Project Number 1004445
 Date Due _____
 Samplers Signature [Signature]

Location ID	Field Sample ID	Depth Interval (ft)
MW-23	MW-23 82.5-82.7	82.5-82.7
MW-23	MW-23 99.8-100.0	99.8-100.0
MW-23	MW-23 103.0-103.3	103.0-103.3
MW-23	MW-23 103.0-103.3 Dup	103.0-103.3

Date Collected	Time Collected	Sample Number	Matrix ^a	Sampling Technique ^b	ANALYSES REQUESTED																
					AB LOT (DDMMYYNN)	EB LOT (DDMMYYNN)	TB LOT (DDMMYYNN)														
5/18/09		50	SO	G																	
		50	SO	G																	
		50	SO	G																	
		50	SO	G																	

LABORATORY USE ONLY

SAMPLES WERE:

1 Shipped or hand delivered
 Notes: _____

2 Ambient or Chilled
 Notes: _____

3 Temperature _____

4 Received Broken/Leaking (Improperly Sealed)
 Y N
 Notes: _____

5 Properly Preserved
 Y N
 Notes: _____

6 Received Within Holding Times
 Y N
 Notes: _____

COC Tape Was:

1 Present on Outer Package
 Y N NA

2 Unbroken on Outer Package
 Y N NA

3 Present on Sample
 Y N NA

4 Unbroken on Sample
 Y N NA
 Notes: _____

Discrepancies Between Sample Labels and COC Record?
 Y N
 Notes: _____

SPECIAL INSTRUCTIONS:

Cone Penetrometer=CN
 Bladder Pump=BP
 Submersible Pump=SP
 Bailor=B
 GeoProbe=PR

Relinquished by/Affiliation _____ **Received by/Affiliation** _____

Date _____ **Time** _____

Relinquished by/Affiliation [Signature] **Received by/Affiliation** [Signature]

Date 5.21.09 **Time** 9:30

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Page 1 of 2
4/10/2009

Quote Number: HH-SOLID

Matrix: Soil HH-Solids

Parameter	Method	Detection Limit	Cost/Sample
Misc.			
Labor Charges for Sample Prep			\$45.00
Sample Preparation			
Air Dry at 34 Degrees C	USDA No. 1, 1972		\$7.00
Crush and Pulverize	USDA No. 1, 1972		\$16.50
Soil Analysis			
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	Calculation	\$0.00
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.1 %	\$14.00
		Cost/Sample:	\$82.50

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

June 22, 2009

Project ID: 1004445
ACZ Project ID: L75953

Betty Van Pelt:

Enclosed are revised analytical reports for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on May 21, 2009 and reported on September 23, 2008. Refer to the case narrative for an explanation of the changes. This project was assigned to ACZ's project number L75953. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 12.0. The enclosed results relate only to the samples received under L75953. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all the requirements of NELAC.

This report should be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after July 15, 2009. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years. Please notify your Project Manager if you have other needs.

If you have any questions, please contact your Project Manager or Customer Service Representative.



Scott Habermehl has reviewed
and approved this report.



MWH Americas Inc.

June 18, 2009

Project ID: 1004445

ACZ Project ID: L75953

Sample Receipt

ACZ Laboratories, Inc. (ACZ) received 7 soil samples from MWH Americas Inc. on May 21, 2009. The samples were received in good condition. Upon receipt, the sample custodian removed the samples from the cooler, inspected the contents, and logged the samples into ACZ's computerized Laboratory Information Management System (LIMS). The samples were assigned ACZ LIMS project number L75953. The custodian verified the sample information entered into the computer against the chain of custody (COC) forms and sample bottle labels.

Samples were received outside the EPA recommended temperature of 0-6 degrees C.

Holding Times

All analyses were performed within EPA recommended holding times.

Sample Analysis

These samples were analyzed for inorganic parameters. The individual methods are referenced on both, the ACZ invoice and the analytical reports. The extended qualifier reports may contain footnotes qualifying specific elements due to QC failures. In addition the following has been noted with this specific project:

1. The extractable Phosphorus data has been qualified with the B1 flag on the extended qualifier report. The chemist noted that a procedural contamination typically occurs in the prep blank (PBS) on this method. The PBS read at 3.4 mg/L.

MWH Americas Inc.

Project ID: 1004445
Sample ID: TS-AG1

ACZ Sample ID: **L75953-01**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digestor							06/05/09 16:21	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	11.10			meq/L	0.01	0.05	06/04/09 16:42	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	3.49			meq/L	0.02	0.08	06/04/09 16:42	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	36			mg/Kg	2	8	06/09/09 1:53	aeH
Sodium Absorption Ratio	Calculation	0.28				0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.76			meq/L	0.01	0.09	06/04/09 16:42	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	1470		*	mmhos/cm	0.001	0.01	06/01/09 18:20	mjc
Organic Matter	USDA No.60 - Method 24	0.4	B	*	%	0.3	1	06/08/09 12:16	bjl
pH, Saturated Paste	USDA No. 60 (21A)	7.7		*	units	0.1	0.1	06/01/09 18:20	mjc
Solids, Percent	CLPSOW390, PART F, D-98	93.7		*	%	0.1	0.5	06/10/09 11:34	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		42.5		*	%	0.1	0.5	06/02/09 0:00	mjc
Sand		57.5		*	%	0.1	0.5	06/02/09 0:00	mjc
Silt			U	*	%	0.1	0.5	06/02/09 0:00	mjc
Texture Classification		SC		*				06/02/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 11:22	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:22	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:09	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 0:12	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digestor	0.0299		*	%	0.0002	0.001	06/06/09 19:31	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	23		*	mg/Kg	1	5	06/10/09 21:30	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: TS-AG2

ACZ Sample ID: **L75953-02**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digester							06/05/09 17:57	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	1.99			meq/L	0.01	0.05	06/04/09 16:45	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.89			meq/L	0.02	0.08	06/04/09 16:45	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	21			mg/Kg	2	8	06/09/09 2:06	aeH
Sodium Absorption Ratio	Calculation	0.10	B			0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.13			meq/L	0.01	0.09	06/04/09 16:45	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	342		*	mmhos/cm	0.001	0.01	06/01/09 20:46	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/08/09 16:32	bjl
pH, Saturated Paste	USDA No. 60 (21A)	8.1		*	units	0.1	0.1	06/01/09 20:46	mjc
Solids, Percent	CLPSOW390, PART F, D-98	95.7		*	%	0.1	0.5	06/10/09 16:13	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		45.0		*	%	0.1	0.5	06/02/09 0:00	mjc
Sand		52.5		*	%	0.1	0.5	06/02/09 0:00	mjc
Silt		2.5		*	%	0.1	0.5	06/02/09 0:00	mjc
Texture Classification		SC		*				06/02/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 11:45	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:26	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:13	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 1:20	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester	0.0555		*	%	0.0009	0.005	06/06/09 19:34	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	10		*	mg/Kg	1	5	06/10/09 21:33	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: TS-AG3

ACZ Sample ID: **L75953-03**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digestor							06/05/09 19:33	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	1.99			meq/L	0.01	0.05	06/04/09 16:48	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.63			meq/L	0.02	0.08	06/04/09 16:48	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	25			mg/Kg	2	8	06/09/09 2:10	aeH
Sodium Absorption Ratio	Calculation	0.08	B			0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.10			meq/L	0.01	0.09	06/04/09 16:48	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	280		*	mmhos/cm	0.001	0.01	06/01/09 23:11	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/08/09 18:40	bjl
pH, Saturated Paste	USDA No. 60 (21A)	8.0		*	units	0.1	0.1	06/01/09 23:11	mjc
Solids, Percent	CLPSOW390, PART F, D-98	96.0		*	%	0.1	0.5	06/10/09 18:33	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		45.0		*	%	0.1	0.5	06/02/09 0:00	mjc
Sand		55.0		*	%	0.1	0.5	06/02/09 0:00	mjc
Silt			U	*	%	0.1	0.5	06/02/09 0:00	mjc
Texture Classification		SC		*				06/02/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 12:07	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:30	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:18	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 2:28	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digestor	0.046		*	%	0.001	0.005	06/06/09 19:36	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	57		*	mg/Kg	1	5	06/10/09 21:34	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: RF5-AG1

ACZ Sample ID: **L75953-04**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digester							06/05/09 20:21	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	1.86			meq/L	0.01	0.05	06/04/09 16:51	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.55			meq/L	0.02	0.08	06/04/09 16:51	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	11			mg/Kg	2	8	06/09/09 2:20	aeH
Sodium Absorption Ratio	Calculation	0.06	B			0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.07	B		meq/L	0.01	0.09	06/04/09 16:51	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	249		*	mmhos/cm	0.001	0.01	06/02/09 1:36	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/08/09 20:49	bjl
pH, Saturated Paste	USDA No. 60 (21A)	8.0		*	units	0.1	0.1	06/02/09 1:36	mjc
Solids, Percent	CLPSOW390, PART F, D-98	97.0		*	%	0.1	0.5	06/10/09 20:52	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		36.3		*	%	0.1	0.5	06/03/09 0:00	mjc
Sand		63.8		*	%	0.1	0.5	06/03/09 0:00	mjc
Silt			U	*	%	0.1	0.5	06/03/09 0:00	mjc
Texture Classification		SC		*				06/03/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 12:30	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:33	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:23	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 3:36	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester	0.0398		*	%	0.0009	0.005	06/06/09 19:37	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	43		*	mg/Kg	1	5	06/10/09 21:35	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: RF6-AG2

ACZ Sample ID: **L75953-05**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digester							06/05/09 21:09	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	0.97			meq/L	0.01	0.05	06/04/09 16:55	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.62			meq/L	0.02	0.08	06/04/09 16:55	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	12			mg/Kg	2	8	06/09/09 2:23	aeH
Sodium Absorption Ratio	Calculation	0.23				0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.21			meq/L	0.01	0.09	06/04/09 16:55	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	201		*	mmhos/cm	0.001	0.01	06/02/09 4:02	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/08/09 22:57	bjl
pH, Saturated Paste	USDA No. 60 (21A)	8.1		*	units	0.1	0.1	06/02/09 4:02	mjc
Solids, Percent	CLPSOW390, PART F, D-98	98.0		*	%	0.1	0.5	06/10/09 23:12	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		42.5		*	%	0.1	0.5	06/03/09 0:00	mjc
Sand		55.0		*	%	0.1	0.5	06/03/09 0:00	mjc
Silt		2.5		*	%	0.1	0.5	06/03/09 0:00	mjc
Texture Classification		SC		*				06/03/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 12:52	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:37	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:27	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 4:44	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester	0.0455		*	%	0.0009	0.005	06/06/09 19:38	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	23		*	mg/Kg	1	5	06/10/09 21:36	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: RF2-AG3

ACZ Sample ID: **L75953-06**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digester							06/05/09 21:57	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	1.1			meq/L	0.1	0.5	06/04/09 17:05	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.9			meq/L	0.2	0.8	06/04/09 17:05	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	11			mg/Kg	2	8	06/09/09 2:26	aeH
Sodium Absorption Ratio	Calculation	0.30				0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.3	B		meq/L	0.1	0.9	06/04/09 17:05	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	285		*	mmhos/cm	0.001	0.01	06/02/09 6:27	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/09/09 1:05	bjl
pH, Saturated Paste	USDA No. 60 (21A)	7.8		*	units	0.1	0.1	06/02/09 6:27	mjc
Solids, Percent	CLPSOW390, PART F, D-98	99.7		*	%	0.1	0.5	06/11/09 1:31	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		50.0		*	%	0.1	0.5	06/03/09 0:00	mjc
Sand		50.0		*	%	0.1	0.5	06/03/09 0:00	mjc
Silt			U	*	%	0.1	0.5	06/03/09 0:00	mjc
Texture Classification		SC		*				06/03/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 13:15	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:41	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:32	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 5:52	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester	0.0212		*	%	0.0002	0.001	06/06/09 19:39	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	32		*	mg/Kg	1	5	06/10/09 21:37	pjb

MWH Americas Inc.

Project ID: 1004445
Sample ID: TS-AG3 DUP

ACZ Sample ID: **L75953-07**
Date Sampled: 05/19/09 00:00
Date Received: 05/21/09
Sample Matrix: Soil

Inorganic Prep

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digester							06/05/09 22:45	ccp

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Calcium, soluble (Sat. Paste)	M6010B ICP	1.70			meq/L	0.01	0.05	06/04/09 17:08	aeH
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.60			meq/L	0.02	0.08	06/04/09 17:08	aeH
Potassium, extractable (AB-DTPA)	M6010B ICP	22			mg/Kg	2	8	06/09/09 2:30	aeH
Sodium Absorption Ratio	Calculation	0.10	B			0.03	0.15	06/18/09 0:00	calc
Sodium, soluble (Sat. Paste)	M6010B ICP	0.11			meq/L	0.01	0.09	06/04/09 17:08	aeH

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Conductivity @25C	SM2510B	241		*	mmhos/cm	0.001	0.01	06/02/09 8:53	mjc
Organic Matter	USDA No.60 - Method 24		U	*	%	0.3	1	06/09/09 3:13	bjl
pH, Saturated Paste	USDA No. 60 (21A)	8.0		*	units	0.1	0.1	06/02/09 8:53	mjc
Solids, Percent	CLPSOW390, PART F, D-98	96.2		*	%	0.1	0.5	06/11/09 3:51	brd/mjc
Texture by Hydrometer	ASTM D 422 Hydrometer								
Clay		42.5		*	%	0.1	0.5	06/03/09 0:00	mjc
Sand		57.5		*	%	0.1	0.5	06/03/09 0:00	mjc
Silt			U	*	%	0.1	0.5	06/03/09 0:00	mjc
Texture Classification		SC		*				06/03/09 0:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
AB-DPTA Extraction	ASA No.9, 3-5.2.3							06/08/09 13:37	mjc
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/23/09 11:45	brd
Saturated Paste Extraction	USDA No. 60 (2)							06/01/09 16:36	brd
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2							05/29/09 7:00	bjl

Wet Chemistry

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester	0.051		*	%	0.001	0.005	06/06/09 19:42	pjb
Phosphorus, extractable (AB-DTPA) Acid	M365.1 - Automated Ascorbic Acid	18		*	mg/Kg	1	5	06/10/09 21:38	pjb

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit, typically 5 times the MDL.
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
Sample	Value of the Sample of interest

QC Sample Types

AS	Analytical Spike (Post Digestion)	LCSWD	Laboratory Control Sample - Water Duplicate
ASD	Analytical Spike (Post Digestion) Duplicate	LFB	Laboratory Fortified Blank
CCB	Continuing Calibration Blank	LFM	Laboratory Fortified Matrix
CCV	Continuing Calibration Verification standard	LFMD	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate	LRB	Laboratory Reagent Blank
ICB	Initial Calibration Blank	MS	Matrix Spike
ICV	Initial Calibration Verification standard	MSD	Matrix Spike Duplicate
ICSAB	Inter-element Correction Standard - A plus B solutions	PBS	Prep Blank - Soil
LCSS	Laboratory Control Sample - Soil	PBW	Prep Blank - Water
LCSSD	Laboratory Control Sample - Soil Duplicate	PQV	Practical Quantitation Verification standard
LCSW	Laboratory Control Sample - Water	SDL	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL. The associated value is an estimated quantity.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantitation limit or the sample detection limit.

Method References

- (1) EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
- (2) EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
- (3) EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
- (5) EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
- (6) Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995 & 20th edition (1998).

Comments

- (1) QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
- (2) Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
- (3) Animal matrices for Inorganic analyses are reported on an "as received" basis.

For a complete list of ACZ's Extended Qualifiers, please click:

<http://www.acz.com/public/extquallist.pdf>

MWH Americas Inc.
 Project ID: 1004445

ACZ Project ID: **L75953**

Calcium, soluble (Sat. Paste) M6010B ICP

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264738													
WG264738ICV	ICV	06/04/09 16:19	II090507-1	100		95.78	mg/L	95.8	90	110			
WG264738ICB	ICB	06/04/09 16:22				U	mg/L		-0.6	0.6			
WG264738PQV	PQV	06/04/09 16:25	II090602-2	1		1.03	mg/L	103	70	130			
WG264738ICSAB1	ICSAB	06/04/09 16:28	II090421-2	250		232.07	mg/L	92.8	80	120			
L75908-01DUP	DUP	06/04/09 16:38			26.5	26.319	meq/L				0.7	20	
WG264738CCV1	CCV	06/04/09 16:58	II090507-2	50		47.07	mg/L	94.1	90	110			
WG264738CCB1	CCB	06/04/09 17:01				U	mg/L		-0.6	0.6			
WG264738CCV2	CCV	06/04/09 17:11	II090507-2	50		47.62	mg/L	95.2	90	110			
WG264738CCB2	CCB	06/04/09 17:14				U	mg/L		-0.6	0.6			

Conductivity @25C SM2510B

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264499													
L75908-01DUP	DUP	06/01/09 15:55			2740	2750	nmhos/cm				0.4	20	

Magnesium, soluble (Sat. Paste) M6010B ICP

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264738													
WG264738ICV	ICV	06/04/09 16:19	II090507-1	100		96.61	mg/L	96.6	90	110			
WG264738ICB	ICB	06/04/09 16:22				U	mg/L		-0.6	0.6			
WG264738PQV	PQV	06/04/09 16:25	II090602-2	1.001		1.04	mg/L	103.9	70	130			
WG264738ICSAB1	ICSAB	06/04/09 16:28	II090421-2	250.25		239.78	mg/L	95.8	80	120			
L75908-01DUP	DUP	06/04/09 16:38			6.01	5.958	meq/L				0.9	20	
WG264738CCV1	CCV	06/04/09 16:58	II090507-2	50		47.04	mg/L	94.1	90	110			
WG264738CCB1	CCB	06/04/09 17:01				U	mg/L		-0.6	0.6			
WG264738CCV2	CCV	06/04/09 17:11	II090507-2	50		47.64	mg/L	95.3	90	110			
WG264738CCB2	CCB	06/04/09 17:14				U	mg/L		-0.6	0.6			

Nitrogen, total Kjeldahl M351.2 - TKN by Block Digester

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264842													
WG264842ICV	ICV	06/06/09 17:24	WI090512-2	4.136		3.84	mg/L	92.8	90	110			
WG264842ICB	ICB	06/06/09 17:25				U	mg/L		-0.3	0.3			
WG264844													
WG264844ICV	ICV	06/06/09 19:27	WI090512-2	4.136		4.18	mg/L	101.1	90	110			
WG264844ICB	ICB	06/06/09 19:28				U	mg/L		-0.3	0.3			
WG264808PBS	PBS	06/06/09 19:29				U	%		-0.0006	0.0006			
WG264808LFB	LFB	06/06/09 19:30	WI090604-2	2.5		2.28	%	91.2	85	115			
L75953-01MS	MS	06/06/09 19:32	WI090604-2	.005	.0299	.03429	%	87.8	75	125			
L75953-02DUP	DUP	06/06/09 19:35			.0555	.05669	%				2.1	20	
WG264844CCV1	CCV	06/06/09 19:40	WI090529-5	5		5.1	mg/L	102	90	110			
WG264844CCB1	CCB	06/06/09 19:41				U	mg/Kg		-0.3	0.3			
WG264844CCV2	CCV	06/06/09 19:45	WI090529-5	5		4.95	mg/L	99	90	110			
WG264844CCB2	CCB	06/06/09 19:46				U	mg/Kg		-0.3	0.3			

MWH Americas Inc.
 Project ID: 1004445

ACZ Project ID: **L75953**

Organic Matter

USDA No.60 - Method 24

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264764													
WG264764LCSS	LCSS	06/08/09 8:00	PCN3174	2		1.95	%	97.5					
WG264764PBS	PBS	06/08/09 10:08				U	%		-0.3	0.3			
L75953-01DUP	DUP	06/08/09 14:24			.4	.49	%				20.2	20	RA
WG264764CCB	CCB	06/09/09 5:21				U	%		-0.3	0.3			
WG264764CCV	CCV	06/09/09 7:30	PCN182	2		1.85	%	92.5	90	110			

Percent Clay

ASTM D 422 Hydrometer

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264535													
L75953-07DUP	DUP	06/03/09 16:00			42.5	45	%				5.7	20	

Percent Sand

ASTM D 422 Hydrometer

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264535													
L75953-07DUP	DUP	06/03/09 16:00			57.5	55	%				4.4	20	

Percent Silt

ASTM D 422 Hydrometer

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264535													
L75953-07DUP	DUP	06/03/09 16:00			U	U	%				0	20	RA

pH, Saturated Paste

USDA No. 60 (21A)

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264499													
L75908-01DUP	DUP	06/01/09 15:55			7.8	7.9	units				1.3	20	

Phosphorus, extractable (AB-DTPA)

M365.1 - Automated Ascorbic Acid

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG265007													
WG265007ICV	ICV	06/10/09 21:26	WI090317-4	.65228		.709	mg/L	108.7	90	110			
WG265007ICB	ICB	06/10/09 21:27				U	mg/L		-0.03	0.03			
WG265007LFB	LFB	06/10/09 21:28	WI090605-2	.5		.5	mg/L	100	90	110			
WG264627PBS	PBS	06/10/09 21:29				3.4	mg/L		-3	3			B1
L75953-01AS	AS	06/10/09 21:31	WI090605-2	50	23	65.3	mg/L	84.6	90	110			M2
WG265007CCV1	CCV	06/10/09 21:39	WI090605-2	.5		.514	mg/L	102.8	90	110			
WG265007CCB1	CCB	06/10/09 21:40				U	mg/L		-0.03	0.03			
L75953-07DUP	DUP	06/10/09 21:41			18	10.9	mg/L				49.1	20	RD
WG265007CCV2	CCV	06/10/09 21:44	WI090605-2	.5		.515	mg/L	103	90	110			
WG265007CCB2	CCB	06/10/09 21:45				U	mg/L		-0.03	0.03			

MWH Americas Inc.
 Project ID: 1004445

ACZ Project ID: **L75953**

Potassium, extractable (AB-DTPA) M6010B ICP

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264896													
WG264896ICV	ICV	06/09/09 1:34	II090507-1	20		19.86	mg/L	99.3	90	110			
WG264896ICB	ICB	06/09/09 1:37				U	mg/L		-0.9	0.9			
WG264896PQV	PQV	06/09/09 1:40	II090602-2	1.5		1.43	mg/L	95.3	70	130			
WG264896ICSABI	ICSAB	06/09/09 1:43	II090421-2	25		25.1	mg/L	100.4	80	120			
WG264627PBS	PBS	06/09/09 1:50				U	mg/L		-6	6			
L75953-01SDL	SDL	06/09/09 1:57			36	36	mg/L				0	10	
L75953-01AS	AS	06/09/09 2:00	II090526-2	498.8093	36	548.1	mg/L	102.7	75	125			
L75953-01ASD	ASD	06/09/09 2:03	II090526-2	498.8093	36	542.1	mg/L	101.5	75	125	1.1	20	
WG264896CCV1	CCV	06/09/09 2:13	II090507-2	10		10.12	mg/L	101.2	90	110			
WG264896CCB1	CCB	06/09/09 2:16				U	mg/L		-0.9	0.9			
L75953-07DUP	DUP	06/09/09 2:33			22	21.4	mg/L				2.8	20	
WG264896CCV2	CCV	06/09/09 2:36	II090507-2	10		10.15	mg/L	101.5	90	110			
WG264896CCB2	CCB	06/09/09 2:40				U	mg/L		-0.9	0.9			

Sodium, soluble (Sat. Paste) M6010B ICP

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264738													
WG264738ICV	ICV	06/04/09 16:19	II090507-1	100		97.68	mg/L	97.7	90	110			
WG264738ICB	ICB	06/04/09 16:22				U	mg/L		-0.9	0.9			
WG264738PQV	PQV	06/04/09 16:25	II090602-2	1.5		1.52	mg/L	101.3	70	130			
WG264738ICSABI	ICSAB	06/04/09 16:28	II090421-2	25		24.69	mg/L	98.8	80	120			
L75908-01DUP	DUP	06/04/09 16:38			4.34	4.04	meq/L				7.2	20	
WG264738CCV1	CCV	06/04/09 16:58	II090507-2	50		47.36	mg/L	94.7	90	110			
WG264738CCB1	CCB	06/04/09 17:01				U	mg/L		-0.9	0.9			
WG264738CCV2	CCV	06/04/09 17:11	II090507-2	50		48.22	mg/L	96.4	90	110			
WG264738CCB2	CCB	06/04/09 17:14				U	mg/L		-0.9	0.9			

Solids, Percent CLPSOW390, PART F, D-98

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG265024													
WG265024PBS	PBS	06/10/09 9:15				U	%		99.9	100.1			
L75953-01DUP	DUP	06/10/09 13:54			93.7	93.96	%				0.3	20	

MWH Americas Inc.

ACZ Project ID: **L75953**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L75953-01	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
			M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.
L75953-02	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
			M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.
L75953-03	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
			M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.
L75953-04	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
			M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.
L75953-05	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
			M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.

MWH Americas Inc.

ACZ Project ID: **L75953**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L75953-06	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
			M365.1 - Automated Ascorbic Acid	DA	Sample required dilution due to reactivity.
			M365.1 - Automated Ascorbic Acid	M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.
		M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.	
L75953-07	WG264764	Organic Matter	USDA No.60 - Method 24	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG264535	Silt	ASTM D 422 Hydrometer	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
	WG265007	Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	B1	Target analyte detected in prep / method blank at or above the method reporting limit. See Case Narrative.
M365.1 - Automated Ascorbic Acid			DA	Sample required dilution due to reactivity.	
M365.1 - Automated Ascorbic Acid			M2	Matrix spike recovery was low, the recovery of the associated control sample (LCS or LFB) was acceptable.	
		M365.1 - Automated Ascorbic Acid	RD	For a solid matrix, the duplicate RPD (spike or matrix) exceeded the control limit, which is attributable to the non-homogeneity of the sample.	

MWH Americas Inc.

ACZ Project ID: **L75953**

Soil Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Conductivity @25C	SM2510B
Organic Matter	USDA No.60 - Method 24
pH, Saturated Paste	USDA No. 60 (21A)
Solids, Percent	CLPSOW390, PART F, D-98
Texture by Hydrometer	ASTM D 422 Hydrometer

Wet Chemistry

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digester
Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid

MWH Americas Inc.
 1004445

ACZ Project ID: L75953
 Date Received: 5/21/2009
 Received By: gac
 Date Printed: 5/24/2009

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?			X
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			X
11) Are the trip blanks (VOA and/or Cyanide) present?			X
12) Are samples requiring no headspace, headspace free?			X
13) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

N/A

Contact (For any discrepancies, the client must be contacted)

N/A

Shipping Containers

Cooler Id	Temp (°C)	Rad (µR/hr)
NA8446	15.1	13

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

MWH Americas Inc.
 1004445

ACZ Project ID: L75953
 Date Received: 5/21/2009
 Received By:

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG < 2	B < 2	O < 2	T > 12	N/A	RAD	ID
L75953-01	TS-AG1									X		<input type="checkbox"/>
L75953-02	TS-AG2									X		<input type="checkbox"/>
L75953-03	TS-AG3									X		<input type="checkbox"/>
L75953-04	RF5-AG1									X		<input type="checkbox"/>
L75953-05	RF6-AG2									X		<input type="checkbox"/>
L75953-06	RF2-AG3									X		<input type="checkbox"/>
L75953-07	TS-AG3 DUP									X		<input type="checkbox"/>

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: gac

175953

CHAIN OF CUSTODY RECORD/LAB WORK REQUEST

Chain of Custody ID _____
 Cooler ID _____ of _____
 Page _____ of _____
 Air Bill No. _____

LABORATORY ACZ
 Contact Scott H.
 MWH
 Phone (801) 617-4200 FAX (801) 617-3200
 MWH Contact Betty Von Pelt, Doug Oliver
 Project 100445 Denison Mines White Mesa
 Project Number 100445
 Date Due _____
 Samplers Signature Ryan T. Jewell

LABORATORY USE ONLY	
SAMPLES WERE:	1 Shipped or hand delivered Notes: 2 Ambient or Chilled Notes: 3 Temperature _____ 4 Received Broken/Leaking (Improperly Sealed) Y N Notes: 5 Properly Preserved Y N Notes: 6 Received Within Holding Times Y N Notes:
COC Tape Was:	1 Present on Outer Package Y N NA 2 Unbroken on Outer Package Y N NA 3 Present on Sample Y N NA 4 Unbroken on Sample Y N NA Notes: Discrepancies Between Sample Labels and COC Record? Y N Notes:

Location ID	Field Sample ID	Depth Interval (ft)	Date Collected	Time Collected	Sample Number	Matrix ^a	Sampling Technique ^b	ANALYSES REQUESTED							
								Hydrometers	pH	EC	Organic Matter	Nutrients (N, P, K)	SAR	AB LOT (DDMMYYNN)	EB LOT (DDMMYYNN)
	TS-AG1	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	TS-AG2	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	TS-AG3	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	RF5-AG1	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	RF6-AG2	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	RF2-AG3	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			
	TS-AG3 Dup	0.5-1.0	5/19/09		50	G	G	X	X	X	X	X			

SPECIAL INSTRUCTIONS:

^a Matrix: WG - Ground Water EPTCLP Leachate
 LF - Trip Blank
 SE - Sediment AA - Air EB - Equipment Blanks
 WS - Surface Water SW - Wipe WW - Wastewater
^b Sampling Technique: Cone Penetrometer=CN
 Composite=C Bladder Pump=BP
 Grab=G Submersible Pump=SP
 Hand Auger=HA Bailee=B
 Peristaltic Pump=PP GeoProbe=PR

Relinquished by/Affiliation	Received by/Affiliation	Date	Time
<u>Ryan T. Jewell / MWH</u>	<u>Scott H. / ACZ</u>	<u>5/19/09</u>	<u>9:30</u>

Accounts Payable
MWH Americas Inc.
P.O. Box 6610
Broomfield, CO 80021

Page 1 of 2
5/15/2009

Quote Number: DENISON-REVEG

Matrix: Soil Denison Mines project

Parameter	Method	Detection Limit	Cost/Sample
Inorganic Prep			
Nitrogen, total Kjeldahl Prep	M351.2 - Block Digestor		\$0.00
Metals Analysis			
Calcium, soluble (Sat. Paste)	M6010B ICP	0.2 meq/L	\$9.00
Magnesium, soluble (Sat. Paste)	M6010B ICP	0.2 meq/L	\$9.00
Potassium, extractable (AB-DTPA)	M6010B ICP	0.3 mg/Kg	\$9.00
Sodium Absorption Ratio	Calculation	Calculation	\$0.00
Sodium, soluble (Sat. Paste)	M6010B ICP	0.3 meq/L	\$9.00
Misc.			
Electronic Data Deliverable			\$0.00
Quality Control Summary			\$0.00
Sample Preparation			
AB-DPTA Extraction	ASA No.9, 3-5.2.3		\$10.00
Air Dry at 34 Degrees C	USDA No. 1, 1972		\$7.00
Saturated Paste Extraction	USDA No. 60 (2)		\$16.00
Sieve-2000 um (2.0mm)	ASA No.9, 15-4.2.2		\$11.00
Soil Analysis			
Conductivity @25C	SM2510B	0.001 mmhos/cm	\$7.00
Organic Matter	USDA No.60 - Method 24	0.3 %	\$20.00
pH, Saturated Paste	USDA No. 60 (21A)	0.1 units	\$7.00
Texture by Hydrometer	ASTM D 422 Hydrometer	0.1 %	\$17.00
Wet Chemistry			
Nitrogen, total Kjeldahl	M351.2 - TKN by Block Digestor	0.1 %	\$23.00
Phosphorus, extractable (AB-DTPA)	M365.1 - Automated Ascorbic Acid	0.01 mg/Kg	\$16.00
		Cost/Sample:	\$170.00

Pricing includes standard deliverables and turnaround. Includes a QC Summary and default electronic data deliverable. Method detection limits are estimates and may be elevated depending on sample matrix.

June 18, 2009

Report to:

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Bill to:

Accounts Payable
MWH Americas Inc.
P.O. Box 6610
Broomfield, CO 80021

Project ID: 1004445

ACZ Project ID: L76007

Betty Van Pelt:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on May 22, 2009. This project has been assigned to ACZ's project number, L76007. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 12.0. The enclosed results relate only to the samples received under L76007. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after July 18, 2009. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



Scott Habermehl has reviewed
and approved this report.



MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 49.3-49.5

ACZ Sample ID: **L76007-01**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 10:43	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	6			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.6		*	%	0.1	0.5	06/04/09 12:35	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:36	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 16:55	bjl
ICP 3052 Digestion	M3052							06/12/09 12:50	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 63.8-64.0

ACZ Sample ID: **L76007-02**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 10:48	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	5			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.5		*	%	0.1	0.5	06/04/09 13:01	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:40	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 17:32	bjl
ICP 3052 Digestion	M3052							06/12/09 15:20	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 89.9-90.0

ACZ Sample ID: **L76007-03**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 10:49	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 13:28	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:43	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 18:08	bjl
ICP 3052 Digestion	M3052							06/12/09 16:10	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-30 53.9-54.0

ACZ Sample ID: **L76007-04**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 10:51	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	9			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.9		*	%	0.1	0.5	06/04/09 13:54	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:46	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 18:45	bjl
ICP 3052 Digestion	M3052							06/12/09 17:00	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-30 59.8-60.0

ACZ Sample ID: **L76007-05**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	1	B	*	mg/Kg	1	6	06/17/09 10:54	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	6			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.6		*	%	0.1	0.5	06/04/09 14:21	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:50	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 19:21	bjl
ICP 3052 Digestion	M3052							06/15/09 13:21	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-30 50.0-50.2

ACZ Sample ID: **L76007-06**
Date Sampled: 05/18/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	2	B	*	mg/Kg	1	6	06/17/09 10:59	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	5			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.5	B	*	%	0.1	0.5	06/04/09 14:47	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:53	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 19:58	bjl
ICP 3052 Digestion	M3052							06/15/09 13:43	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-30 31.3-31.5

ACZ Sample ID: **L76007-07**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:01	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	69			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	6.9		*	%	0.1	0.5	06/08/09 15:45	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 9:57	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 20:34	bjl
ICP 3052 Digestion	M3052							06/15/09 14:05	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 68.9-69.3

ACZ Sample ID: **L76007-08**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:04	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	182			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	18.2		*	%	0.1	0.5	06/08/09 17:15	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:00	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 21:11	bjl
ICP 3052 Digestion	M3052							06/15/09 14:27	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-23 59.3-59.5

ACZ Sample ID: **L76007-09**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:06	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	12			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	1.2		*	%	0.1	0.5	06/04/09 15:14	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:04	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 21:47	bjl
ICP 3052 Digestion	M3052							06/15/09 14:49	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 29.7-29.9

ACZ Sample ID: **L76007-10**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	3	B	*	mg/Kg	1	6	06/17/09 11:11	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 15:40	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:07	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 22:24	bjl
ICP 3052 Digestion	M3052							06/15/09 15:54	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 34.9-35.1

ACZ Sample ID: **L76007-11**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:13	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 16:07	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:11	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 23:00	bjl
ICP 3052 Digestion	M3052							06/15/09 16:16	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 40.0-40.2

ACZ Sample ID: **L76007-12**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:14	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 16:33	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:14	bjl
Crush and Pulverize	USDA No. 1, 1972							05/26/09 23:37	bjl
ICP 3052 Digestion	M3052							06/15/09 16:38	brd/as

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 44.7-44.9

ACZ Sample ID: **L76007-13**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/17/09 11:19	erf

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/18/09 10:00	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/04/09 16:59	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:18	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 0:13	bjl
ICP 3052 Digestion	M3052							06/15/09 16:59	brd/as

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit, typically 5 times the MDL.
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
Sample	Value of the Sample of interest

QC Sample Types

AS	Analytical Spike (Post Digestion)	LCSWD	Laboratory Control Sample - Water Duplicate
ASD	Analytical Spike (Post Digestion) Duplicate	LFB	Laboratory Fortified Blank
CCB	Continuing Calibration Blank	LFM	Laboratory Fortified Matrix
CCV	Continuing Calibration Verification standard	LFMD	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate	LRB	Laboratory Reagent Blank
ICB	Initial Calibration Blank	MS	Matrix Spike
ICV	Initial Calibration Verification standard	MSD	Matrix Spike Duplicate
ICSAB	Inter-element Correction Standard - A plus B solutions	PBS	Prep Blank - Soil
LCSS	Laboratory Control Sample - Soil	PBW	Prep Blank - Water
LCSSD	Laboratory Control Sample - Soil Duplicate	PQV	Practical Quantitation Verification standard
LCSW	Laboratory Control Sample - Water	SDL	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL. The associated value is an estimated quantity.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantitation limit or the sample detection limit.

Method References

- (1) EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
- (2) EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
- (3) EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
- (5) EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
- (6) Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995 & 20th edition (1998).

Comments

- (1) QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
- (2) Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
- (3) Animal matrices for Inorganic analyses are reported on an "as received" basis.

For a complete list of ACZ's Extended Qualifiers, please click:

<http://www.acz.com/public/extquallist.pdf>

MWH Americas Inc.
 Project ID: 1004445

ACZ Project ID: **L76007**

Neutralization Potential as CaCO3 M600/2-78-054 3.2.3

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264688													
WG264688LCSS	LCSS	06/04/09 9:56	PCN20880	100		112.19	%	112.2	80	120			
L75952-01DUP	DUP	06/04/09 10:49			.4	.38	%				5.1	20	RA
WG264898													
WG264898LCSS	LCSS	06/08/09 15:00	PCN20880	100		96.26	%	96.3	80	120			
L76007-07DUP	DUP	06/08/09 16:30			6.9	6.51	%				5.8	20	

Uranium, total (3052) M6020 ICP-MS

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG265312													
WG265312ICV	ICV	06/17/09 10:33	MS090604-1	.05		.05234	mg/L	104.7	90	110			
WG265312ICB	ICB	06/17/09 10:35				.00019	mg/L		-0.0003	0.0003			
WG265312ICSA	ICSA	06/17/09 10:36				U	mg/L		-0.0005	0.0005			
WG265312ICSAB	ICSAB	06/17/09 10:38	MS090526-7	.02		.02093	mg/L	104.7	80	120			
WG265187PBS	PBS	06/17/09 10:41				U	mg/Kg		-3	3			
WG265296PBS	PBS	06/17/09 10:53				U	mg/Kg		-3	3			
WG265312CCV1	CCV	06/17/09 10:56	MS090604-1	.05		.05036	mg/L	100.7	90	110			
WG265312CCB1	CCB	06/17/09 10:58				.00012	mg/L		-0.0003	0.0003			
L76007-07SDL	SDL	06/17/09 11:02			U	U	mg/Kg					10	
L76007-09MS	MS	06/17/09 11:08	MS25XSOIL	62.65	U	46.2	mg/Kg	73.7	75	125			MA
L76007-09MSD	MSD	06/17/09 11:09	MS25XSOIL	62.65	U	48.6	mg/Kg	77.6	75	125	5.06	20	
WG265312CCV2	CCV	06/17/09 11:16	MS090604-1	.05		.05029	mg/L	100.6	90	110			
WG265312CCB2	CCB	06/17/09 11:18				U	mg/L		-0.0003	0.0003			
WG265312CCV3	CCV	06/17/09 11:21	MS090604-1	.05		.04983	mg/L	99.7	90	110			
WG265312CCB3	CCB	06/17/09 11:23				.00022	mg/L		-0.0003	0.0003			

MWH Americas Inc.

ACZ Project ID: **L76007**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76007-01	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-02	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-03	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-04	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-05	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-06	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH Americas Inc.

ACZ Project ID: **L76007**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76007-07	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
L76007-08	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
L76007-09	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264688	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-10	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-11	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-12	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76007-13	WG265312	Uranium, total (3052)	M6020 ICP-MS	MA	Recovery for either the spike or spike duplicate was outside of the acceptance limits; the RPD was within the acceptance limits.
			M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
			M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH Americas Inc.

ACZ Project ID: **L76007**

Metals Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Uranium, total (3052)

M6020 ICP-MS

Soil Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Neutralization Potential as CaCO₃

M600/2-78-054 3.2.3

MWH Americas Inc.
 1004445

ACZ Project ID: L76007
 Date Received: 5/22/2009
 Received By:
 Date Printed: 5/22/2009

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?	X		
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			X
11) Is the trip blank for Cyanide present?			X
12) Is the trip blank for VOA present?			X
13) Are samples requiring no headspace, headspace free?			X
14) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

N/A

Contact (For any discrepancies, the client must be contacted)

N/A

Shipping Containers

Cooler Id	Temp (°C)	Rad (µR/hr)
NA8444	13.5	14

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

MWH Americas Inc.
 1004445

ACZ Project ID: L76007
 Date Received: 5/22/2009
 Received By:

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG < 2	B < 2	O < 2	T > 12	N/A	RAD	ID
L76007-01	MW-23 49.3-49.5									X		<input type="checkbox"/>
L76007-02	MW-23 63.8-64.0									X		<input type="checkbox"/>
L76007-03	MW-23 89.9-90.0									X		<input type="checkbox"/>
L76007-04	MW-30 53.9-54.0									X		<input type="checkbox"/>
L76007-05	MW-30 59.8-60.0									X		<input type="checkbox"/>
L76007-06	MW-30 50.0-50.2									X		<input type="checkbox"/>
L76007-07	MW-30 31.3-31.5									X		<input type="checkbox"/>
L76007-08	MW-23 68.9-69.3									X		<input type="checkbox"/>
L76007-09	MW-23 59.3-59.5									X		<input type="checkbox"/>
L76007-10	MW-24 29.7-29.9									X		<input type="checkbox"/>
L76007-11	MW-24 34.9-35.1									X		<input type="checkbox"/>
L76007-12	MW-24 40.0-40.2									X		<input type="checkbox"/>
L76007-13	MW-24 44.7-44.9									X		<input type="checkbox"/>

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: _____

176007

CHAIN OF CUSTODY RECORD/LAB WORK REQUEST

Chain of Custody ID _____
 Cooler ID _____ of _____
 Page _____ of _____
 Air Bill No. _____

LABORATORY ACZ
 Contact Scott H
 MWH
 Phone (801) 617-4200 FAX (801) 617-3200
 MWH Contact Beth Van Relt, Doug Oliver
 Project Denison Mines White Mesa
 Project Number 1004445
 Date Due _____
 Samplers Signature Peggy-Judith

Location ID	Field Sample ID	Depth Interval (ft)	Date Collected	Time Collected	Sample Number	Matrix ^a	Sampling Technique ^b	ANALYSES REQUESTED										LABORATORY USE ONLY
								AB LOT (DDMMYYNN)	EB LOT (DDMMYYNN)	TB LOT (DDMMYYNN)								
MW-23	MW-23 49.3 - 49.5	49.3-49.5	5/18/09				X AND Fe & HFO	X										1 Shipped or hand delivered Notes:
MW-23	MW-23 63.8 - 64.0	63.8-64.0																2 Ambient or Chilled Notes:
MW-23	MW-23 89.9 - 90.0	89.9-90.0																3 Temperature _____
MW-30	MW-30 53.9 - 54.0	53.9-54.0																4 Received Broken/Leaking (Improperly Sealed) Y N Notes:
MW-30	MW-30 59.8 - 60.0	59.8-60.0																5 Properly Preserved Y N Notes:
MW-30	MW-30 50.0 - 50.2	50.0-50.2																6 Received Within Holding Times Y N Notes:
MW-30	MW-30 31.3 - 31.5	31.3-31.5	5/19/09															COC Tape Was:
MW-23	MW-23 68.9 - 69.3	68.9-69.3																1 Present on Outer Package Y N NA
MW-23	MW-23 59.3 - 59.5	59.3-59.5																2 Unbroken on Outer Package Y N NA
MW-24	MW-24 29.7 - 29.9	29.7-29.9																3 Present on Sample Y N NA
MW-24	MW-24 34.9 - 35.1	34.9-35.1																4 Unbroken on Sample Y N NA Notes:
MW-24	MW-24 40.0 - 40.2	40.0-40.2																Discrepancies Between Sample Labels and COC Record? Y N Notes:
MW-24	MW-24 44.7 - 44.9	44.7-44.9																

^a Matrix: WG - Ground Water EP/TCLP Leachate
 SO - Soil LF - Trip Blank, WQ - Trip Blank, Composite=C
 SE - Sediment AA - Air EB - Equipment Blanks Grab=C
 WS - Surface Water SW - Wipe WW - Wastewater Hand Auger=HA
 Paristatic Pump=PP
^b Sampling Technique: Cone Penetrometer=CN
 Bladder Pump=BP
 Submersible Pump=SP
 Bail=B
 GeoProbe=PR

Relinquished by/Affiliation	Received by/Affiliation	Date	Time
<u>Peggy-Judith / mwh</u>	<u>Scott H</u>	<u>5/20/09</u>	<u>9:30</u>

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Page 1 of 2
4/10/2009

Quote Number: HH-SOLID

Matrix: Soil HH-Solids

Parameter	Method	Detection Limit	Cost/Sample
Misc.			
Labor Charges for Sample Prep			\$45.00
Sample Preparation			
Air Dry at 34 Degrees C	USDA No. 1, 1972		\$7.00
Crush and Pulverize	USDA No. 1, 1972		\$16.50
Soil Analysis			
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	Calculation	\$0.00
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.1 %	\$14.00
		Cost/Sample:	\$82.50

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Analytical
Quote

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Page 2 of 2
4/10/2009

Quote Number: HH-SOLID

Pricing includes shipment of all standard sample containers and related paperwork by UPS Ground Service. Please allow three to five days for delivery when ordering containers. ACZ must be notified prior to receiving samples of all special requests such as electronic data deliverables or special reporting requirements. The client will be charged for special sample containers or express shipping and additional charges may apply for non-standard requests.

This quotation is valid for six months from the bid date unless specified otherwise in the bid. All bids must be signed and returned to ACZ before project(s) is received. The authorized signature represents acceptance of the pricing as well as the general terms and conditions of ACZ Laboratories, Inc. Our general terms and conditions can be downloaded from our web site at <http://www.acz.com/eservices/download.html>. Please note that MDL's in this quote may possibly increase due to sample matrix or samples with high TDS.

All orders that require shipping of coolers are subject to a minimum charge of \$200.00. Local orders without shipping are subject to a minimum charge of \$125.00. Samples may incur a \$10.00/sample disposal fee for any samples deemed to be hazardous.

ACZ Representative (Authorized signature and date) _____

Client Representative (Authorized signature and date) _____

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Analytical Quote

Doug Oliver
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Page 1 of 2
4/20/2007

Quote Number: HH-LEACHATE

Matrix: Leachate 96 Hour HH Extraction Leachates for metals

Parameter	Method	Detection Limit	Cost/Sample
Metals Analysis			
Aluminum, dissolved	M200.7 ICP	0.03 mg/L	\$9.00
Calcium, dissolved	M200.7 ICP	0.2 mg/L	\$9.00
Iron, dissolved	M200.7 ICP	0.02 mg/L	\$9.00
Magnesium, dissolved	M200.7 ICP	0.2 mg/L	\$9.00
Manganese, dissolved	M200.7 ICP	0.005 mg/L	\$9.00
Uranium, dissolved	M200.8 ICP-MS	0.0001 mg/L	\$38.00
		Cost/Sample:	\$83.00

HH_leach_procedure_2007.txt

Hydroxylamine-hydrochloride (HH) extractions at 50°C. 200 g of 0.25M NH₂OH·HCl in 0.25M HCl at 50°C shall be added to 10 g of crushed sample (<3 mm) in a 250 mL bottle and placed in a water bath at 50±2°C. The bottles shall be shaken by hand (end over end) at least once per day, or a shaking water bath may be employed. After 96 hr, a sample of the extract shall be withdrawn and filtered (0.45 µm). The extract shall be analyzed for iron, ~~manganese, aluminum, calcium and magnesium~~. Concentrations shall be calculated back to the solid composition and reported in mass/mass units (mg/Kg ~~or µg/g~~).

Analytical Method:

WG

ACZ Laboratories, Inc.

Analyst: SRS

Start Date:

End Date:

ACZID	10g Sample	100 ml 25% H ₂ O Soln.	Stir + Timing/Temp 90m/Temp	Water temp tubes	Wash	Thru	Fr	Vehicle Log in #'s
PBS				30°C	30°C	30°C	30°C	62140-00
6657-1				30°C	30°C	30°C	30°C	-1
-2				30°C	30°C	30°C	30°C	-2
-3				30°C	30°C	30°C	30°C	-3
-4				30°C	30°C	30°C	30°C	-4
-5				30°C	30°C	30°C	30°C	-5
-6				30°C	30°C	30°C	30°C	-6
-7				30°C	30°C	30°C	30°C	-7
-8				30°C	30°C	30°C	30°C	-8
-8D				30°C	30°C	30°C	30°C	-9

Comments: ~~all~~ all sample rotated @ 90m mixer.

Rim's 30°C filtered with ~ 0.4µm filter syringe, HH solution
SI070416.1, PCN 26729

June 22, 2009

Report to:

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Bill to:

Accounts Payable
MWH Americas Inc.
P.O. Box 6610
Broomfield, CO 80021

Project ID: 1004445

ACZ Project ID: L76008

Betty Van Pelt:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on May 22, 2009. This project has been assigned to ACZ's project number, L76008. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 12.0. The enclosed results relate only to the samples received under L76008. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after July 22, 2009. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



Scott Habermehl has reviewed
and approved this report.



MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 49.8-49.9

ACZ Sample ID: **L76008-01**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/18/09 23:37	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/22/09 7:46	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/05/09 11:42	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:21	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 0:50	bjl
ICP 3052 Digestion	M3052							06/16/09 15:40	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 56.0-56.2

ACZ Sample ID: **L76008-02**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	1	B	*	mg/Kg	1	6	06/18/09 23:46	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	8			t CaCO3/Kt	1	5	06/22/09 7:46	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.8		*	%	0.1	0.5	06/05/09 12:24	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:24	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 1:26	bjl
ICP 3052 Digestion	M3052							06/16/09 16:58	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 63.4-63.5

ACZ Sample ID: **L76008-03**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	2	B	*	mg/Kg	1	6	06/18/09 23:53	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	6			t CaCO3/Kt	1	5	06/22/09 7:46	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.6		*	%	0.1	0.5	06/05/09 12:45	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:28	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 2:03	bjl
ICP 3052 Digestion	M3052							06/16/09 17:24	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 73.0-73.2

ACZ Sample ID: **L76008-04**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/18/09 23:56	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	2			t CaCO3/Kt	1	5	06/22/09 7:46	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.2	B	*	%	0.1	0.5	06/05/09 13:07	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:31	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 2:39	bjl
ICP 3052 Digestion	M3052							06/16/09 17:50	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-24 80.0-80.3

ACZ Sample ID: **L76008-05**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/18/09 23:59	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	25			t CaCO3/Kt	1	5	06/22/09 7:46	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	2.5		*	%	0.1	0.5	06/08/09 18:00	mjc

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:35	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 3:16	bjl
ICP 3052 Digestion	M3052							06/16/09 18:16	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 34.0-34.2

ACZ Sample ID: **L76008-06**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	2	B	*	mg/Kg	1	6	06/19/09 0:09	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	8			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.8		*	%	0.1	0.5	06/05/09 13:28	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:38	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 3:52	bjl
ICP 3052 Digestion	M3052							06/16/09 18:42	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 39.4-39.6

ACZ Sample ID: **L76008-07**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	3	B	*	mg/Kg	1	6	06/19/09 0:12	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	8			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.8		*	%	0.1	0.5	06/05/09 13:49	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:42	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 4:29	bjl
ICP 3052 Digestion	M3052							06/16/09 19:08	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 45.6-46.0

ACZ Sample ID: **L76008-08**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	3	B	*	mg/Kg	1	6	06/19/09 0:15	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	36			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	3.6		*	%	0.1	0.5	06/05/09 14:10	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:45	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 5:05	bjl
ICP 3052 Digestion	M3052							06/16/09 19:34	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 50.0-50.3

ACZ Sample ID: **L76008-09**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS	2	B	*	mg/Kg	1	6	06/19/09 0:18	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	7			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.7		*	%	0.1	0.5	06/05/09 14:31	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:49	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 5:42	bjl
ICP 3052 Digestion	M3052							06/16/09 20:00	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 55.5-55.7

ACZ Sample ID: **L76008-10**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:25	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/05/09 14:53	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:52	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 6:18	bjl
ICP 3052 Digestion	M3052							06/17/09 12:40	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 60.2-60.3

ACZ Sample ID: **L76008-11**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:34	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	2			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.2	B	*	%	0.1	0.5	06/05/09 15:14	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:55	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 6:55	bjl
ICP 3052 Digestion	M3052							06/17/09 14:40	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 69.8-70.0

ACZ Sample ID: **L76008-12**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:47	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	10			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	1.0		*	%	0.1	0.5	06/05/09 15:35	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 10:59	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 7:31	bjl
ICP 3052 Digestion	M3052							06/17/09 15:20	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 84.0-84.3

ACZ Sample ID: **L76008-13**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:50	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	4			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.4	B	*	%	0.1	0.5	06/05/09 15:56	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 11:02	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 8:08	bjl
ICP 3052 Digestion	M3052							06/17/09 16:00	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-100 11.1-11.3

ACZ Sample ID: **L76008-14**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:54	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	28			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	2.8		*	%	0.1	0.5	06/05/09 16:17	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 11:06	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 8:44	bjl
ICP 3052 Digestion	M3052							06/17/09 16:40	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-100 16.0-16.2

ACZ Sample ID: **L76008-15**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 0:57	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	8			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	0.8		*	%	0.1	0.5	06/05/09 16:38	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 11:09	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 9:20	bjl
ICP 3052 Digestion	M3052							06/17/09 17:20	brd

MWH Americas Inc.

Project ID: 1004445
Sample ID: MW-100 19.8-20.0

ACZ Sample ID: **L76008-16**
Date Sampled: 05/19/09 00:00
Date Received: 05/22/09
Sample Matrix: Soil

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Uranium, total (3052)	M6020 ICP-MS		U	*	mg/Kg	1	6	06/19/09 1:00	msh

Soil Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Acid Neutralization Potential (calc)	M600/2-78-054 1.3	29			t CaCO3/Kt	1	5	06/22/09 7:47	calc
Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	2.9		*	%	0.1	0.5	06/05/09 17:00	mjc/brd

Soil Preparation

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Air Dry at 34 Degrees C	USDA No. 1, 1972							05/26/09 11:13	bjl
Crush and Pulverize	USDA No. 1, 1972							05/27/09 9:57	bjl
ICP 3052 Digestion	M3052							06/17/09 18:00	brd

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit, typically 5 times the MDL.
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
Sample	Value of the Sample of interest

QC Sample Types

AS	Analytical Spike (Post Digestion)	LCSWD	Laboratory Control Sample - Water Duplicate
ASD	Analytical Spike (Post Digestion) Duplicate	LFB	Laboratory Fortified Blank
CCB	Continuing Calibration Blank	LFM	Laboratory Fortified Matrix
CCV	Continuing Calibration Verification standard	LFMD	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate	LRB	Laboratory Reagent Blank
ICB	Initial Calibration Blank	MS	Matrix Spike
ICV	Initial Calibration Verification standard	MSD	Matrix Spike Duplicate
ICSAB	Inter-element Correction Standard - A plus B solutions	PBS	Prep Blank - Soil
LCSS	Laboratory Control Sample - Soil	PBW	Prep Blank - Water
LCSSD	Laboratory Control Sample - Soil Duplicate	PQV	Practical Quantitation Verification standard
LCSW	Laboratory Control Sample - Water	SDL	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL. The associated value is an estimated quantity.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantitation limit or the sample detection limit.

Method References

- (1) EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
- (2) EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
- (3) EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
- (5) EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
- (6) Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995 & 20th edition (1998).

Comments

- (1) QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
- (2) Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
- (3) Animal matrices for Inorganic analyses are reported on an "as received" basis.

For a complete list of ACZ's Extended Qualifiers, please click:

<http://www.acz.com/public/extquallist.pdf>

MWH Americas Inc.
 Project ID: 1004445

ACZ Project ID: **L76008**

Neutralization Potential as CaCO3 M600/2-78-054 3.2.3

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG264793													
WG264793LCSS	LCSS	06/05/09 11:21	PCN20880	100		112.19	%	112.2	80	120			
L76008-01DUP	DUP	06/05/09 12:03			.4	.33	%				19.2	20	RA
WG264898													
WG264898LCSS	LCSS	06/08/09 15:00	PCN20880	100		96.26	%	96.3	80	120			
L76007-07DUP	DUP	06/08/09 16:30			6.9	6.51	%				5.8	20	

Uranium, total (3052) M6020 ICP-MS

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG265520													
WG265520ICV	ICV	06/18/09 23:18	MS090604-1	.05		.04548	mg/L	91	90	110			
WG265520ICB	ICB	06/18/09 23:21				U	mg/L		-0.0003	0.0003			
WG265520ICSA	ICSA	06/18/09 23:24				U	mg/L		-0.0005	0.0005			
WG265520ICSAB	ICSAB	06/18/09 23:27	MS090526-7	.02		.0192	mg/L	96	80	120			
WG265374PBS	PBS	06/18/09 23:34				U	mg/Kg		-3	3			
L76008-01MS	MS	06/18/09 23:40	MS25XSOIL	62.75	U	61.9	mg/Kg	98.6	75	125			
L76008-01MSD	MSD	06/18/09 23:43	MS25XSOIL	62.75	U	64.5	mg/Kg	102.8	75	125	4.11	20	
L76008-02SDL	SDL	06/18/09 23:50			1	U	mg/Kg					10	
WG265520CCV1	CCV	06/19/09 0:02	MS090604-1	.05		.04575	mg/L	91.5	90	110			
WG265520CCB1	CCB	06/19/09 0:06				U	mg/L		-0.0003	0.0003			
WG265394PBS	PBS	06/19/09 0:22				U	mg/Kg		-3	3			
L76008-10MS	MS	06/19/09 0:28	MS25XSOIL	62.75	U	60.8	mg/Kg	96.9	75	125			
L76008-10MSD	MSD	06/19/09 0:31	MS25XSOIL	62.75	U	62.8	mg/Kg	100.1	75	125	3.24	20	
L76008-11SDL	SDL	06/19/09 0:37			U	U	mg/Kg					10	
WG265520CCV2	CCV	06/19/09 0:41	MS090604-1	.05		.04569	mg/L	91.4	90	110			
WG265520CCB2	CCB	06/19/09 0:44				U	mg/L		-0.0003	0.0003			
WG265520CCV3	CCV	06/19/09 1:03	MS090604-1	.05		.0459	mg/L	91.8	90	110			
WG265520CCB3	CCB	06/19/09 1:06				U	mg/L		-0.0003	0.0003			

MWH Americas Inc.

ACZ Project ID: **L76008**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76008-01	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-02	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-03	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-04	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-05	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
L76008-06	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-07	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-08	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-09	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH Americas Inc.

ACZ Project ID: **L76008**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76008-10	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-11	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-12	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-13	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-14	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-15	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).
L76008-16	WG265520	Uranium, total (3052)	M6020 ICP-MS	ZQ	Analyte was not evaluated in the laboratory control standard. Either the analyte is not included in the scope of the analytical method or a commercial standard containing the analyte is not available.
	WG264793	Neutralization Potential as CaCO3	M600/2-78-054 3.2.3	RA	Relative Percent Difference (RPD) was not used for data validation because the sample concentration is too low for accurate evaluation (< 10x MDL).

MWH Americas Inc.

ACZ Project ID: **L76008**

Metals Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Uranium, total (3052)

M6020 ICP-MS

Soil Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Neutralization Potential as CaCO₃

M600/2-78-054 3.2.3

MWH Americas Inc.
 1004445

ACZ Project ID: L76008
 Date Received: 5/22/2009
 Received By:
 Date Printed: 5/22/2009

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?	X		
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			X
11) Is the trip blank for Cyanide present?			X
12) Is the trip blank for VOA present?			X
13) Are samples requiring no headspace, headspace free?			X
14) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

N/A

Contact (For any discrepancies, the client must be contacted)

N/A

Shipping Containers

Cooler Id	Temp (°C)	Rad (µR/hr)
NA8444	13.5	14

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

MWH Americas Inc.
 1004445

ACZ Project ID: L76008
 Date Received: 5/22/2009
 Received By:

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG < 2	B < 2	O < 2	T > 12	N/A	RAD	ID
L76008-01	MW-24 49.8-49.9									X		<input type="checkbox"/>
L76008-02	MW-24 56.0-56.2									X		<input type="checkbox"/>
L76008-03	MW-24 63.4-63.5									X		<input type="checkbox"/>
L76008-04	MW-24 73.0-73.2									X		<input type="checkbox"/>
L76008-05	MW-24 80.0-80.3									X		<input type="checkbox"/>
L76008-06	TW4-22 34.0-34.2									X		<input type="checkbox"/>
L76008-07	TW4-22 39.4-39.6									X		<input type="checkbox"/>
L76008-08	TW4-22 45.6-46.0									X		<input type="checkbox"/>
L76008-09	TW4-22 50.0-50.3									X		<input type="checkbox"/>
L76008-10	TW4-22 55.5-55.7									X		<input type="checkbox"/>
L76008-11	TW4-22 60.2-60.3									X		<input type="checkbox"/>
L76008-12	TW4-22 69.8-70.0									X		<input type="checkbox"/>
L76008-13	TW4-22 84.0-84.3									X		<input type="checkbox"/>
L76008-14	MW-100 11.1-11.3									X		<input type="checkbox"/>
L76008-15	MW-100 16.0-16.2									X		<input type="checkbox"/>
L76008-16	MW-100 19.8-20.0									X		<input type="checkbox"/>

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: _____

CHAIN OF CUSTODY RECORD/LAB WORK REQUEST

Chain of Custody ID _____
 Cooler ID _____ of _____
 Page _____ of _____
 Air Bill No. _____

LABORATORY ACZ
 Contact Scott H.
 MWH
 Phone (801) 617-4200 FAX (801) 617-3200
 MWH Contact Betty van Pelt, Doug Oliver
 Project Denison Mines White Mesa
 Project Number 1004445
 Date Due _____
 Samplers Signature Ry-T. Joubert

Location ID	Field Sample ID	Depth Interval (ft)	Date Collected	Time Collected	Sample Number	Matrix ^a	Sampling Technique ^b	ANALYSES REQUESTED										LABORATORY USE ONLY
								AB LOT (DDMMYYNN)	EB LOT (DDMMYYNN)	TB LOT (DDMMYYNN)								
MW-24	MW-24 49.8-49.9	49.8-49.9	5/19/09			SO	G	X	X									1 Shipped or hand delivered Notes:
MW-24	MW-24 56.0-56.2	56.0-56.2																2 Ambient or Chilled Notes:
MW-24	MW-24 63.4-63.5	63.4-63.5																3 Temperature _____
MW-24	MW-24 73.0-73.2	73.0-73.2																4 Received Broken/Leaking (Improperly Sealed) Y N Notes:
MW-24	MW-24 80.0-80.3	80.0-80.3																5 Properly Preserved Y N Notes:
Tw4-22	Tw4-22 34.0-34.2	34.0-34.2																6 Received Within Holding Times Y N Notes:
Tw4-22	Tw4-22 39.4-39.6	39.4-39.6																COC Tape Was:
Tw4-22	Tw4-22 45.6-46.0	45.6-46.0																1 Present on Outer Package Y N NA
Tw4-22	Tw4-22 50.0-50.3	50.0-50.3																2 Unbroken on Outer Package Y N NA
Tw4-22	Tw4-22 55.5-55.7	55.5-55.7																3 Present on Sample Y N NA
Tw4-22	Tw4-22 60.2-60.3	60.2-60.3																4 Unbroken on Sample Y N NA Notes:
Tw4-22	Tw4-22 69.8-70.0	69.8-70.0																Discrepancies Between Sample Labels and COC Record? Y N Notes:
Tw4-22	Tw4-22 84.0-84.3	84.0-84.3																

L76008

July 02, 2009

Report to:

Betty Van Pelt
MWH Americas Inc.
10619 S. Jordan Gateway Suite 100
Salt Lake City, UT 84095

Bill to:

Accounts Payable
MWH Americas Inc.
P.O. Box 6610
Broomfield, CO 80021

Project ID: 1004445

ACZ Project ID: L76665

Betty Van Pelt:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on June 29, 2009. This project has been assigned to ACZ's project number, L76665. Please reference this number in all future inquiries.

All analyses were performed according to ACZ's Quality Assurance Plan, version 12.0. The enclosed results relate only to the samples received under L76665. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after August 02, 2009. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than \$10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.



Scott Habermehl has reviewed
and approved this report.



MWH Americas Inc.Project ID: 1004445
Sample ID: MW-24 49.8-49.9ACZ Sample ID: **L76665-01**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	5.06		*	mg/L	0.02	0.05	07/01/09 12:47	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0016		*	mg/L	0.0001	0.0005	07/01/09 16:25	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-24 56.0-56.2ACZ Sample ID: **L76665-02**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	43.60		*	mg/L	0.02	0.05	07/01/09 12:57	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0172		*	mg/L	0.0001	0.0005	07/01/09 16:29	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-24 63.4-63.5ACZ Sample ID: **L76665-03**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	226		*	mg/L	0.02	0.05	07/01/09 13:00	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0114		*	mg/L	0.0001	0.0005	07/01/09 16:33	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-24 73.0-73.2ACZ Sample ID: **L76665-04**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	10.40		*	mg/L	0.02	0.05	07/01/09 13:04	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0025		*	mg/L	0.0001	0.0005	07/01/09 16:45	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-24 80.0-80.3ACZ Sample ID: **L76665-05**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	8.41		*	mg/L	0.02	0.05	07/01/09 13:13	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0015		*	mg/L	0.0001	0.0005	07/01/09 16:49	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 34.0-34.2ACZ Sample ID: **L76665-06**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	405		*	mg/L	0.02	0.05	07/01/09 13:17	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0141		*	mg/L	0.0001	0.0005	07/01/09 17:01	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 39.4-39.6ACZ Sample ID: **L76665-07**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	428		*	mg/L	0.02	0.05	07/01/09 13:20	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0147		*	mg/L	0.0001	0.0005	07/01/09 17:05	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 45.5-46.0ACZ Sample ID: **L76665-08**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	280		*	mg/L	0.02	0.05	07/01/09 13:23	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0118		*	mg/L	0.0001	0.0005	07/01/09 17:08	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 50.0-50.3ACZ Sample ID: **L76665-09**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	509		*	mg/L	0.1	0.3	07/01/09 14:55	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0432		*	mg/L	0.0001	0.0005	07/01/09 17:12	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 55.5-55.7ACZ Sample ID: **L76665-10**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	52.90		*	mg/L	0.02	0.05	07/01/09 13:30	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0057		*	mg/L	0.0001	0.0005	07/01/09 17:16	erf

MWH Americas Inc.

Project ID: 1004445
Sample ID: TW4-22 60.2 60.3

ACZ Sample ID: **L76665-11**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	16.30		*	mg/L	0.04	0.1	07/01/09 13:33	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0021		*	mg/L	0.0001	0.0005	07/01/09 17:20	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 69.8-70.0ACZ Sample ID: **L76665-12**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	111		*	mg/L	0.02	0.05	07/01/09 13:43	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0076		*	mg/L	0.0001	0.0005	07/01/09 17:24	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: TW4-22 84.0-84.3ACZ Sample ID: **L76665-13**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	105		*	mg/L	0.02	0.05	07/01/09 13:53	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0040		*	mg/L	0.0001	0.0005	07/01/09 17:28	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-100 11.1-11.3ACZ Sample ID: **L76665-14**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	9.02		*	mg/L	0.02	0.05	07/01/09 13:56	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0015		*	mg/L	0.0001	0.0005	07/01/09 17:48	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-100 16.0-16.2ACZ Sample ID: **L76665-15**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	40.90		*	mg/L	0.02	0.05	07/01/09 13:59	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0159		*	mg/L	0.0001	0.0005	07/01/09 17:52	erf

MWH Americas Inc.Project ID: 1004445
Sample ID: MW-100 19.8-20.0ACZ Sample ID: **L76665-16**
Date Sampled: 06/29/09 00:00
Date Received: 06/29/09
Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	106		*	mg/L	0.02	0.05	07/01/09 14:03	aeH
Uranium, dissolved	M200.8 ICP-MS	0.0078		*	mg/L	0.0001	0.0005	07/01/09 17:56	erf

MWH Americas Inc.

Project ID: 1004445

Sample ID: PBS

ACZ Sample ID: **L76665-17**

Date Sampled: 06/29/09 00:00

Date Received: 06/29/09

Sample Matrix: Leachate

Metals Analysis

Parameter	EPA Method	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Iron, dissolved	M200.7 ICP	0.05		*	mg/L	0.02	0.05	07/01/09 14:06	aeH
Uranium, dissolved	M200.8 ICP-MS		U	*	mg/L	0.0001	0.0005	07/01/09 18:00	erf

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit, typically 5 times the MDL.
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
Sample	Value of the Sample of interest

QC Sample Types

AS	Analytical Spike (Post Digestion)	LCSWD	Laboratory Control Sample - Water Duplicate
ASD	Analytical Spike (Post Digestion) Duplicate	LFB	Laboratory Fortified Blank
CCB	Continuing Calibration Blank	LFM	Laboratory Fortified Matrix
CCV	Continuing Calibration Verification standard	LFMD	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate	LRB	Laboratory Reagent Blank
ICB	Initial Calibration Blank	MS	Matrix Spike
ICV	Initial Calibration Verification standard	MSD	Matrix Spike Duplicate
ICSAB	Inter-element Correction Standard - A plus B solutions	PBS	Prep Blank - Soil
LCSS	Laboratory Control Sample - Soil	PBW	Prep Blank - Water
LCSSD	Laboratory Control Sample - Soil Duplicate	PQV	Practical Quantitation Verification standard
LCSW	Laboratory Control Sample - Water	SDL	Serial Dilution

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method or calibration procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.
Standard	Verifies the validity of the calibration.

ACZ Qualifiers (Qual)

B	Analyte concentration detected at a value between MDL and PQL. The associated value is an estimated quantity.
H	Analysis exceeded method hold time. pH is a field test with an immediate hold time.
U	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantitation limit or the sample detection limit.

Method References

- (1) EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
- (2) EPA 600/R-93-100. Methods for the Determination of Inorganic Substances in Environmental Samples, August 1993.
- (3) EPA 600/R-94-111. Methods for the Determination of Metals in Environmental Samples - Supplement I, May 1994.
- (5) EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December 1996.
- (6) Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995 & 20th edition (1998).

Comments

- (1) QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
- (2) Soil, Sludge, and Plant matrices for Inorganic analyses are reported on a dry weight basis.
- (3) Animal matrices for Inorganic analyses are reported on an "as received" basis.

For a complete list of ACZ's Extended Qualifiers, please click:

<http://www.acz.com/public/extquallist.pdf>

MWH Americas Inc.

ACZ Project ID: **L76665**

Project ID: 1004445

Iron, dissolved

M200.7 ICP

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG266127													
WG266127ICV	ICV	07/01/09 12:27	II090507-1	2		1.935	mg/L	96.8	95	105			
WG266127ICB	ICB	07/01/09 12:31				U	mg/L		-0.06	0.06			
WG266127PQV	PQV	07/01/09 12:34	II090622-3	.05		.057	mg/L	114	70	130			
WG266127SIC	SIC	07/01/09 12:37	II090624-1	200.05		186.631	mg/L	93.3	1	200			
WG266127LFB	LFB	07/01/09 12:44	II090623-2	1		1.073	mg/L	107.3	85	115			
L76665-01AS	AS	07/01/09 12:50	II090623-2	1	5.06	5.783	mg/L	72.3	85	115			M3
L76665-01ASD	ASD	07/01/09 12:54	II090623-2	1	5.06	5.747	mg/L	68.7	85	115	0.62	20	M3
WG266127CCV1	CCV	07/01/09 13:07	II090507-2	1		.988	mg/L	98.8	90	110			
WG266127CCB1	CCB	07/01/09 13:10				U	mg/L		-0.06	0.06			
L76665-11AS	AS	07/01/09 13:36	II090623-2	2	16.3	17.115	mg/L	40.7	85	115			M3
L76665-11ASD	ASD	07/01/09 13:40	II090623-2	2	16.3	17.276	mg/L	48.8	85	115	0.94	20	M3
WG266127CCV2	CCV	07/01/09 13:46	II090507-2	1		1.002	mg/L	100.2	90	110			
WG266127CCB2	CCB	07/01/09 13:50				U	mg/L		-0.06	0.06			
WG266127CCV3	CCV	07/01/09 14:09	II090507-2	1		1	mg/L	100	90	110			
WG266127CCB3	CCB	07/01/09 14:13				U	mg/L		-0.06	0.06			

WG266266

WG266266CCV	CCV	07/01/09 14:36	II090507-2	1		1.023	mg/L	102.3	90	110			
WG266266CCB	CCB	07/01/09 14:39				U	mg/L		-0.06	0.06			
WG266266PQV	PQV	07/01/09 14:42	II090622-3	.05		.057	mg/L	114	70	130			
WG266266SIC	SIC	07/01/09 14:46	II090624-1	200.05		191.724	mg/L	95.8	1	200			
WG266266LFB	LFB	07/01/09 14:52	II090623-2	1		1.02	mg/L	102	85	115			
L76665-09AS	AS	07/01/09 14:59	II090623-2	5	509	495.95	mg/L	-261	85	115			M3
L76665-09ASD	ASD	07/01/09 15:02	II090623-2	5	509	498.48	mg/L	-210.4	85	115	0.51	20	M3
WG266266CCV1	CCV	07/01/09 15:05	II090507-2	1		1.022	mg/L	102.2	90	110			
WG266266CCB1	CCB	07/01/09 15:09				U	mg/L		-0.06	0.06			

Uranium, dissolved

M200.8 ICP-MS

ACZ ID	Type	Analyzed	PCN/SCN	QC	Sample	Found	Units	Rec	Lower	Upper	RPD	Limit	Qual
WG266238													
WG266238ICV	ICV	07/01/09 16:09	MS090604-1	.05		.04923	mg/L	98.5	90	110			
WG266238ICB	ICB	07/01/09 16:13				.00013	mg/L		-0.00022	0.00022			
WG266238PQV	PQV	07/01/09 16:17	MS090630-2	.0005		.00048	mg/L	96	70	130			
WG266238LFB	LFB	07/01/09 16:21	MS090526-2	.05		.04358	mg/L	87.2	85	115			
L76665-03AS	AS	07/01/09 16:37	MS090526-2	.05	.0114	.05614	mg/L	89.5	70	130			
L76665-03ASD	ASD	07/01/09 16:41	MS090526-2	.05	.0114	.05571	mg/L	88.6	70	130	0.77	20	
WG266238CCV1	CCV	07/01/09 16:53	MS090630-4	.1		.09926	mg/L	99.3	90	110			
WG266238CCB1	CCB	07/01/09 16:57				U	mg/L		-0.0003	0.0003			
L76665-13AS	AS	07/01/09 17:32	MS090526-2	.05	.004	.04582	mg/L	83.6	70	130			
L76665-13ASD	ASD	07/01/09 17:36	MS090526-2	.05	.004	.04778	mg/L	87.6	70	130	4.19	20	
WG266238CCV2	CCV	07/01/09 17:40	MS090630-4	.1		.09774	mg/L	97.7	90	110			
WG266238CCB2	CCB	07/01/09 17:44				.0001	mg/L		-0.0003	0.0003			
WG266238CCV3	CCV	07/01/09 18:04	MS090630-4	.1		.09637	mg/L	96.4	90	110			
WG266238CCB3	CCB	07/01/09 18:08				.00011	mg/L		-0.0003	0.0003			

MWH Americas Inc.

ACZ Project ID: **L76665**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76665-01	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-02	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-03	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-04	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-05	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-06	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-07	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-08	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-09	WG266266	Iron, dissolved	M200.7 ICP M200.7 ICP	D1 M3	Sample required dilution due to matrix. The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-10	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-11	WG266127	Iron, dissolved	M200.7 ICP M200.7 ICP	DJ M3	Sample dilution required due to insufficient sample. The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-12	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-13	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-14	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.

MWH Americas Inc.

ACZ Project ID: **L76665**

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L76665-15	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-16	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.
L76665-17	WG266127	Iron, dissolved	M200.7 ICP	M3	The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The recovery of the associated control sample (LCS or LFB) was acceptable.

MWH Americas Inc.

ACZ Project ID: **L76665**

Metals Analysis

The following parameters are not offered for certification or are not covered by NELAC certificate #ACZ.

Iron, dissolved	M200.7 ICP
Uranium, dissolved	M200.8 ICP-MS

76665

CHAIN OF CUSTODY RECORD/LAB WORK REQUEST

LABORATORY ACZ
 Contact Scott H.
 MWH
 Phone (801) 617-4200 FAX (801) 617-3200
 MWH Contact Betty van Pelt, Doug Oliver
 Project Denison Mines White Mesa
 Project Number 100445
 Date Due _____
 Samplers Signature Pgt. J. Judd

Chain of Custody ID _____
 Cooler ID _____
 Page _____ of _____
 Air Bill No. _____

Location ID	Field Sample ID	Depth Interval (ft)
MW-24	MW-24 49.8-49.9	49.8-49.9
MW-24	MW-24 56.0-56.2	56.0-56.2
MW-24	MW-24 63.4-63.5	63.4-63.5
MW-24	MW-24 73.0-73.2	73.0-73.2
MW-24	MW-24 80.0-80.3	80.0-80.3
TW4-22	TW4-22 34.0-34.2	34.0-34.2
TW4-22	TW4-22 39.4-39.6	39.4-39.6
TW4-22	TW4-22 45.6-46.0	45.6-46.0
TW4-22	TW4-22 50.0-50.3	50.0-50.3
TW4-22	TW4-22 55.5-55.7	55.5-55.7
TW4-22	TW4-22 60.2-60.3	60.2-60.3
TW4-22	TW4-22 69.8-70.0	69.8-70.0
TW4-22	TW4-22 84.0-84.3	84.0-84.3

Date Collected	Time Collected	Sample Number	Matrix ^a	Sampling Technique ^b	ANALYSES REQUESTED										AB LOT (DDMMYYNN)	EB LOT (DDMMYYNN)	TB LOT (DDMMYYNN)
					ANP	Fe-HFO											
5/19/09			SO	G	X	X											

LABORATORY USE ONLY	
SAMPLES WERE:	
1 Shipped or hand delivered	Notes:
2 Ambient or Chilled	Notes:
3 Temperature _____	
4 Received Broken/Leaking (Improperly Sealed)	Y N
5 Properly Preserved	Y N
6 Received Within Holding Times	Y N
COC Tape Was:	
1 Present on Outer Package	Y N NA
2 Unbroken on Outer Package	Y N NA
3 Present on Sample	Y N NA
4 Unbroken on Sample	Y N NA
Discrepancies Between Sample Labels and COC Record?	
	Y N

^a Matrix: WG - Ground Water EP/TCLP Leachate
 SO - Soil LF - Product WQ - Trip Blank
 SE - Sediment AA - Air EB - Equipment Blanks
 WS - Surface Water SW - Wipe WW - Wastewater

^b Sampling Technique: Cone Penetrometer=CN
 Composite=C Bladder Pump=BP
 Grab=G Submersible Pump=SP
 Hand Auger=HA Bailer=B
 Peristaltic Pump=PP GeoProbe=PR

SPECIAL INSTRUCTIONS:

Relinquished by/Affiliation	Received by/Affiliation	Date	Time	Relinquished by/Affiliation	Received by/Affiliation	Date	Time
Pgt. J. Judd/MWH	(Signature)	5/21/09	9:20				

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7/10/09
5/21/09

APPENDIX B

**LABORATORY REPORT WITH UNSATURATED AND
SATURATED HYDRAULIC PROPERTIES OF THE BEDROCK
CORE SAMPLES**

Laboratory Report for
MWH Americas, Inc.
(Contract No. 87146-OM)

April 27, 2007



Daniel B. Stephens & Associates, Inc.

6020 Academy NE, Suite 100 • Albuquerque, New Mexico 87109



April 27, 2007

Mr. Doug Oliver
MWH Americas, Inc.
10619 South Jordan Gateway
South Jordan, UT 84095
(810) 617-3200

Re: DBS&A Laboratory Report for MWH Americas, Inc.; Contract No. 87146-OM

Dear Mr. Oliver:

Enclosed is the final report for the MWH Americas, Inc.; contract No. 87146-OM samples. Please review this report and provide any comments as samples will be held for a maximum of 30 days. After 30 days samples will be returned or disposed of in an appropriate manner. All testing results were evaluated subjectively for consistency and reasonableness, and the results appear to be reasonably representative of the material tested. However, DBS&A does not assume any responsibility for interpretations or analyses based on the data enclosed, nor can we guarantee that these data are fully representative of the undisturbed materials at the field site. We recommend that careful evaluation of these laboratory results be made for your particular application.

The testing utilized to generate the enclosed final report employs methods that are standard for the industry. The results do not constitute a professional opinion by DBS&A, nor can the results affect any professional or expert opinions rendered with respect thereto by DBS&A. You have acknowledged that all the testing undertaken by us, and the final report provided, constitutes mere test results using standardized methods, and cannot be used to disqualify DBS&A from rendering any professional or expert opinion, having waived any claim of conflict of interest by DBS&A.

We are pleased to provide this service to MWH Americas, Inc. and look forward to future laboratory testing on other projects. If you have any questions about the enclosed data, please do not hesitate to call.

Sincerely,

DANIEL B. STEPHENS & ASSOCIATES, INC.
LABORATORY / TESTING FACILITY

Joleen Hines
Laboratory Supervising Manager

Enclosure

Daniel B. Stephens & Associates, Inc.

6020 Academy NE, Suite 100

505-822-9400

Albuquerque, NM 87109

FAX 505-822-8877

Summaries



Daniel B. Stephens & Associates, Inc.

Summary of Tests Performed

Laboratory Sample Number	Initial Soil Properties ¹ (θ , ρ_d , ϕ)	Saturated Hydraulic Conductivity ²		Moisture Characteristics ³				Unsaturated Hydraulic Conductivity	Particle Size ⁴			Effective Porosity	Particle Density	Air Permeability	1/3, 15 Bar Points and Water Holding Capacity	Atterberg Limits	Proctor Compaction
		CH	FH	HC	PP	TH	WP		RH	DS	WS						
MW-23 55.5-56.0	X		X	X	X		X	X									
MW-23 74.3-74.6	X		X	X	X		X	X									
MW-23 82.7-82.9	X		X	X	X		X	X									
MW-23 103.3-103.5	X		X	X	X		X	X									
MW-30 35.5-36.0	X		X	X	X		X	X									
MW-30 44.0-44.5	X		X	X	X		X	X									

¹ θ = Initial moisture content, ρ_d = Dry bulk density, ϕ = Calculated porosity

² CH = Constant head, FH = falling head

³ HC = Hanging column, PP = Pressure plate, TH = Thermocouple psychrometer, WP = Water activity meter, RH = Relative humidity box

⁴ DS = Dry sieve, WS = Wet sieve, H = Hydrometer



Summary of Sample Volume Changes

Sample Number	As Received Properties			Final Densities*		
	Moisture Content (% g/g)	Moisture Content (cm ³ /cm ³)	Dry Bulk Density (g/cm ³)	Final Measured Dry Bulk Density (g/cm ³)	Final % Volume Change (%)	Final % of Original Density (%)
MW-23 55.5-56.0	0.3	0.7	2.03	----	----	----
MW-23 74.3-74.6	0.6	1.4	2.33	----	----	----
MW-23 82.7-82.9	0.3	0.7	2.10	----	----	----
MW-23 103.3-103.5	0.8	1.4	1.84	----	----	----
MW-30 35.5-36.0	0.3	0.5	1.98	----	----	----
MW-30 44.0-44.5*	1.7	3.8	2.23	2.12	(+) 5.5%	94.8%

*Final Densities: Volume change measurements were obtained after saturated hydraulic conductivity testing and throughout unsaturated hydraulic conductivity testing. The reported values are the final sample dimensions.

*Sample MW-30 44.0-44.5 experienced swelling and water gain during and after the initial saturation process. This sample also cracked horizontally during moisture retention testing.

Note: (+) denotes observed sample swelling, and (-) denotes observed sample settling.

---- = Not Applicable, no volume change occurred.



Daniel B. Stephens & Associates, Inc.

**Summary of Initial Moisture Content, Dry Bulk Density
Wet Bulk Density and Calculated Porosity**

Sample Number	Moisture Content				Dry Bulk Density (g/cm ³)	Wet Bulk Density (g/cm ³)	Calculated Porosity (%)
	As Received		Remolded				
	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)			
MW-23 55.5-56.0	0.3	0.7	---	---	2.03	2.03	23.5
MW-23 74.3-74.6	0.6	1.4	---	---	2.33	2.34	12.1
MW-23 82.7-82.9	0.3	0.7	---	---	2.10	2.11	20.7
MW-23 103.3-103.5	0.8	1.4	---	---	1.84	1.85	30.7
MW-30 35.5-36.0	0.3	0.5	---	---	1.98	1.98	25.4
MW-30 44.0-44.5	1.7	3.8	---	---	2.23	2.27	15.8

NA = Not analyzed

--- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Summary of Saturated Hydraulic Conductivity Tests

Sample Number	K_{sat} (cm/sec)	Method of Analysis	
		Constant Head Flexible Wall	Falling Head Flexible Wall
MW-23 55.5-56.0	1.1E-04		X
MW-23 74.3-74.6	2.9E-05		X
MW-23 82.7-82.9	1.7E-04		X
MW-23 103.3-103.5	3.0E-03		X
MW-30 35.5-36.0	8.1E-04		X
MW-30 44.0-44.5	8.2E-06		X



Daniel B. Stephens & Associates, Inc.

Summary of Moisture Characteristics of the Initial Drainage Curve

Sample Number	Pressure Head (-cm water)	Moisture Content (%, cm ³ /cm ³)
MW-23 55.5-56.0	0	18.2
	13	17.7
	35	17.6
	100	15.8
	510	8.5
	15195	3.2
	42832	2.1
	851293	0.3
MW-23 74.3-74.6	0	12.3
	14	12.3
	56	12.2
	155	11.9
	510	11.7
	43851	4.9
	851293	1.6
	MW-23 82.7-82.9	0
12		15.3
38		15.3
97		14.9
510		9.6
23557		3.4
851293		0.3
MW-23 103.3-103.5		0
	8	19.3
	24	19.2
	85	14.0
	510	6.8
	16827	3.3
	32838	2.5
	851293	0.6



Daniel B. Stephens & Associates, Inc.

**Summary of Moisture Characteristics
of the Initial Drainage Curve (Continued)**

Sample Number	Pressure Head (-cm water)	Moisture Content (%, cm ³ /cm ³)	
MW-30 35.5-36.0	0	19.5	
	7	19.2	
	20	19.0	
	74	14.1	
	510	7.6	
	23251	2.6	
	35081	2.1	
	851293	0.4	
MW-30 44.0-44.5	0	27.9	
	35	26.7	
	101	24.7	
	197	23.6	
	510	20.5	
	23353	10.9	
	851293	3.4	
	MW-30 44.0-44.5 (Volume Adjusted)	0	26.7
35		25.6	
101		23.5	
197		22.4	
510		19.4	
23353		10.4	
851293		3.2	



Daniel B. Stephens & Associates, Inc.

Summary of Calculated Unsaturated Hydraulic Properties

Sample Number	α (cm^{-1})	N (dimensionless)	θ_r (% vol)	θ_s (% vol)	Oversize Corrected	
					θ_r (% vol)	θ_s (% vol)
MW-23 55.5-56.0	0.0103	1.3860	0.00	18.38	NA	NA
MW-23 74.3-74.6	0.0003	1.3544	0.00	12.16	NA	NA
MW-23 82.7-82.9	0.0069	1.3362	0.00	16.01	NA	NA
MW-23 103.3-103.5	0.0287	1.3494	0.00	20.51	NA	NA
MW-30 35.5-36.0	0.0266	1.3480	0.00	19.86	NA	NA
MW-30 44.0-44.5	0.0074	1.2019	0.00	27.59	NA	NA
MW-30 44.0-44.5 (Volume Adjusted)	0.0081	1.2006	0.00	26.43	NA	NA

--- = Oversize correction is unnecessary since coarse fraction < 5% of composite mass

NA = Not analyzed

Laboratory Data and Graphical Plots

Initial Properties



Daniel B. Stephens & Associates, Inc.

**Summary of Initial Moisture Content, Dry Bulk Density
Wet Bulk Density and Calculated Porosity**

Sample Number	Moisture Content				Dry Bulk Density (g/cm ³)	Wet Bulk Density (g/cm ³)	Calculated Porosity (%)
	As Received		Remolded				
	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)			
MW-23 55.5-56.0	0.3	0.7	---	---	2.03	2.03	23.5
MW-23 74.3-74.6	0.6	1.4	---	---	2.33	2.34	12.1
MW-23 82.7-82.9	0.3	0.7	---	---	2.10	2.11	20.7
MW-23 103.3-103.5	0.8	1.4	---	---	1.84	1.85	30.7
MW-30 35.5-36.0	0.3	0.5	---	---	1.98	1.98	25.4
MW-30 44.0-44.5	1.7	3.8	---	---	2.23	2.27	15.8

NA = Not analyzed

--- = This sample was not remolded



Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 55.5-56.0
Ring Number: NA
Depth: 55.5-56.0

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	172.04	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	171.46	
Sample volume (cm ³):	84.63	
Assumed particle density (g/cm ³):	2.65	

Gravimetric Moisture Content (% g/g):	0.3
Volumetric Moisture Content (% vol):	0.7
Dry bulk density (g/cm ³):	2.03
Wet bulk density (g/cm ³):	2.03
Calculated Porosity (% vol):	23.5
Percent Saturation:	2.9

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

- * Weight including tares
- NA = Not analyzed
- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 74.3-74.6
Ring Number: NA
Depth: 74.3-74.6

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	162.07	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	161.11	
Sample volume (cm ³):	69.19	
Assumed particle density (g/cm ³):	2.65	
<hr/>		
Gravimetric Moisture Content (% g/g):	0.6	
Volumetric Moisture Content (% vol):	1.4	
Dry bulk density (g/cm ³):	2.33	
Wet bulk density (g/cm ³):	2.34	
Calculated Porosity (% vol):	12.1	
Percent Saturation:	11.4	

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

- * Weight including tares
- NA = Not analyzed
- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 82.7-82.9
Ring Number: NA
Depth: 82.7-82.9

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	152.51	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	151.98	
Sample volume (cm ³):	72.35	
Assumed particle density (g/cm ³):	2.65	

Gravimetric Moisture Content (% g/g):	0.3
Volumetric Moisture Content (% vol):	0.7
Dry bulk density (g/cm ³):	2.10
Wet bulk density (g/cm ³):	2.11
Calculated Porosity (% vol):	20.7
Percent Saturation:	3.5

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

- * Weight including tares
- NA = Not analyzed
- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 103.3-103.5
Ring Number: NA
Depth: 103.3-103.5

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	127.13	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	126.16	
Sample volume (cm ³):	68.67	
Assumed particle density (g/cm ³):	2.65	
<hr/>		
Gravimetric Moisture Content (% g/g):	0.8	
Volumetric Moisture Content (% vol):	1.4	
Dry bulk density (g/cm ³):	1.84	
Wet bulk density (g/cm ³):	1.85	
Calculated Porosity (% vol):	30.7	
Percent Saturation:	4.6	

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

- * Weight including tares
- NA = Not analyzed
- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-30 35.5-36.0
Ring Number: NA
Depth: 35.5'-36.0'

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	170.24	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	169.77	
Sample volume (cm ³):	85.85	
Assumed particle density (g/cm ³):	2.65	

Gravimetric Moisture Content (% g/g):	0.3
Volumetric Moisture Content (% vol):	0.5
Dry bulk density (g/cm ³):	1.98
Wet bulk density (g/cm ³):	1.98
Calculated Porosity (% vol):	25.4
Percent Saturation:	2.2

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

* Weight including tares
NA = Not analyzed
--- = This sample was not remolded



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-30 44.0-44.5
Ring Number: NA
Depth: 44.0-44.5

	<u>As Received</u>	<u>Remolded</u>
Test Date:	16-Mar-07	---
Field weight* of sample (g):	197.08	
Tare weight, ring (g):	0.00	
Tare weight, pan/plate (g):	0.00	
Tare weight, other (g):	0.00	
Dry weight of sample (g):	193.77	
Sample volume (cm ³):	86.88	
Assumed particle density (g/cm ³):	2.65	

Gravimetric Moisture Content (% g/g):	1.7
Volumetric Moisture Content (% vol):	3.8
Dry bulk density (g/cm ³):	2.23
Wet bulk density (g/cm ³):	2.27
Calculated Porosity (% vol):	15.8
Percent Saturation:	24.1

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines

Comments:

- * Weight including tares
- NA = Not analyzed
- = This sample was not remolded

**Saturated Hydraulic
Conductivity**



Daniel B. Stephens & Associates, Inc.

Summary of Saturated Hydraulic Conductivity Tests

Sample Number	K_{sat} (cm/sec)	Method of Analysis	
		Constant Head Flexible Wall	Falling Head Flexible Wall
MW-23 55.5-56.0	1.1E-04		X
MW-23 74.3-74.6	2.9E-05		X
MW-23 82.7-82.9	1.7E-04		X
MW-23 103.3-103.5	3.0E-03		X
MW-30 35.5-36.0	8.1E-04		X
MW-30 44.0-44.5	8.2E-06		X



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 55.5-56.0

Date/Time sampled: NA

Depth: 55.5-56.0

Remolded or Initial Sample Properties

Initial Mass (g): 172.04
Diameter (cm): 5.369
Length (cm): 3.738
Area (cm²): 22.64
Volume (cm³): 84.63
Dry Density (g/cm³): 2.03
Dry Density (pcf): 126.48
Water Content (% g/g): 0.3
Water Content (% vol): 0.7
Porosity (% vol): 23.5
Saturation (%): 2.9

Final (Post Test) Sample Properties

Saturated Mass (g): 186.87
Dry Mass (g): 171.46
Diameter (cm): 5.369
Length (cm): 3.738
Area (cm²): 22.64
Volume (cm³): 84.63
Dry Density (g/cm³): 2.03
Dry Density (pcf): 126.48
Water Content (% g/g): 9.0
Water Content (% vol): 18.2
Porosity (% vol): 23.5
Saturation (%)*: 77.3

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.0
Effluent pressure (PSI): 30.0
Panel Used: A B C
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 0.95
Date/Time: 3/20/07 1503

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated or skewed during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 55.5-56.0

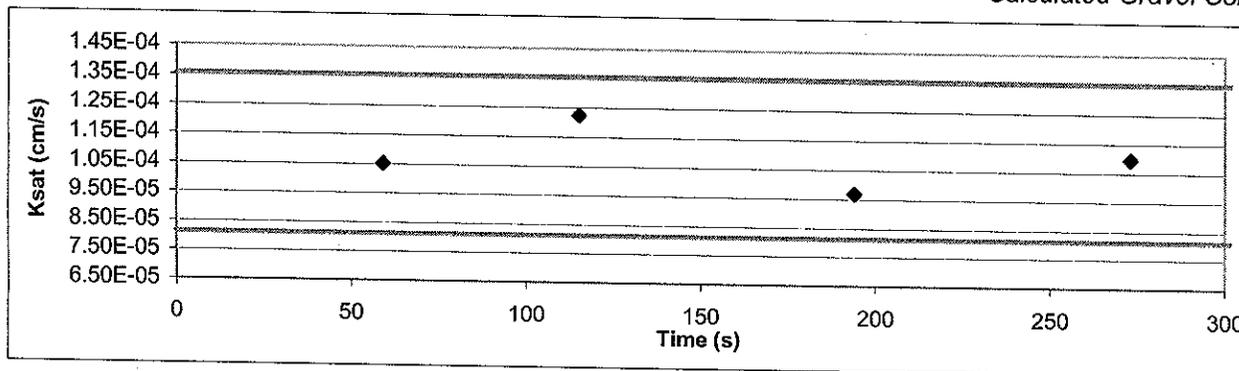
Date/Time sampled: NA

Depth: 55.5-56.0

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient ($\Delta H/\Delta L$)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k _{sat} T°C (cm/s)	k _{sat} Corrected (cm/s)
Test # 1:											
20-Mar-07	14:19:06	24.0	15.00	19.40	1.36						
20-Mar-07	14:20:05	24.0	15.20	19.20	1.24	0.17	59	1.00	9%	1.15E-04	1.05E-04
Test # 2:											
20-Mar-07	14:20:05	24.0	15.20	19.20	1.24						
20-Mar-07	14:21:01	24.0	15.40	19.00	1.11	0.17	56	1.00	10%	1.35E-04	1.22E-04
Test # 3:											
20-Mar-07	14:21:01	24.0	15.40	19.00	1.11						
20-Mar-07	14:22:20	24.2	15.60	18.80	0.99	0.17	79	1.00	11%	1.07E-04	9.68E-05
Test # 4:											
20-Mar-07	14:22:20	24.2	15.60	18.80	0.99						
20-Mar-07	14:23:39	24.2	15.80	18.60	0.86	0.17	79	1.00	13%	1.21E-04	1.09E-04

Average Ksat (cm/sec): 1.08E-04

Calculated Gravel Corrected Average Ksat (cm/sec): ---



ASTM Required Range (+/- 25%)

Ksat (-25%) (cm/s): 8.13E-05

Ksat (+25%) (cm/s): 1.36E-04



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 74.3-74.6

Date/Time sampled: NA

Depth: 74.3-74.6

Remolded or Initial Sample Properties

Initial Mass (g): 162.07
Diameter (cm): 5.376
Length (cm): 3.048
Area (cm²): 22.70
Volume (cm³): 69.19
Dry Density (g/cm³): 2.33
Dry Density (pcf): 145.37
Water Content (% g/g): 0.6
Water Content (% vol): 1.4
Porosity (% vol): 12.1
Saturation (%): 11.4

Final (Post Test) Sample Properties

Saturated Mass (g): 169.61
Dry Mass (g): 161.11
Diameter (cm): 5.376
Length (cm): 3.048
Area (cm²): 22.70
Volume (cm³): 69.19
Dry Density (g/cm³): 2.33
Dry Density (pcf): 145.37
Water Content (% g/g): 5.3
Water Content (% vol): 12.3
Porosity (% vol): 12.1
Saturation (%)*: 101.3

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.1
Effluent pressure (PSI): 30.0
Panel Used: D E F
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 1.00
Date/Time: 3/20/07 1500

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 74.3-74.6

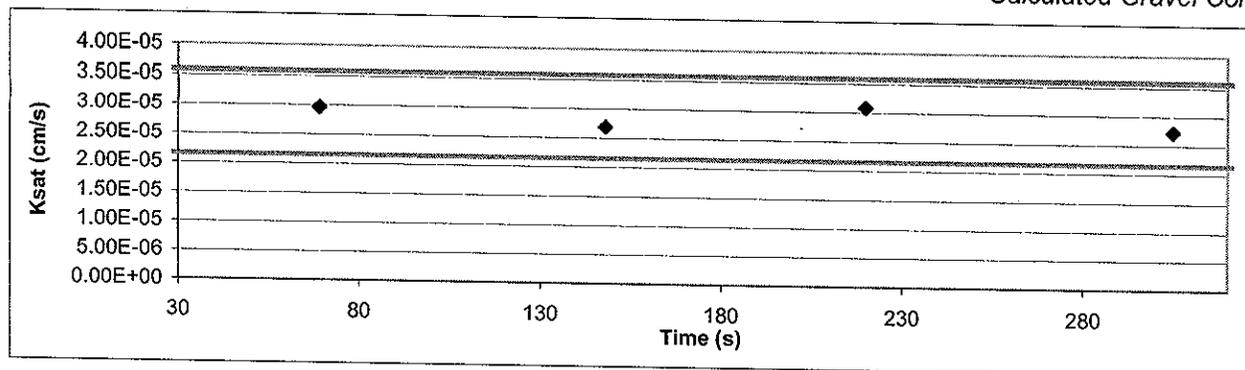
Date/Time sampled: NA

Depth: 74.3-74.6

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient (ΔH/ΔL)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k _{sat} T°C (cm/s)	k _{sat} Corrected (cm/s)
Test # 1:											
20-Mar-07	14:30:19	24.2	15.40	19.85	3.99	0.17					
20-Mar-07	14:31:28	24.2	15.60	19.65	3.84	0.17	69	1.00	4%	3.27E-05	2.96E-05
Test # 2:											
20-Mar-07	14:31:28	24.2	15.60	19.65	3.84	0.17					
20-Mar-07	14:32:47	24.2	15.80	19.45	3.69	0.17	79	1.00	4%	2.97E-05	2.69E-05
Test # 3:											
20-Mar-07	14:32:47	24.2	15.80	19.45	3.69	0.17					
20-Mar-07	14:33:59	24.2	16.00	19.25	3.54	0.17	72	1.00	4%	3.40E-05	3.08E-05
Test # 4:											
20-Mar-07	14:33:59	24.2	16.00	19.25	3.54	0.17					
20-Mar-07	14:35:24	24.2	16.20	19.05	3.39	0.17	85	1.00	4%	3.00E-05	2.72E-05

Average Ksat (cm/sec): 2.86E-05

Calculated Gravel Corrected Average Ksat (cm/sec):



ASTM Required Range (+/- 25%)

Ksat (-25%) (cm/s): 2.15E-05

Ksat (+25%) (cm/s): 3.58E-05



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 82.7-82.9

Date/Time sampled: NA

Depth: 82.7-82.9

Remolded or Initial Sample Properties

Initial Mass (g): 152.51
Diameter (cm): 5.373
Length (cm): 3.191
Area (cm²): 22.67
Volume (cm³): 72.35
Dry Density (g/cm³): 2.10
Dry Density (pcf): 131.13
Water Content (% g/g): 0.3
Water Content (% vol): 0.7
Porosity (% vol): 20.7
Saturation (%): 3.5

Final (Post Test) Sample Properties

Saturated Mass (g): 163.8
Dry Mass (g): 151.98
Diameter (cm): 5.373
Length (cm): 3.191
Area (cm²): 22.67
Volume (cm³): 72.35
Dry Density (g/cm³): 2.10
Dry Density (pcf): 131.13
Water Content (% g/g): 7.8
Water Content (% vol): 16.3
Porosity (% vol): 20.7
Saturation (%)*: 78.8

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.0
Effluent pressure (PSI): 30.0
Panel Used: D E F
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 0.95
Date/Time: 3/19/07 1305

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 82.7-82.9

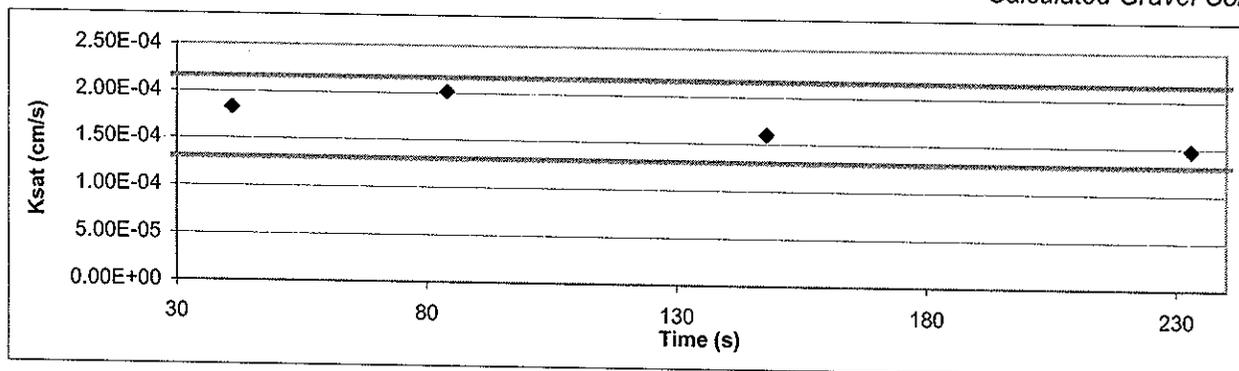
Date/Time sampled: NA

Depth: 82.7-82.9

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient (ΔH/ΔL)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k _{sat} T°C (cm/s)	k _{sat} Corrected (cm/s)
Test # 1:											
19-Mar-07	13:32:09	23.6	13.20	18.00	1.74						
19-Mar-07	13:32:50	23.6	13.50	17.70	1.52	0.26	41	1.00	13%	1.99E-04	1.83E-04
Test # 2:											
19-Mar-07	13:32:50	23.6	13.50	17.70	1.52						
19-Mar-07	13:33:33	23.6	13.80	17.40	1.30	0.26	43	1.00	14%	2.19E-04	2.01E-04
Test # 3:											
19-Mar-07	13:33:33	23.6	13.80	17.40	1.30						
19-Mar-07	13:34:37	23.6	14.10	17.10	1.09	0.26	64	1.00	17%	1.74E-04	1.60E-04
Test # 4:											
19-Mar-07	13:34:37	23.6	14.10	17.10	1.09						
19-Mar-07	13:36:02	23.6	14.40	16.80	0.87	0.26	85	1.00	20%	1.61E-04	1.47E-04

Average Ksat (cm/sec): 1.73E-04

Calculated Gravel Corrected Average Ksat (cm/sec):



ASTM Required Range (+/- 25%)

Ksat (-25%) (cm/s): 1.30E-04

Ksat (+25%) (cm/s): 2.16E-04



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 103.3-103.5

Date/Time sampled: NA

Depth: 103.3-103.5

Remolded or Initial Sample Properties

Initial Mass (g): 127.13
Diameter (cm): 5.362
Length (cm): 3.041
Area (cm²): 22.58
Volume (cm³): 68.67
Dry Density (g/cm³): 1.84
Dry Density (pcf): 114.69
Water Content (% g/g): 0.8
Water Content (% vol): 1.4
Porosity (% vol): 30.7
Saturation (%): 4.6

Final (Post Test) Sample Properties

Saturated Mass (g): 140.16
Dry Mass (g): 126.16
Diameter (cm): 5.362
Length (cm): 3.041
Area (cm²): 22.58
Volume (cm³): 68.67
Dry Density (g/cm³): 1.84
Dry Density (pcf): 114.69
Water Content (% g/g): 11.1
Water Content (% vol): 20.4
Porosity (% vol): 30.7
Saturation (%)*: 66.5

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.0
Effluent pressure (PSI): 30.0
Panel Used: D E F
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 0.95
Date/Time: 3/19/07 1306

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-23 103.3-103.5

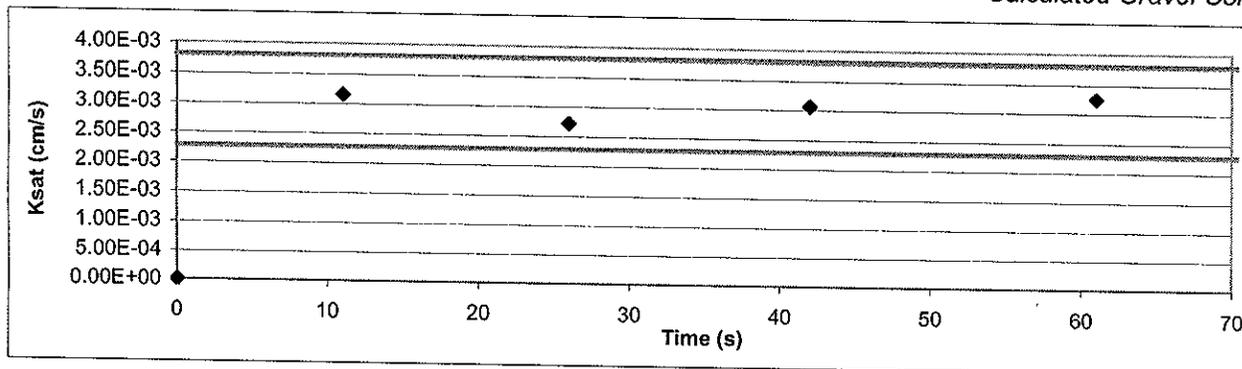
Date/Time sampled: NA

Depth: 103.3-103.5

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient ($\Delta H/\Delta L$)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k _{sat} T°C (cm/s)	k _{sat} Corrected (cm/s)
Test # 1:											
19-Mar-07	13:52:17	23.8	15.90	20.35	1.69	1.17	11	1.00	13%	3.46E-03	3.16E-03
19-Mar-07	13:52:28	23.8	16.20	20.05	1.46	1.17	11	1.00	13%	3.46E-03	3.16E-03
Test # 2:											
19-Mar-07	13:52:28	23.8	16.20	20.05	1.46	1.17	15	1.00	16%	2.97E-03	2.71E-03
19-Mar-07	13:52:43	23.8	16.50	19.75	1.23	1.17	15	1.00	16%	2.97E-03	2.71E-03
Test # 3:											
19-Mar-07	13:52:43	23.8	16.50	19.75	1.23	1.17	16	1.00	18%	3.35E-03	3.06E-03
19-Mar-07	13:52:59	23.8	16.80	19.45	1.01	1.17	16	1.00	18%	3.35E-03	3.06E-03
Test # 4:											
19-Mar-07	13:52:59	23.8	16.80	19.45	1.01	1.17	19	1.00	23%	3.55E-03	3.24E-03
19-Mar-07	13:53:18	23.8	17.10	19.15	0.78	1.17	19	1.00	23%	3.55E-03	3.24E-03

Average Ksat (cm/sec): **3.04E-03**

Calculated Gravel Corrected Average Ksat (cm/sec):



ASTM Required Range (+/- 25%)

Ksat (-25%) (cm/s): 2.28E-03

Ksat (+25%) (cm/s): 3.81E-03



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.
Job number: LB07.0048.00
Sample number: MW-30 35.5-36.0
Date/Time sampled: NA
Depth: 35.5-36.0

Remolded or Initial Sample Properties

Initial Mass (g): 170.24
Diameter (cm): 5.381
Length (cm): 3.775
Area (cm²): 22.74
Volume (cm³): 85.85
Dry Density (g/cm³): 1.98
Dry Density (pcf): 123.45
Water Content (% g/g): 0.3
Water Content (% vol): 0.5
Porosity (% vol): 25.4
Saturation (%): 2.2

Final (Post Test) Sample Properties

Saturated Mass (g): 186.53
Dry Mass (g): 169.77
Diameter (cm): 5.381
Length (cm): 3.775
Area (cm²): 22.74
Volume (cm³): 85.85
Dry Density (g/cm³): 1.98
Dry Density (pcf): 123.45
Water Content (% g/g): 9.9
Water Content (% vol): 19.5
Porosity (% vol): 25.4
Saturation (%)*: 76.9

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.0
Effluent pressure (PSI): 30.0
Panel Used: A B C
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 0.95
Date/Time: 3/20/07 1510

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated or skewed during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-30 35.5-36.0

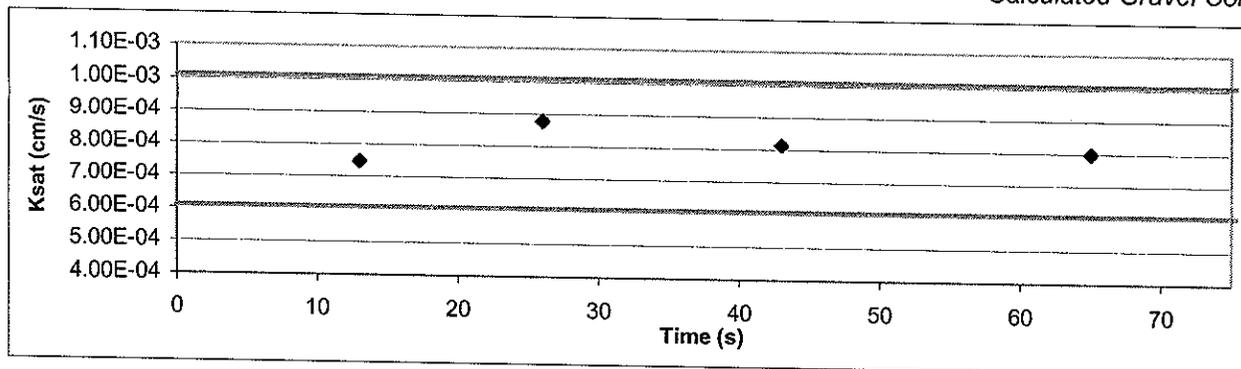
Date/Time sampled: NA

Depth: 35.5-36.0

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient ($\Delta H/\Delta L$)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k_{sat} T°C (cm/s)	k_{sat} Corrected (cm/s)
Test # 1:											
20-Mar-07	14:14:19	24.0	15.70	18.60	0.89						
20-Mar-07	14:14:32	24.0	15.90	18.40	0.76	0.17	13	1.00	14%	8.21E-04	7.47E-04
Test # 2:											
20-Mar-07	14:14:32	24.0	15.90	18.40	0.76						
20-Mar-07	14:14:45	24.0	16.10	18.20	0.64	0.17	13	1.00	16%	9.64E-04	8.77E-04
Test # 3:											
20-Mar-07	14:14:45	24.0	16.10	18.20	0.64						
20-Mar-07	14:15:02	24.0	16.30	18.00	0.52	0.17	17	1.00	19%	8.93E-04	8.13E-04
Test # 4:											
20-Mar-07	14:15:02	24.0	16.30	18.00	0.52						
20-Mar-07	14:15:24	24.0	16.50	17.80	0.40	0.17	22	1.00	24%	8.76E-04	7.97E-04

Average K_{sat} (cm/sec): **8.08E-04**

Calculated Gravel Corrected Average K_{sat} (cm/sec): ---



ASTM Required Range (+/- 25%)

K_{sat} (-25%) (cm/s): 6.06E-04

K_{sat} (+25%) (cm/s): 1.01E-03



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-30 44.0-44.5

Date/Time sampled: NA

Depth: 44.0-44.5

Remolded or Initial Sample Properties

Initial Mass (g): 197.08
Diameter (cm): 5.361
Length (cm): 3.849
Area (cm²): 22.57
Volume (cm³): 86.88
Dry Density (g/cm³): 2.23
Dry Density (pcf): 139.23
Water Content (% g/g): 1.7
Water Content (% vol): 3.8
Porosity (% vol): 15.8
Saturation (%): 24.1

Final (Post Test) Sample Properties

Saturated Mass (g): 214.34
Dry Mass (g): 193.77
Diameter (cm): 5.361
Length (cm): 3.849
Area (cm²): 22.57
Volume (cm³): 86.88
Dry Density (g/cm³): 2.23
Dry Density (pcf): 139.23
Water Content (% g/g): 10.6
Water Content (% vol): 23.7
Porosity (% vol): 15.8
Saturation (%)*: 149.5

Test and Sample Conditions

Permeant liquid used: Water
Sample Preparation: In situ sample, extruded
 Remolded Sample
Number of Lifts: NA
Split: NA
Percent Coarse Material (%): NA
Particle Density (g/cm³): 2.65 Assumed Measured
Cell pressure (PSI): 32.0
Influent pressure (PSI): 30.2
Effluent pressure (PSI): 30.0
Panel Used: A B C
Reading: Annulus Pipette
B-Value (% saturation) prior to test*: 0.95
Date/Time: 3/20/07 1505

* Per ASTM D5084 percent saturation is ensured (B-Value \geq 95%) prior to testing, as post test saturation values may be exaggerated or skewed during depressurizing and sample removal.

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Flexible Wall Falling Head-Rising Tail Method

Job name: MWH AMERICAS, INC.

Job number: LB07.0048.00

Sample number: MW-30 44.0-44.5

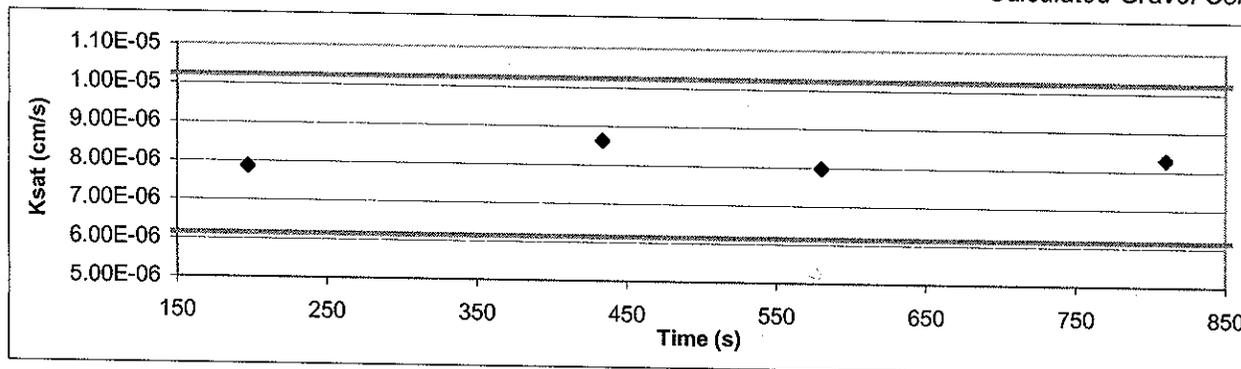
Date/Time sampled: NA

Depth: 44.0-44.5

Date	Time	Temp (°C)	Influent Pipette Reading	Effluent Pipette Reading	Gradient ($\Delta H/\Delta L$)	Average Flow (cm ³)	Elapsed Time (s)	Ratio (outflow to inflow)	Change in Head (Not to exceed 25%)	k _{sat} T°C (cm/s)	k _{sat} Corrected (cm/s)
Test # 1:											
20-Mar-07	14:23:21	24.2	1.20	19.60	9.18						
20-Mar-07	14:26:38	24.2	1.55	19.25	8.97	0.30	197	1.00	2%	8.68E-06	7.86E-06
Test # 2:											
20-Mar-07	14:26:38	24.2	1.55	19.25	8.97						
20-Mar-07	14:30:35	24.2	2.00	18.80	8.70	0.39	237	1.00	3%	9.53E-06	8.63E-06
Test # 3:											
20-Mar-07	14:30:35	24.2	2.00	18.80	8.70						
20-Mar-07	14:33:01	24.2	2.25	18.55	8.55	0.22	146	1.00	2%	8.80E-06	7.97E-06
Test # 4:											
20-Mar-07	14:33:01	24.2	2.25	18.55	8.55						
20-Mar-07	14:36:51	24.2	2.65	18.15	8.31	0.35	230	1.00	3%	9.15E-06	8.28E-06

Average Ksat (cm/sec): 8.19E-06

Calculated Gravel Corrected Average Ksat (cm/sec): ---



ASTM Required Range (+/- 25%)

Ksat (-25%) (cm/s): 6.14E-06

Ksat (+25%) (cm/s): 1.02E-05

Moisture Retention Characteristics



Daniel B. Stephens & Associates, Inc.

Summary of Moisture Characteristics of the Initial Drainage Curve

Sample Number	Pressure Head (-cm water)	Moisture Content (%, cm ³ /cm ³)
MW-23 55.5-56.0	0	18.2
	13	17.7
	35	17.6
	100	15.8
	510	8.5
	15195	3.2
	42832	2.1
	851293	0.3
MW-23 74.3-74.6	0	12.3
	14	12.3
	56	12.2
	155	11.9
	510	11.7
	43851	4.9
	851293	1.6
	MW-23 82.7-82.9	0
12		15.3
38		15.3
97		14.9
510		9.6
23557		3.4
851293		0.3
MW-23 103.3-103.5		0
	8	19.3
	24	19.2
	85	14.0
	510	6.8
	16827	3.3
	32838	2.5
	851293	0.6



Daniel B. Stephens & Associates, Inc.

**Summary of Moisture Characteristics
of the Initial Drainage Curve (Continued)**

Sample Number	Pressure Head (-cm water)	Moisture Content (%, cm^3/cm^3)	
MW-30 35.5-36.0	0	19.5	
	7	19.2	
	20	19.0	
	74	14.1	
	510	7.6	
	23251	2.6	
	35081	2.1	
	851293	0.4	
MW-30 44.0-44.5	0	27.9	
	35	26.7	
	101	24.7	
	197	23.6	
	510	20.5	
	23353	10.9	
	851293	3.4	
	MW-30 44.0-44.5 (Volume Adjusted)	0	26.7
35		25.6	
101		23.5	
197		22.4	
510		19.4	
23353		10.4	
851293		3.2	



Daniel B. Stephens & Associates, Inc.

Summary of Calculated Unsaturated Hydraulic Properties

Sample Number	α (cm^{-1})	N (dimensionless)	θ_r (% vol)	θ_s (% vol)	Oversize Corrected	
					θ_r (% vol)	θ_s (% vol)
MW-23 55.5-56.0	0.0103	1.3860	0.00	18.38	NA	NA
MW-23 74.3-74.6	0.0003	1.3544	0.00	12.16	NA	NA
MW-23 82.7-82.9	0.0069	1.3362	0.00	16.01	NA	NA
MW-23 103.3-103.5	0.0287	1.3494	0.00	20.51	NA	NA
MW-30 35.5-36.0	0.0266	1.3480	0.00	19.86	NA	NA
MW-30 44.0-44.5	0.0074	1.2019	0.00	27.59	NA	NA
MW-30 44.0-44.5 (Volume Adjusted)	0.0081	1.2006	0.00	26.43	NA	NA

--- = Oversize correction is unnecessary since coarse fraction < 5% of composite mass

NA = Not analyzed



Daniel B. Stephens & Associates, Inc.

Moisture Retention Data
Hanging Column/Pressure Plate/Thermocouple

Job Name: MWH AMERICAS, INC.	Dry wt. of sample (g): 171.46
Job Number: LB07.0048.00	Tare wt., ring (g): 0.00
Sample Number: MW-23 55.5-56.0	Tare wt., screen & clamp (g): 0.00
Ring Number: NA	Sample volume (cm ³): 84.63
Depth: 55.5-56.0	

Saturated weight* at 0 cm tension (g): 186.87
 Volume of water[†] in saturated sample (cm³): 15.41
 Saturated moisture content (% vol): 18.21
 Sample bulk density (g/cm³): 2.03

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Hanging column:	21-Mar-07 / 10:45	186.87	0.00	18.21
	27-Mar-07 / 10:10	186.47	12.50	17.74
	02-Apr-07 / 08:47	186.38	34.50	17.63
	10-Apr-07 / 13:05	184.81	99.80	15.77
Pressure plate:	19-Apr-07 / 08:35	178.62	509.90	8.46

Comments:

* Weight including tares

† Assumed density of water is 1.0 g/cm³

Laboratory analysis by: D. O'Dowd
 Data entered by: T. Bowekaty
 Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Moisture Retention Data Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 55.5-56.0
Ring Number: NA
Depth: 55.5-56.0

Dry weight* of water activity meter sample (g): 246.44
Tare weight, jar (g): 199.21
Sample bulk density (g/cm³): 2.03

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Water Activity Meter:	16-Apr-07 / 11:03	247.19	15195.0	3.22
	13-Apr-07 / 14:45	246.94	42831.6	2.14

Dry weight* of relative humidity box sample (g): 82.32
Tare weight (g): 39.51
Sample bulk density (g/cm³): 2.03

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Relative humidity box:	21-Mar-07 / 12:00	82.39	851293	0.32

Comments:

* Weight including tares

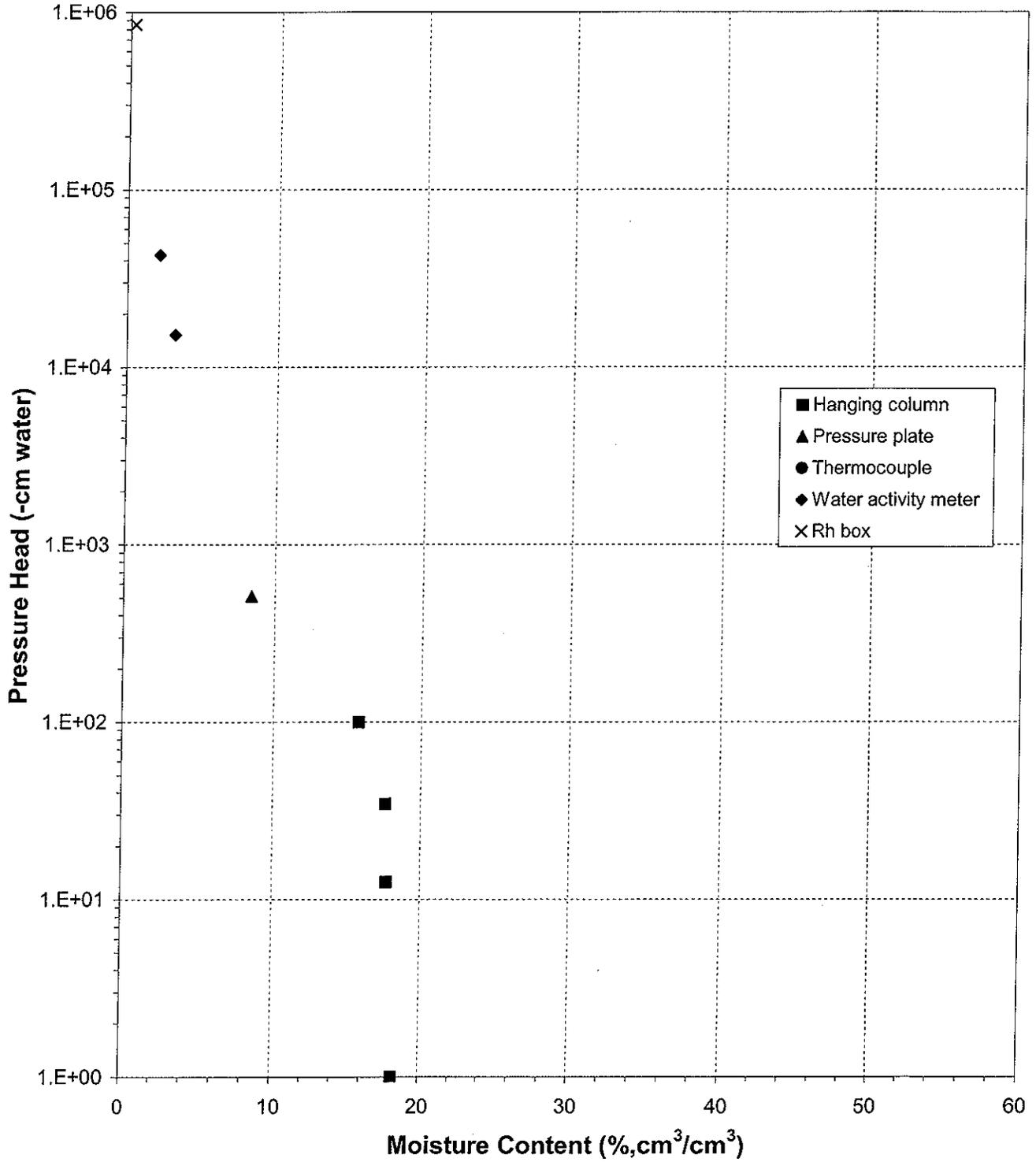
[†] Assumed density of water is 1.0 g/cm³

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

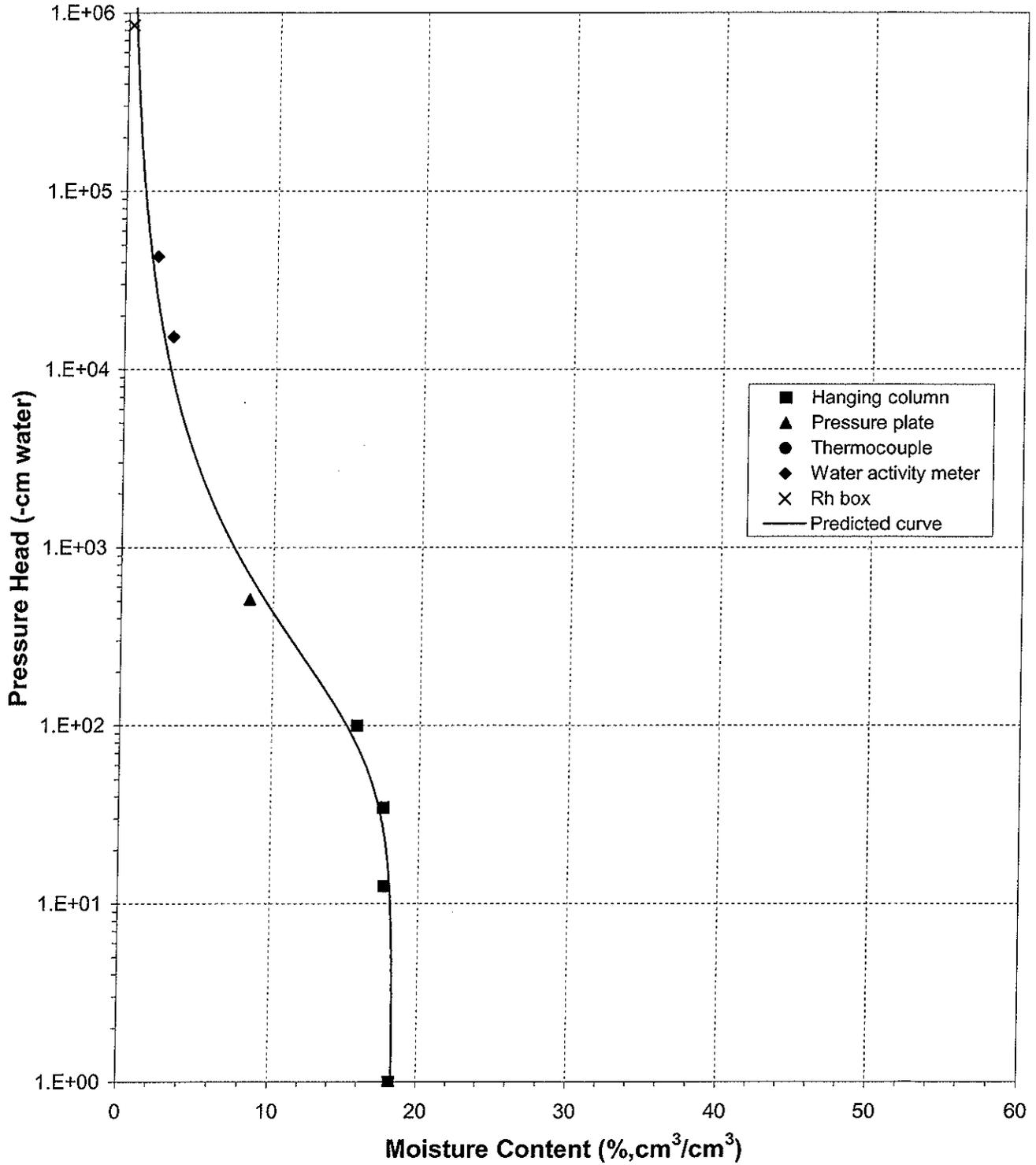
Sample Number: MW-23 55.5-56.0





Predicted Water Retention Curve and Data Points

Sample Number: MW-23 55.5-56.0

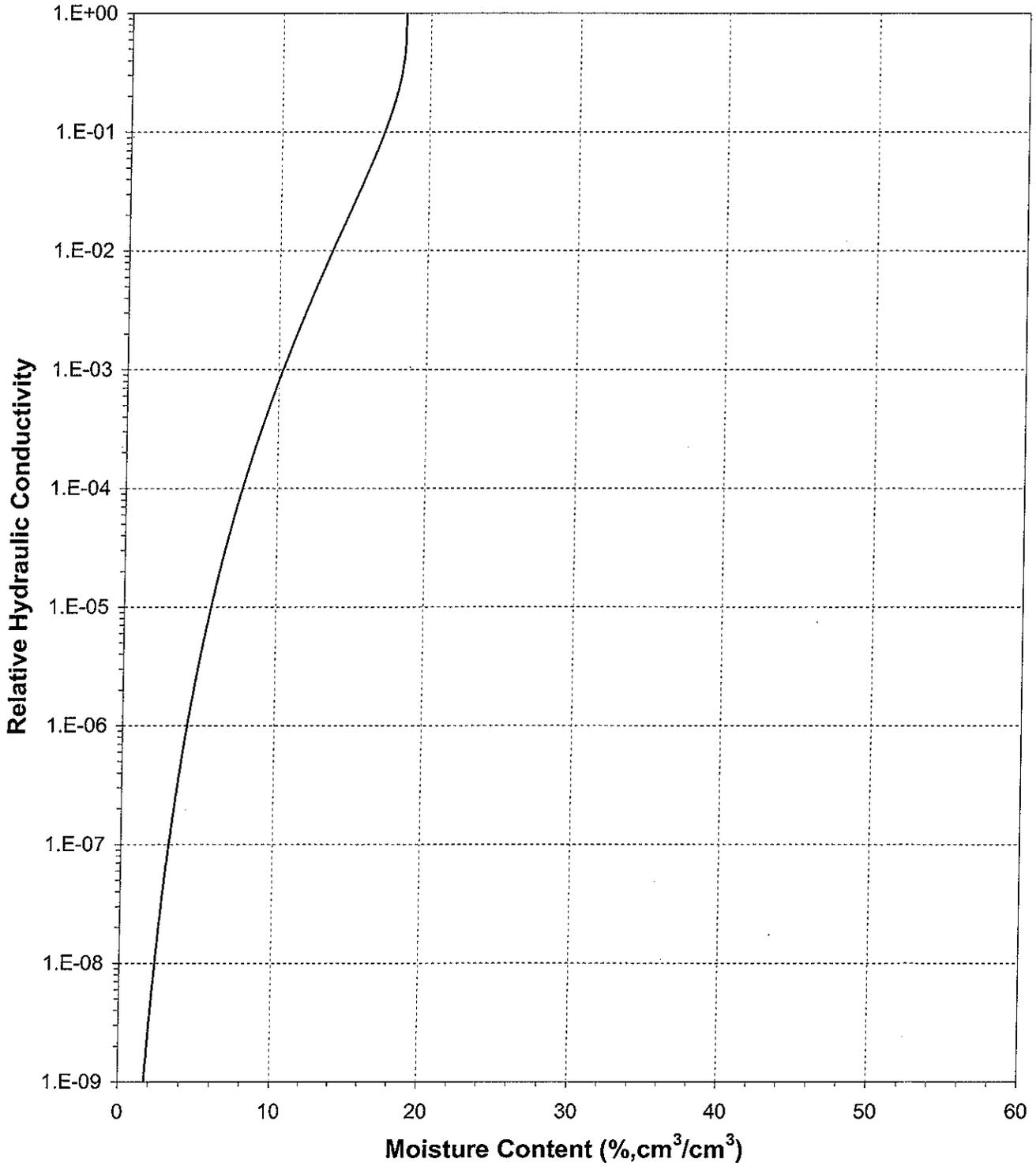




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 55.5-56.0

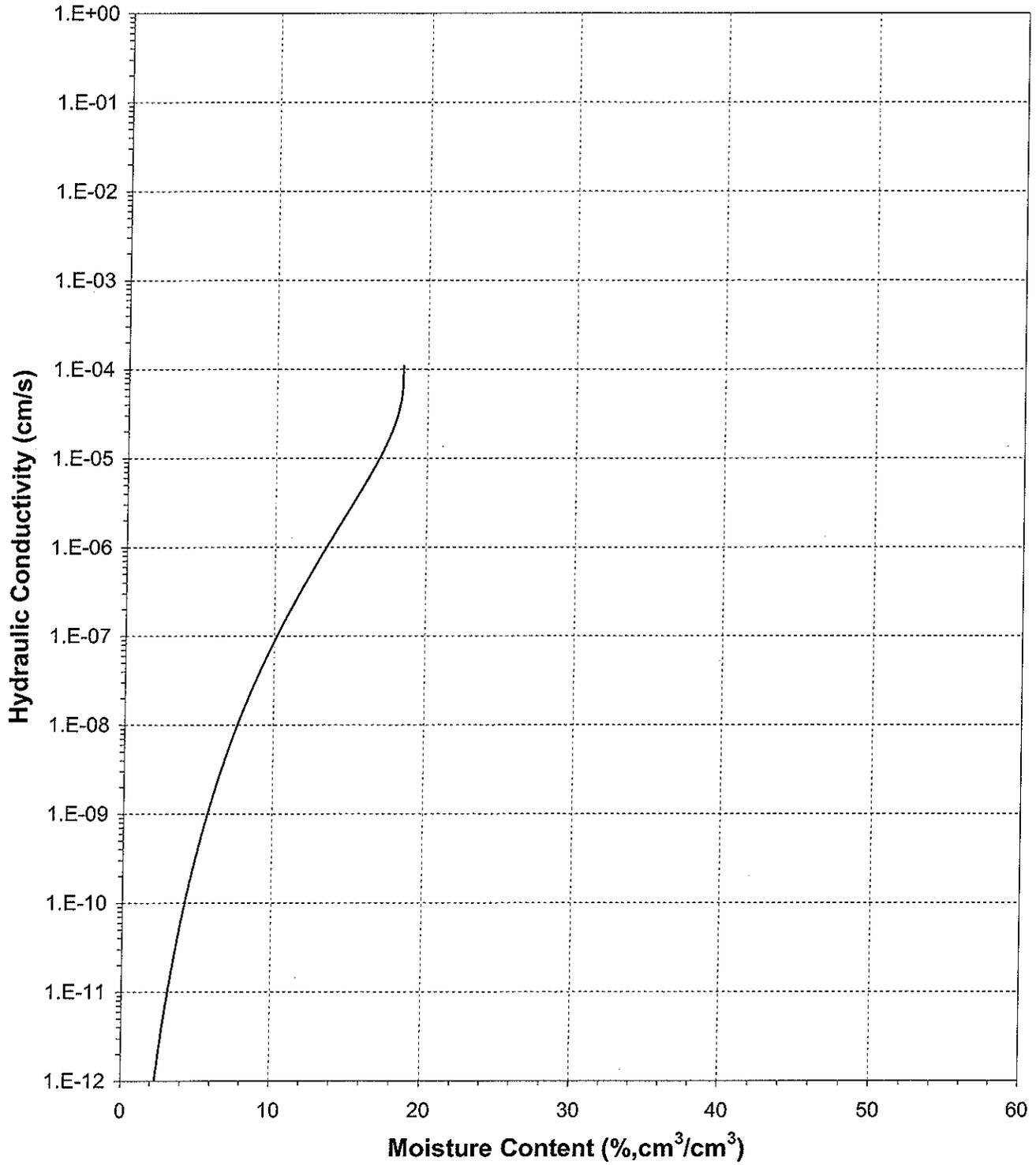




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 55.5-56.0

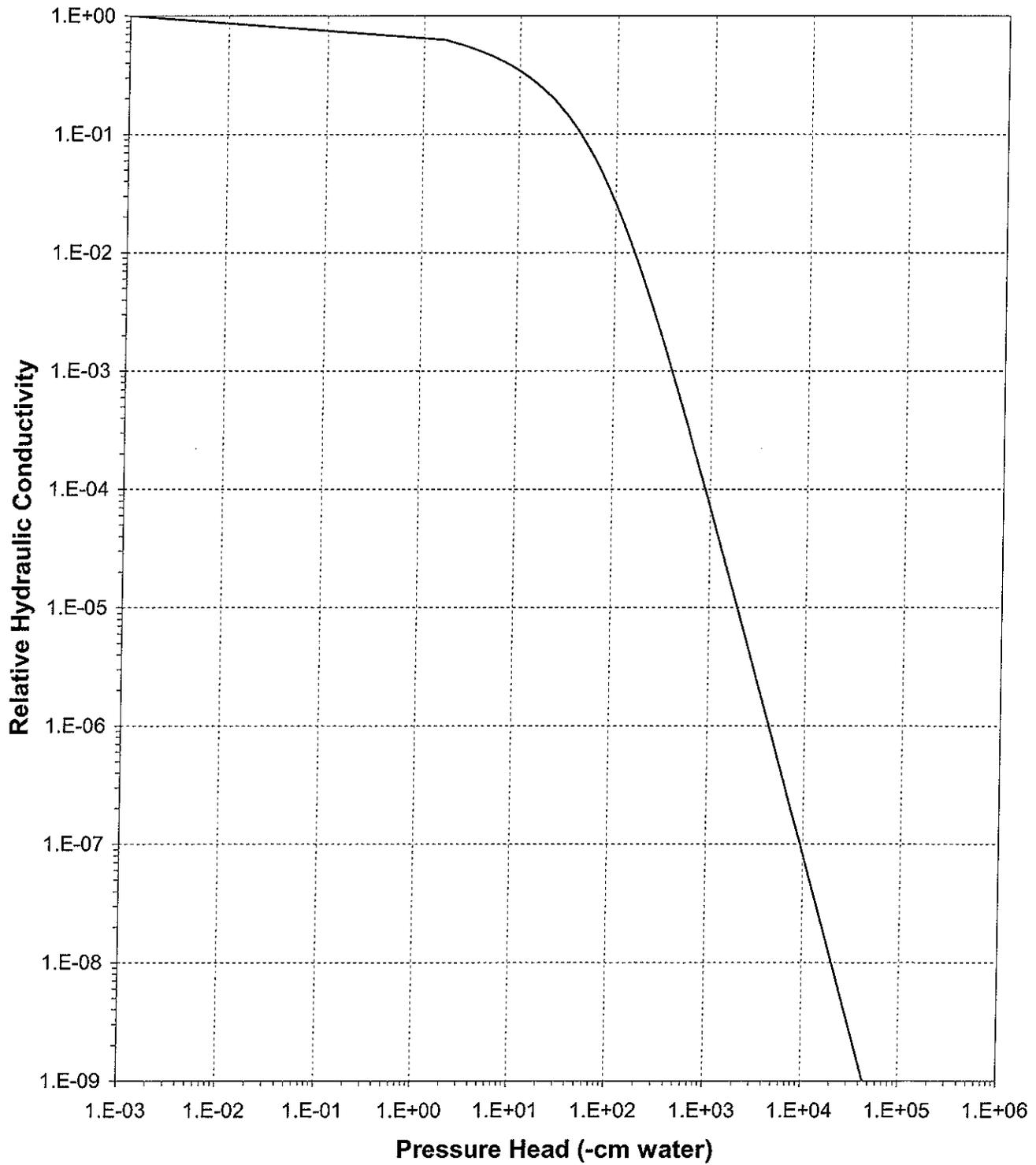




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 55.5-56.0

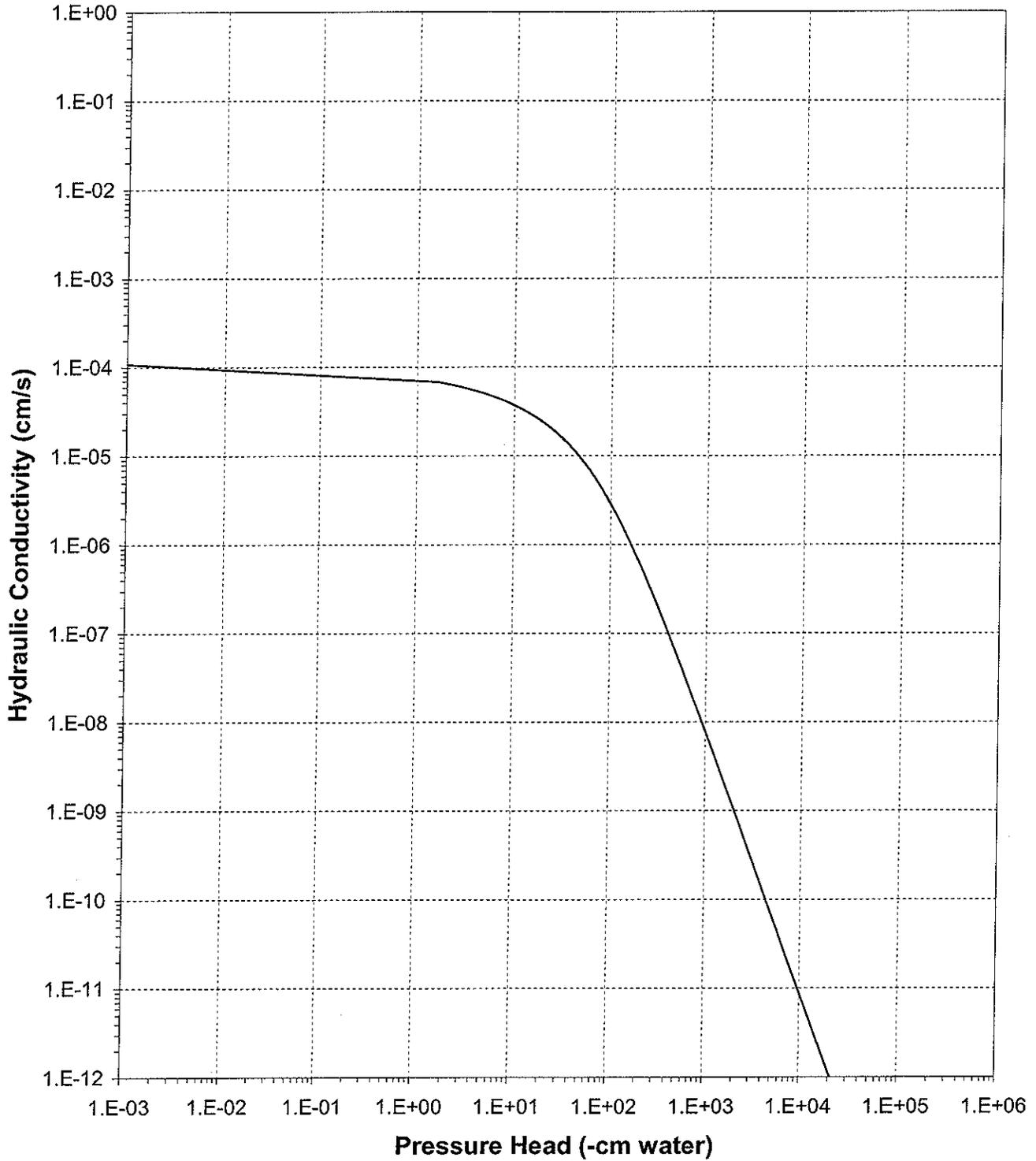




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 55.5-56.0





Daniel B. Stephens & Associates, Inc.

Moisture Retention Data Hanging Column/Pressure Plate/Thermocouple

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 74.3-74.6
Ring Number: NA
Depth: 74.3-74.6

Dry wt. of sample (g): 161.11
Tare wt., ring (g): 0.00
Tare wt., screen & clamp (g): 0.00
Sample volume (cm³): 69.19

Saturated weight* at 0 cm tension (g): 169.61
Volume of water[†] in saturated sample (cm³): 8.50
Saturated moisture content (% vol): 12.29
Sample bulk density (g/cm³): 2.33

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Hanging column:	21-Mar-07 / 10:45	169.61	0.00	12.29
	27-Mar-07 / 10:20	169.60	14.10	12.27
	02-Apr-07 / 08:50	169.58	56.40	12.24
	10-Apr-07 / 13:40	169.35	155.00	11.91
Pressure plate:	19-Apr-07 / 08:30	169.23	509.90	11.74

Comments:

* Weight including tares

† Assumed density of water is 1.0 g/cm³

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Moisture Retention Data Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 74.3-74.6
Ring Number: NA
Depth: 74.3-74.6

Dry weight* of water activity meter sample (g): 246.06
Tare weight, jar (g): 197.61
Sample bulk density (g/cm³): 2.33

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Water Activity Meter:	13-Apr-07 / 16:14	247.08	43851.4	4.90

Dry weight* of relative humidity box sample (g): 94.13
Tare weight (g): 41.67
Sample bulk density (g/cm³): 2.33

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Relative humidity box:	21-Mar-07 / 12:00	94.49	851293	1.60

Comments:

* Weight including tares

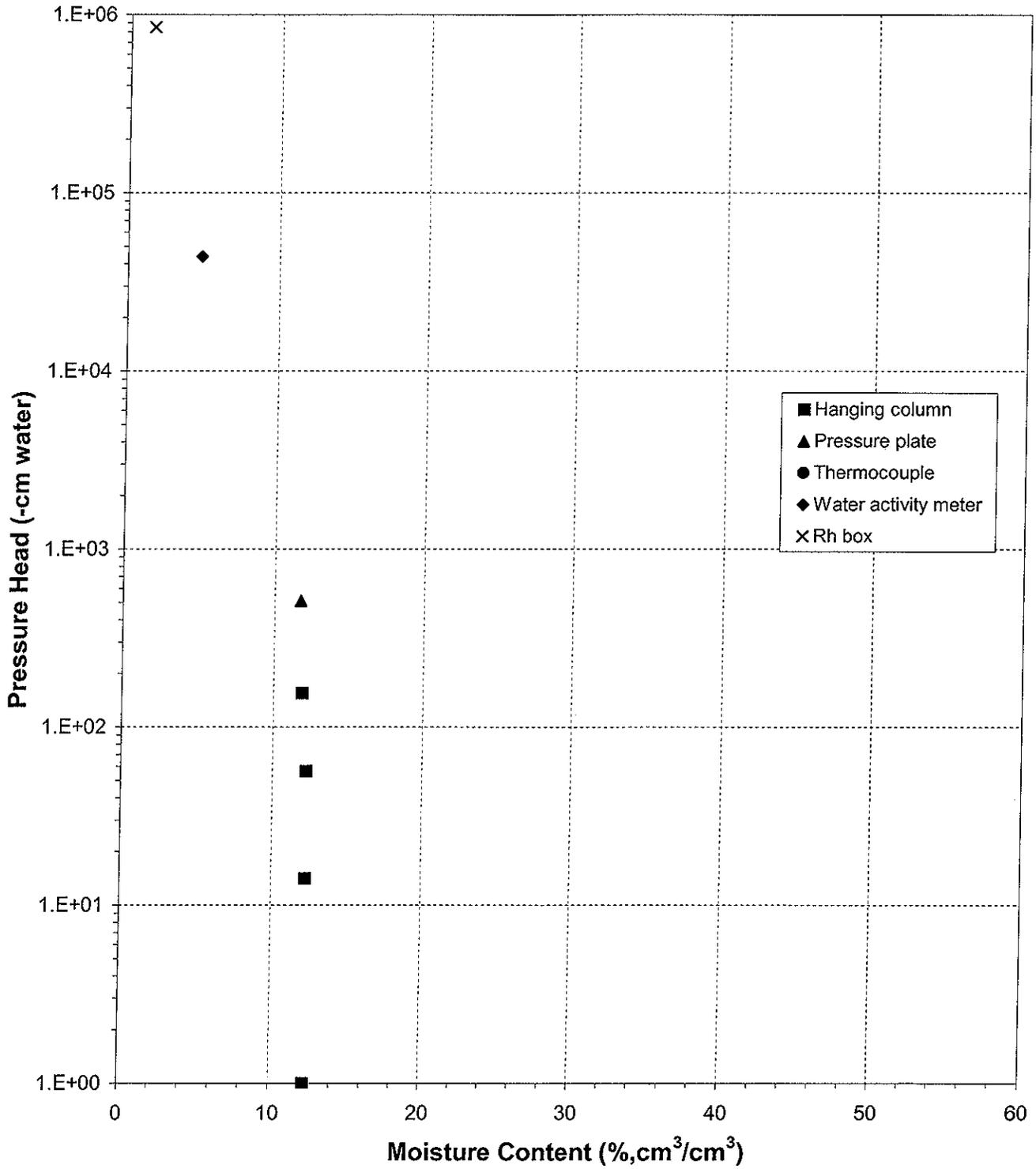
[†] Assumed density of water is 1.0 g/cm³

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

Sample Number: MW-23 74.3-74.6

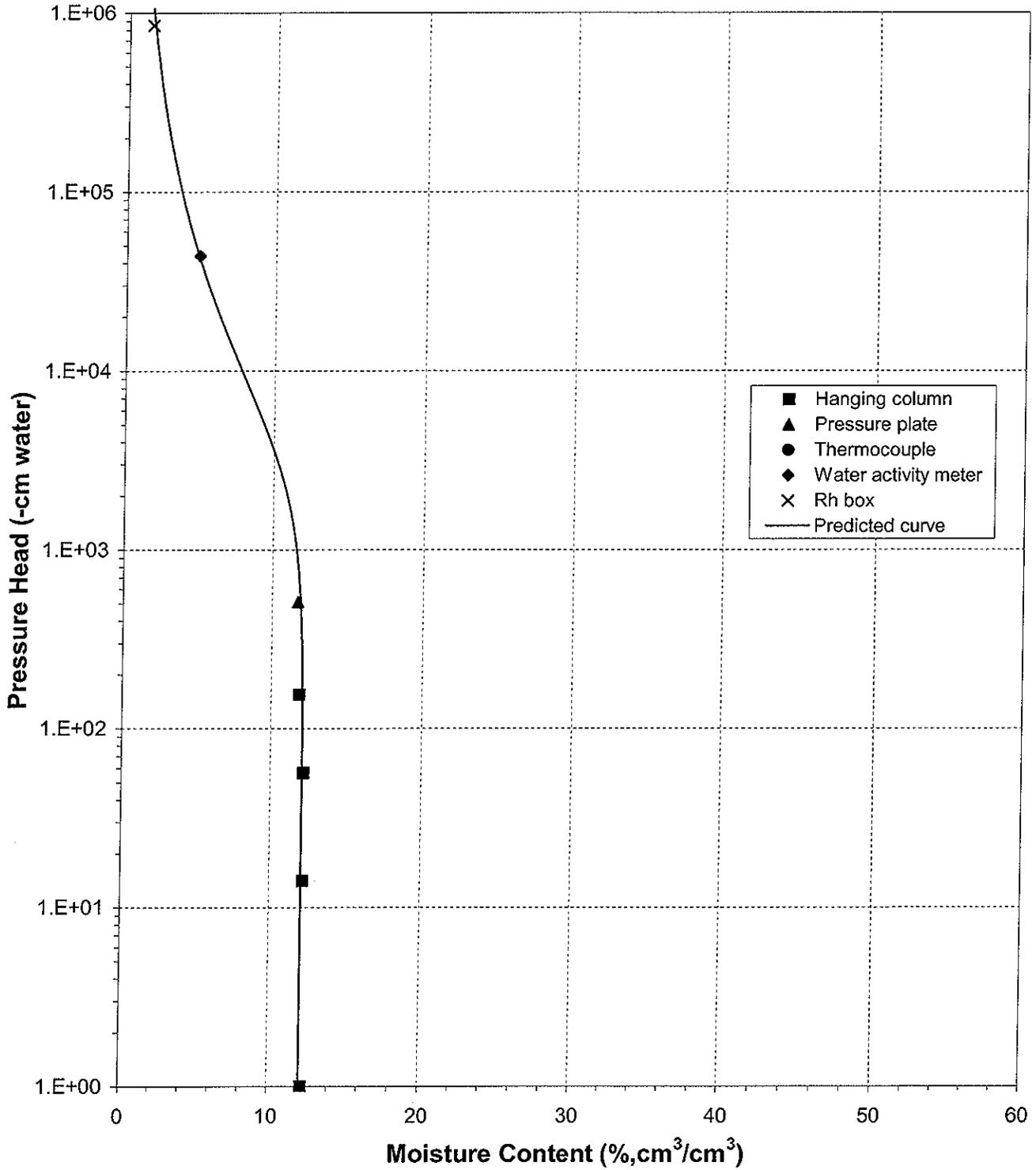




Daniel B. Stephens & Associates, Inc.

Predicted Water Retention Curve and Data Points

Sample Number: MW-23 74.3-74.6

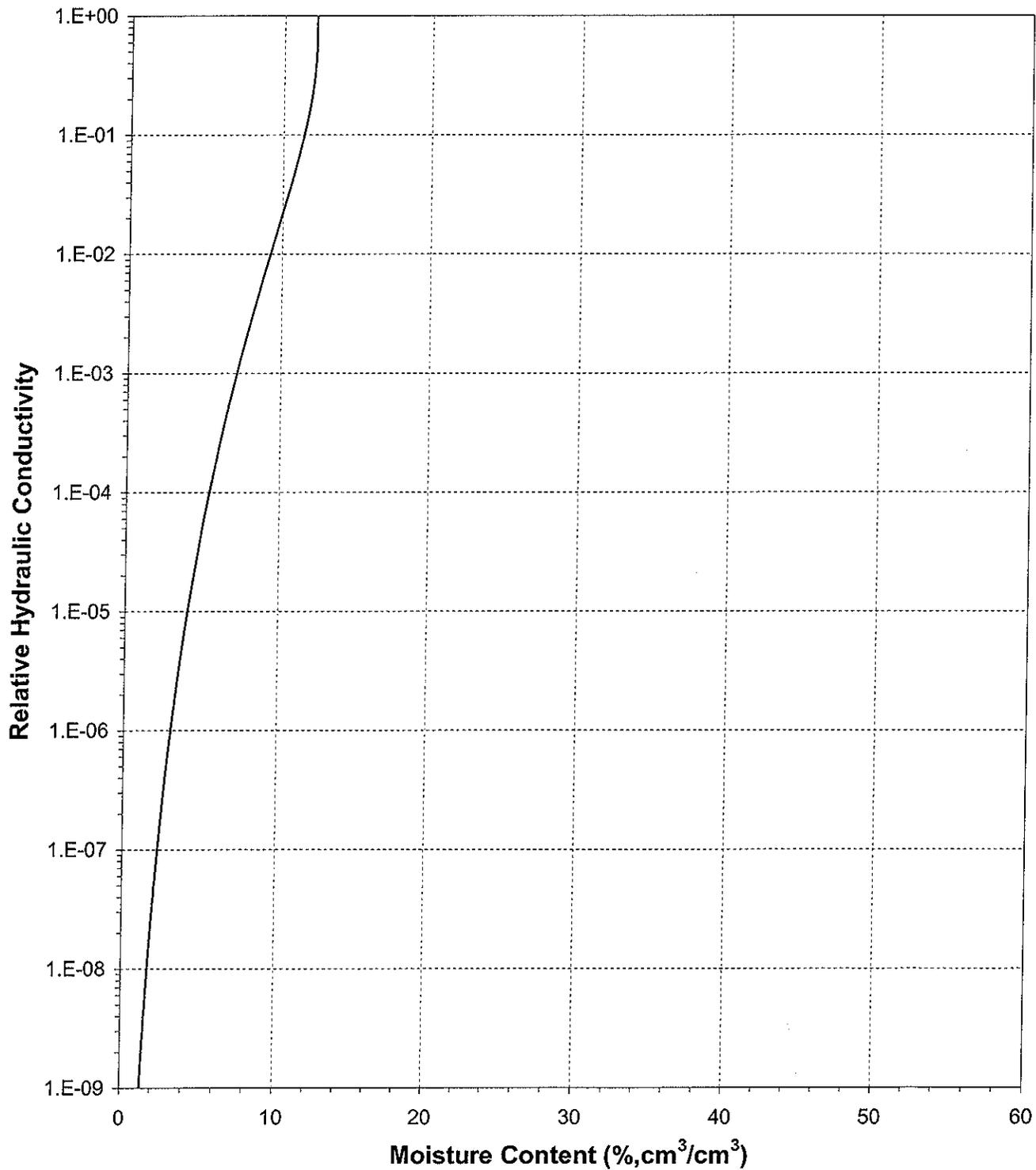




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 74.3-74.6

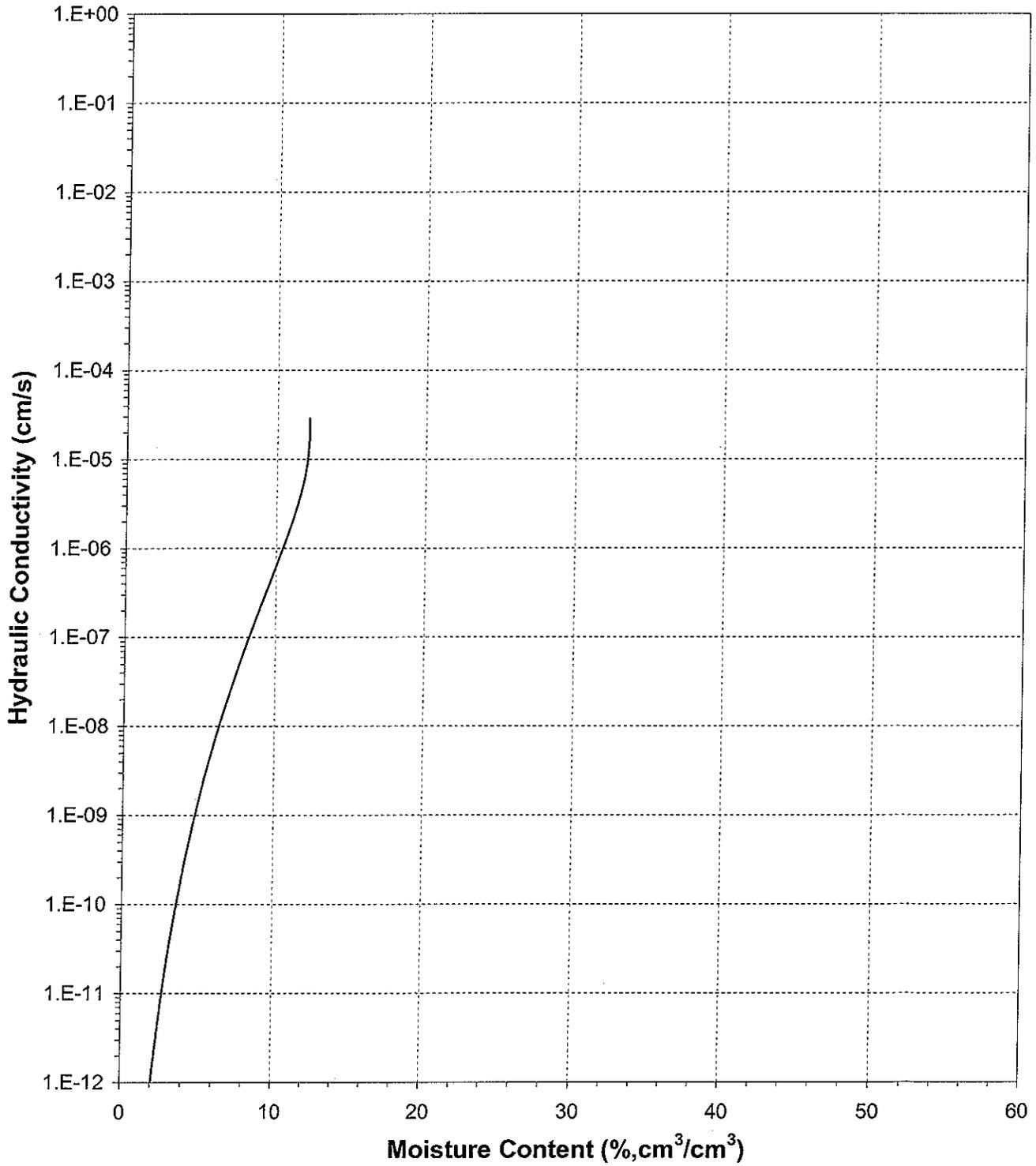




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 74.3-74.6

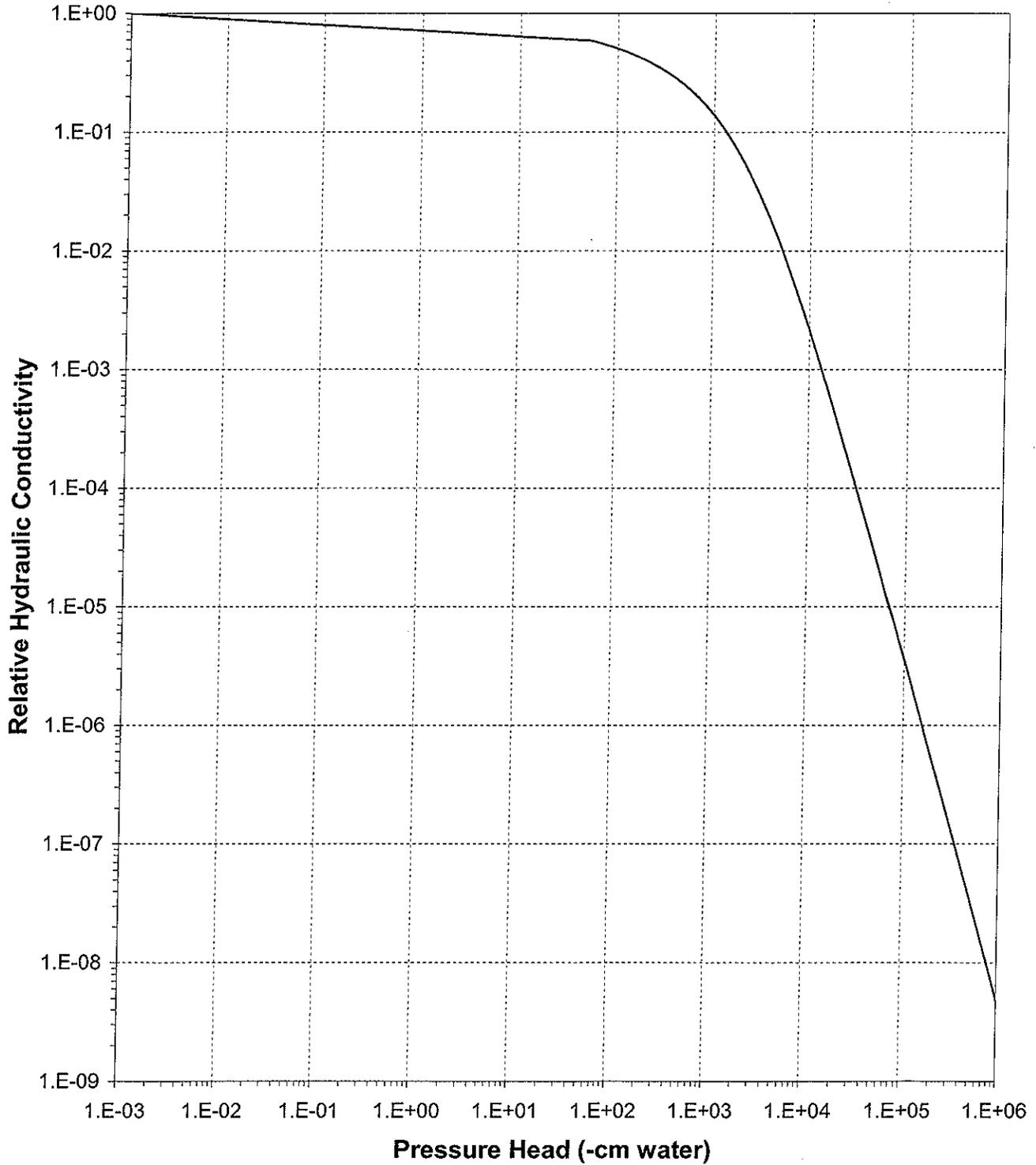




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 74.3-74.6

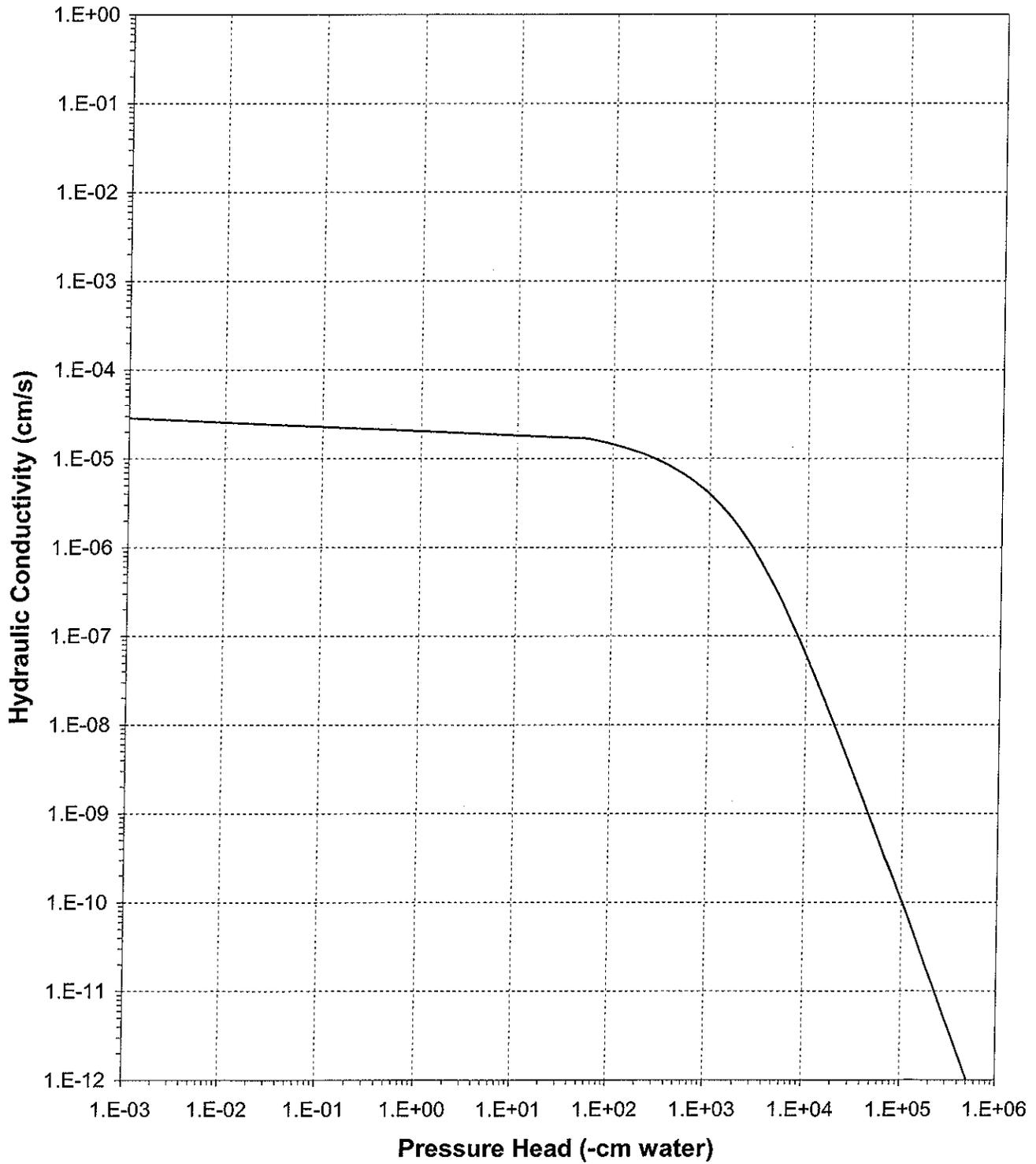




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 74.3-74.6





Daniel B. Stephens & Associates, Inc.

Moisture Retention Data
Hanging Column/Pressure Plate/Thermocouple

Job Name: MWH AMERICAS, INC.	Dry wt. of sample (g): 151.98
Job Number: LB07.0048.00	Tare wt., ring (g): 0.00
Sample Number: MW-23 82.7-82.9	Tare wt., screen & clamp (g): 0.00
Ring Number: NA	Sample volume (cm ³): 72.35
Depth: 82.7-82.9	

Saturated weight* at 0 cm tension (g): 163.80
 Volume of water[†] in saturated sample (cm³): 11.82
 Saturated moisture content (% vol): 16.34
 Sample bulk density (g/cm³): 2.10

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Hanging column:	19-Mar-07 / 15:30	163.80	0.00	16.34
	25-Mar-07 / 15:00	163.08	11.80	15.34
	31-Mar-07 / 08:15	163.02	38.00	15.26
	10-Apr-07 / 13:10	162.73	96.50	14.86
Pressure plate:	19-Apr-07 / 08:40	158.95	509.90	9.63

Comments:

* Weight including tares

[†] Assumed density of water is 1.0 g/cm³

Laboratory analysis by: D. O'Dowd
 Data entered by: T. Bowekaty
 Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Moisture Retention Data
Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 82.7-82.9
Ring Number: NA
Depth: 82.7-82.9

Dry weight* of water activity meter sample (g): 240.86
Tare weight, jar (g): 197.73
Sample bulk density (g/cm³): 2.10

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Water Activity Meter:	16-Apr-07 / 11:13	241.56	23557.4	3.41

Dry weight* of relative humidity box sample (g): 64.98
Tare weight (g): 41.87
Sample bulk density (g/cm³): 2.10

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Relative humidity box:	22-Mar-07 / 12:00	65.02	851293	0.35

Comments:

* Weight including tares

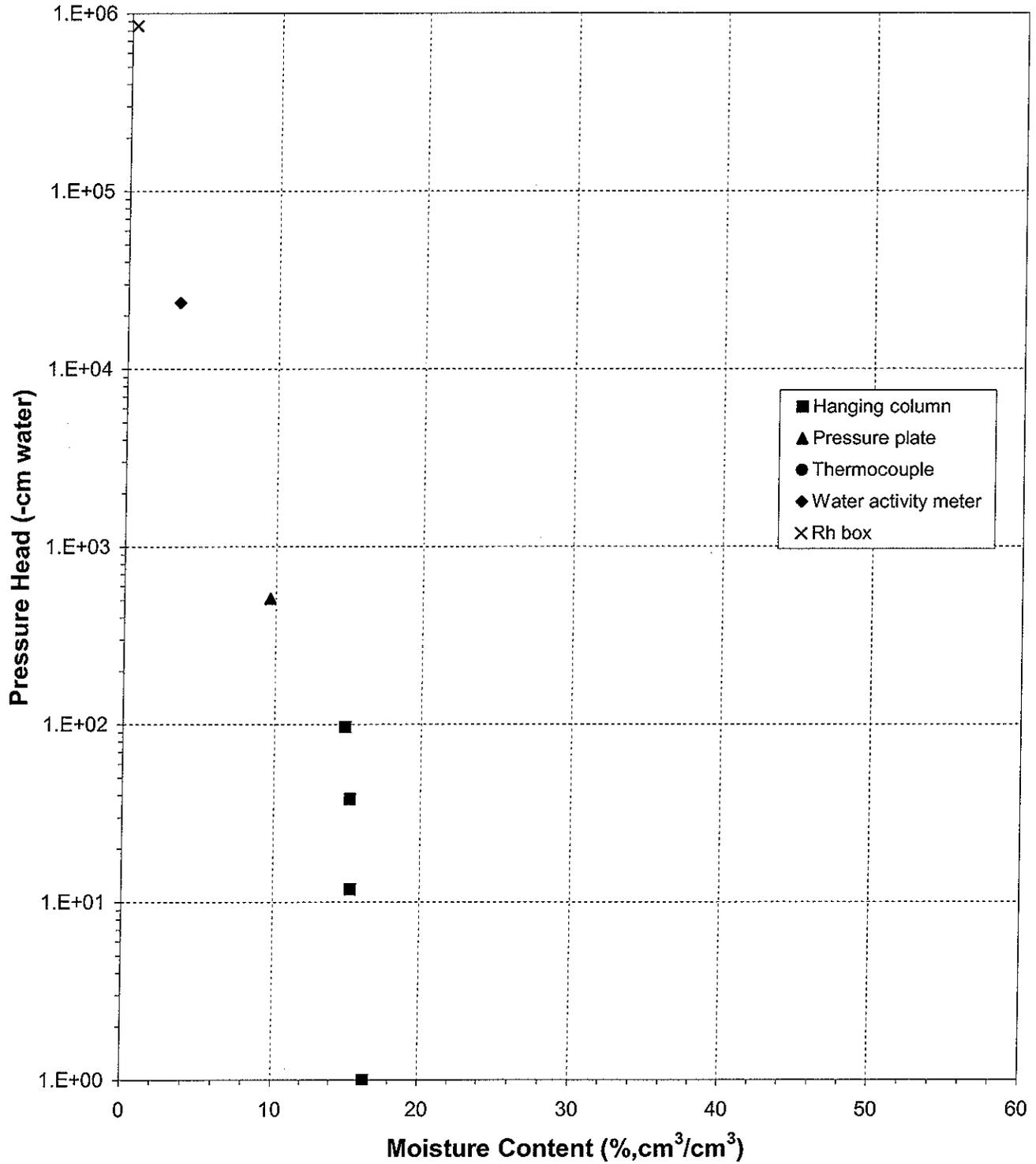
[†] Assumed density of water is 1.0 g/cm³

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

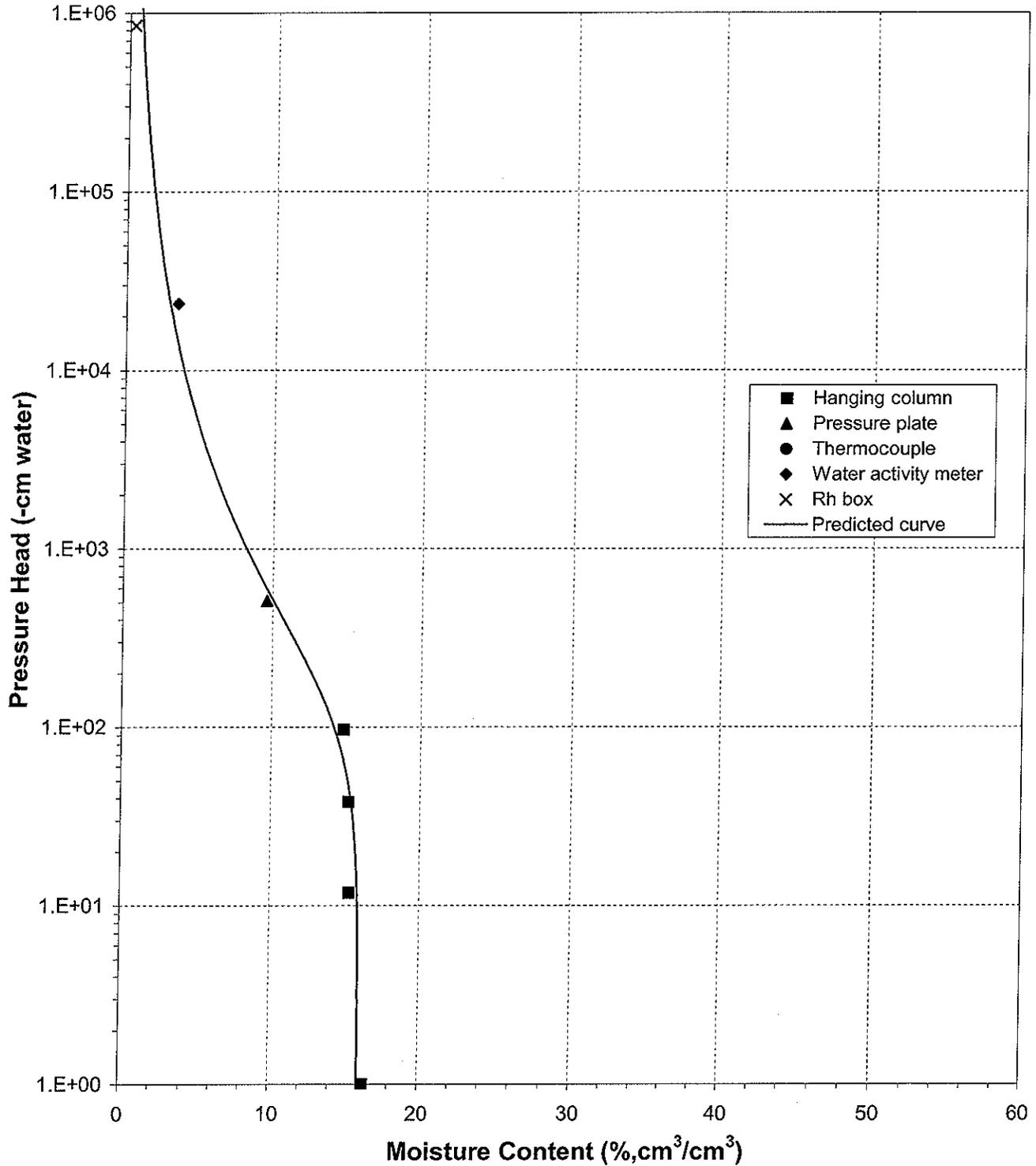
Sample Number: MW-23 82.7-82.9





Predicted Water Retention Curve and Data Points

Sample Number: MW-23 82.7-82.9

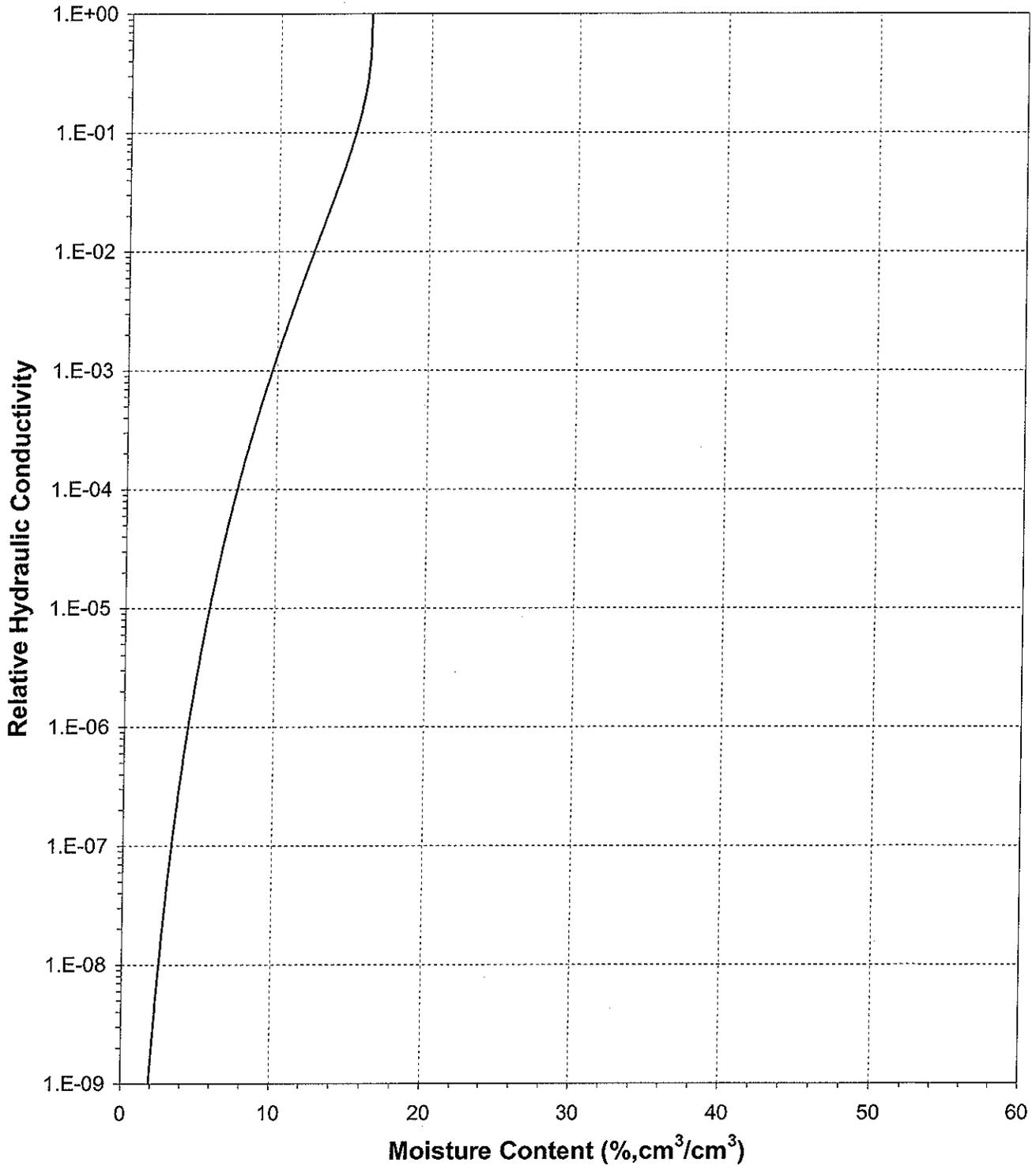




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 82.7-82.9

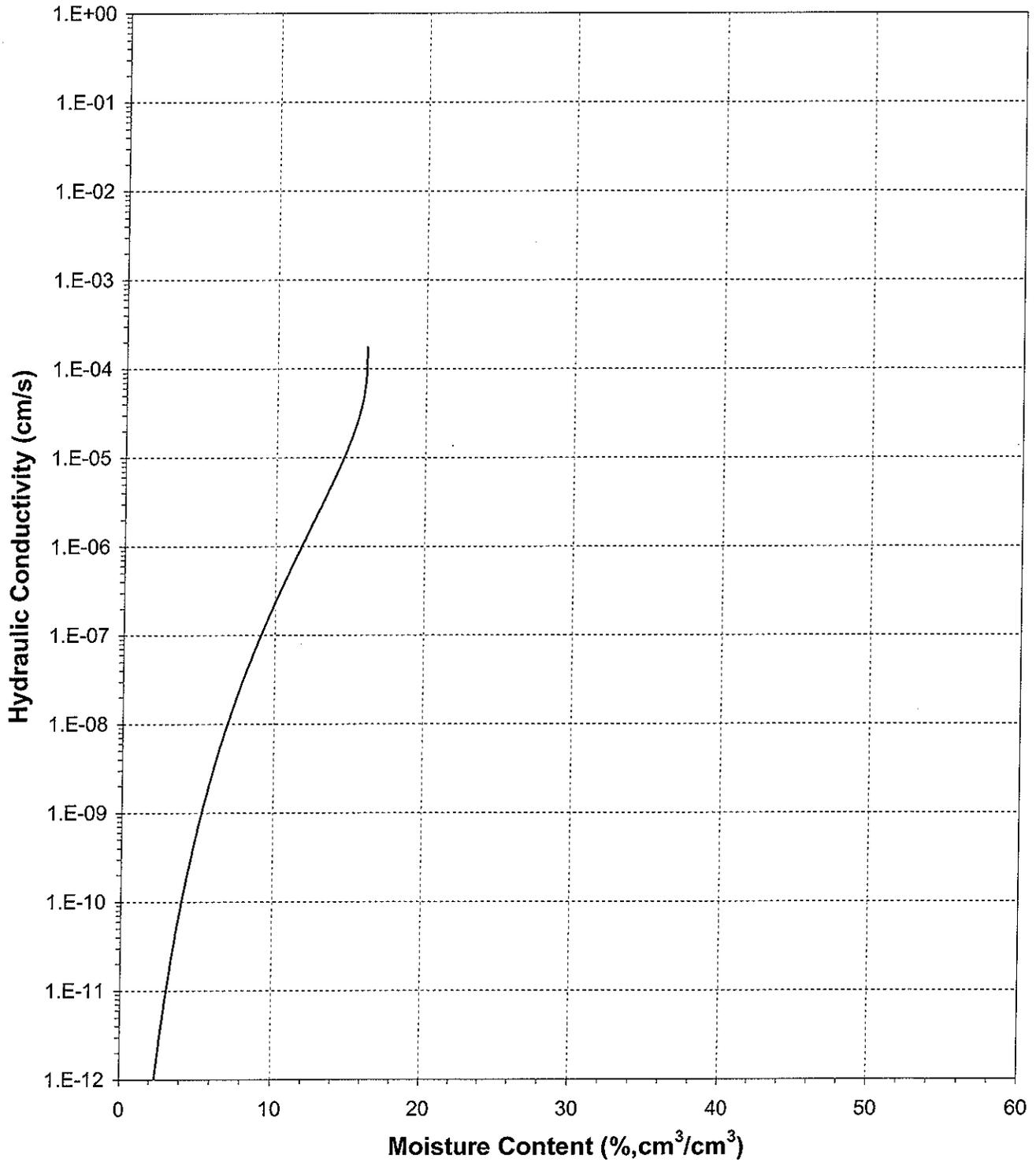




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 82.7-82.9

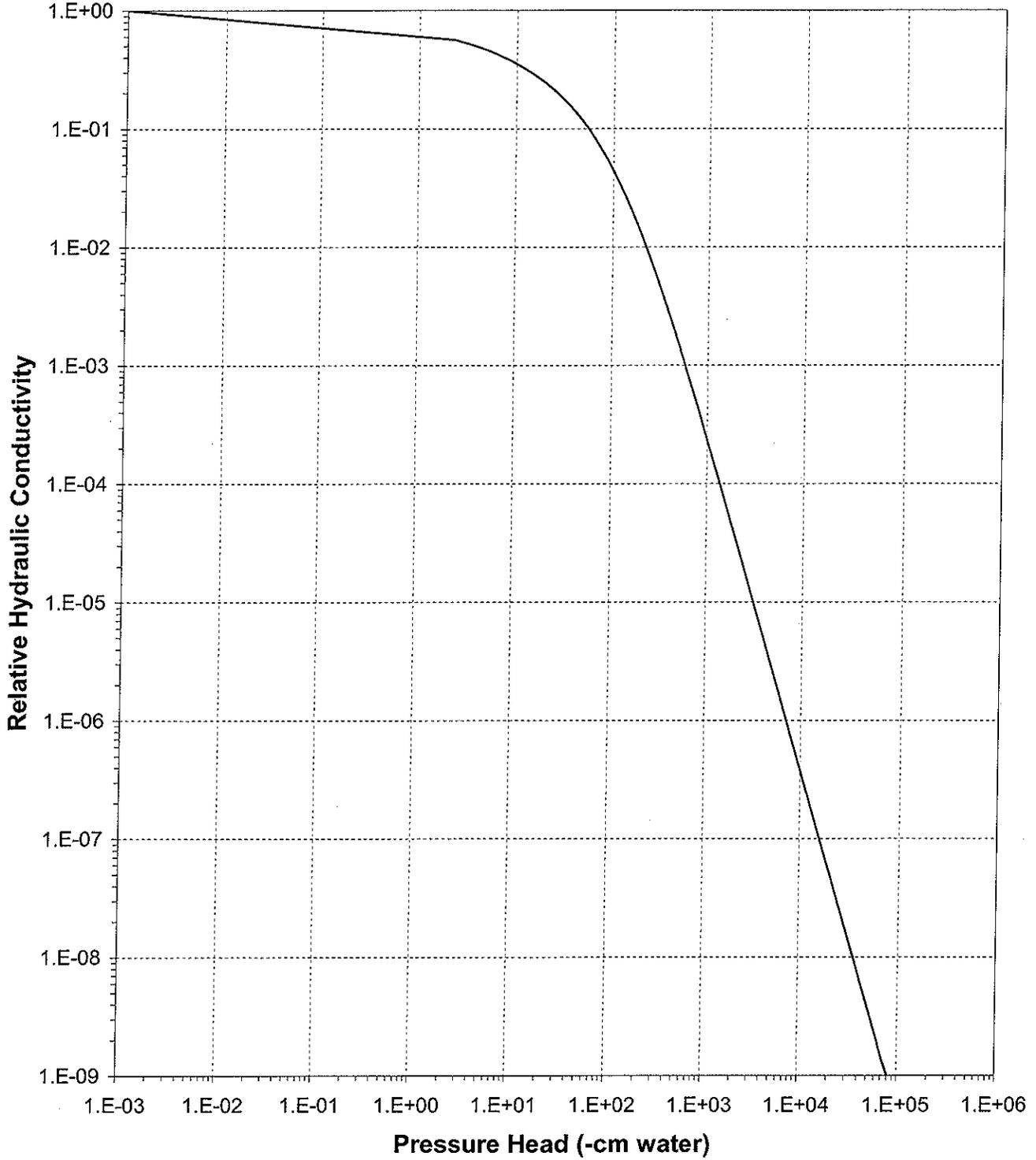




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 82.7-82.9

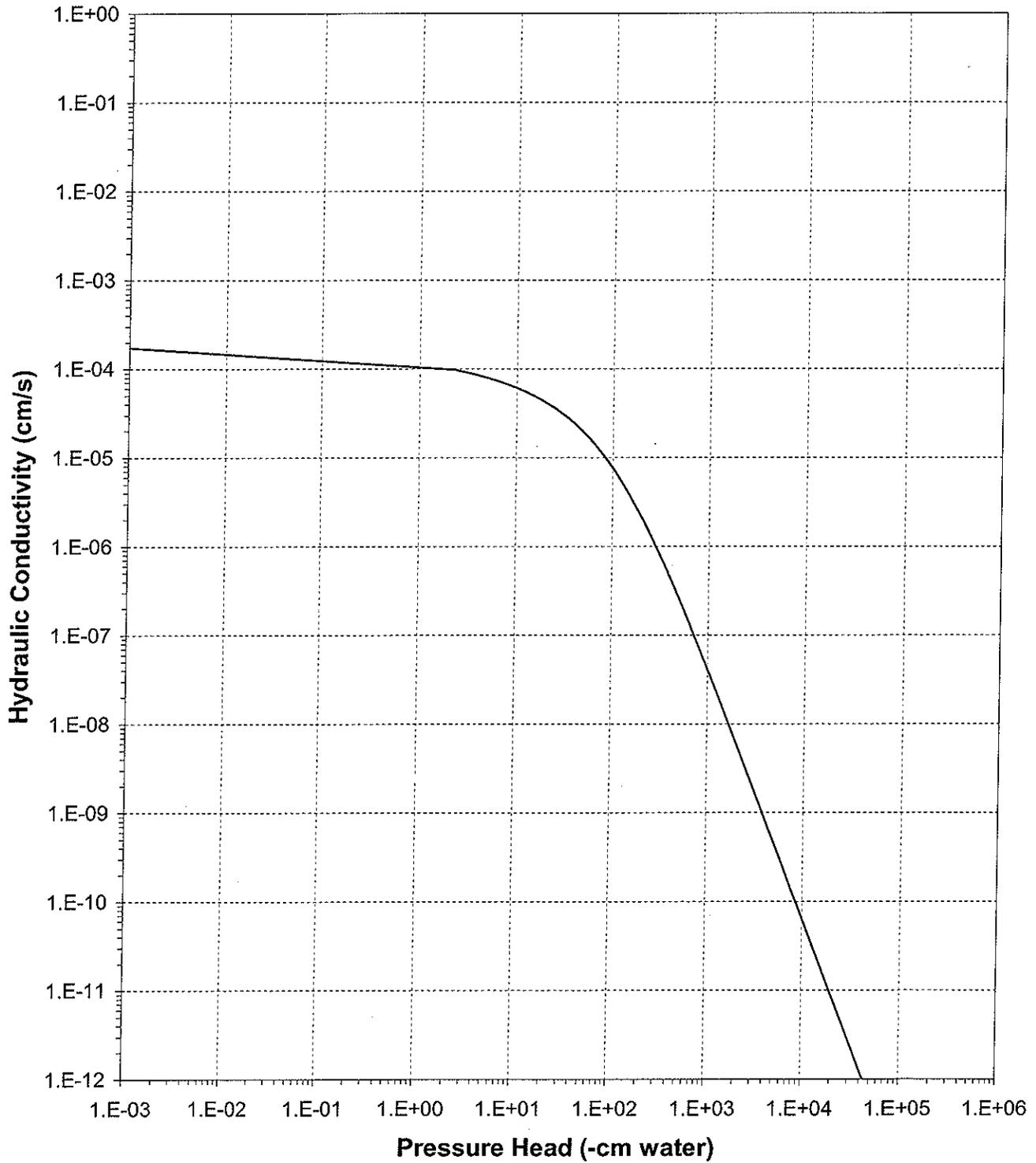




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 82.7-82.9





Daniel B. Stephens & Associates, Inc.

Moisture Retention Data
Hanging Column/Pressure Plate/Thermocouple

Job Name: MWH AMERICAS, INC.	Dry wt. of sample (g): 126.16
Job Number: LB07.0048.00	Tare wt., ring (g): 0.00
Sample Number: MW-23 103.3-103.5	Tare wt., screen & clamp (g): 0.00
Ring Number: NA	Sample volume (cm ³): 68.67
Depth: 103.3-103.5	

Saturated weight* at 0 cm tension (g): 140.16
 Volume of water[†] in saturated sample (cm³): 14.00
 Saturated moisture content (% vol): 20.39
 Sample bulk density (g/cm³): 1.84

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Hanging column:	19-Mar-07 / 15:30	140.16	0.00	20.39
	25-Mar-07 / 15:02	139.41	7.60	19.30
	31-Mar-07 / 08:15	139.36	23.50	19.22
	10-Apr-07 / 13:15	135.79	85.00	14.02
Pressure plate:	19-Apr-07 / 08:40	130.83	509.90	6.80

Comments:

* Weight including tares

† Assumed density of water is 1.0 g/cm³

Laboratory analysis by: D. O'Dowd
 Data entered by: T. Bowekaty
 Checked by: J. Hines



Moisture Retention Data
Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-23 103.3-103.5
Ring Number: NA
Depth: 103.3-103.5

Dry weight* of water activity meter sample (g): 259.47
Tare weight, jar (g): 199.70
Sample bulk density (g/cm³): 1.84

Table with 4 columns: Date/Time, Weight* (g), Matric Potential (-cm water), Moisture Content† (% vol). Rows for Water Activity Meter at 13-Apr-07 and 12-Apr-07.

Dry weight* of relative humidity box sample (g): 87.89
Tare weight (g): 38.83
Sample bulk density (g/cm³): 1.84

Table with 4 columns: Date/Time, Weight* (g), Matric Potential (-cm water), Moisture Content† (% vol). Row for Relative humidity box at 23-Mar-07.

Comments:

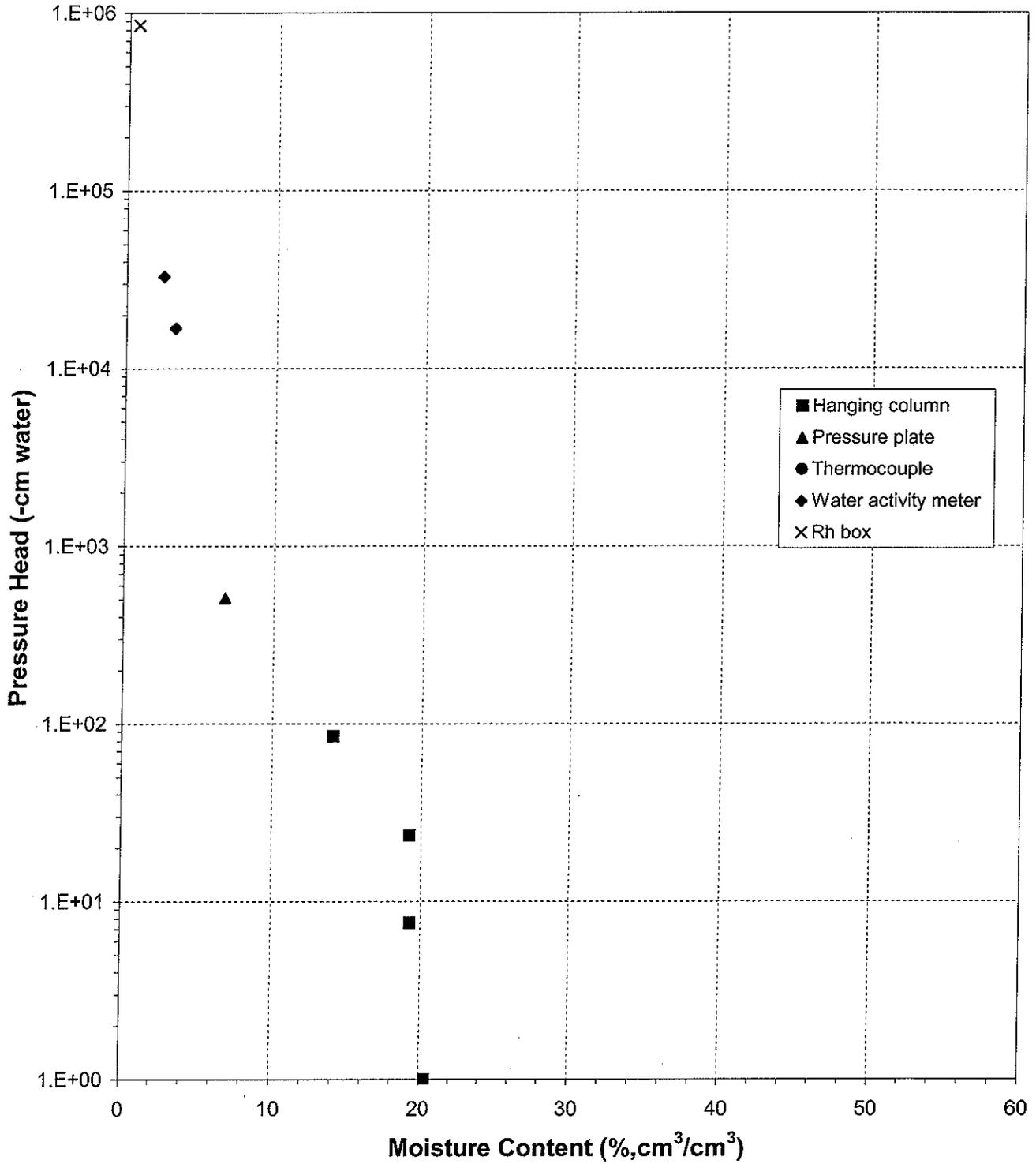
- * Weight including tares
† Assumed density of water is 1.0 g/cm³

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

Sample Number: MW-23 103.3-103.5

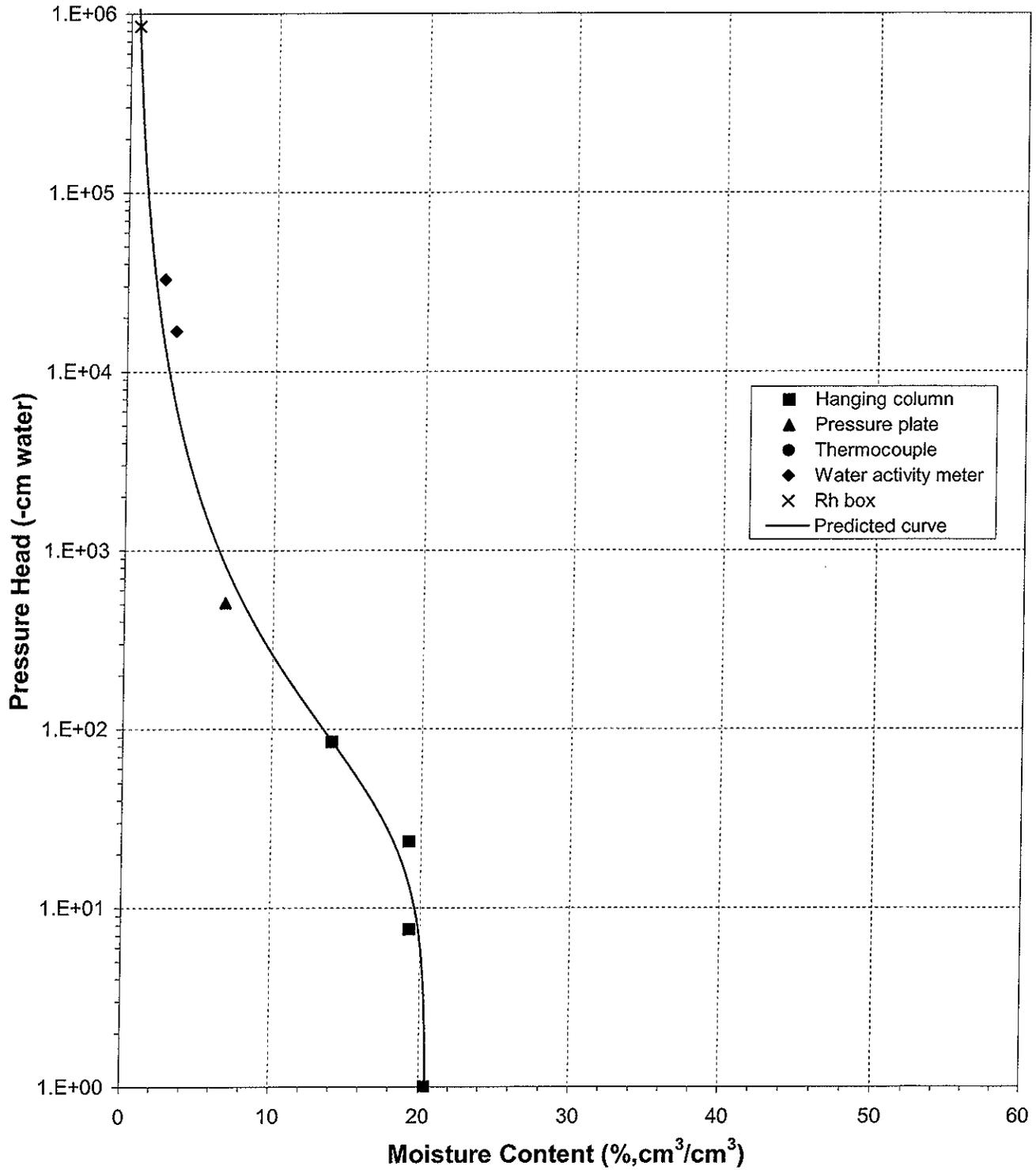




Daniel B. Stephens & Associates, Inc.

Predicted Water Retention Curve and Data Points

Sample Number: MW-23 103.3-103.5

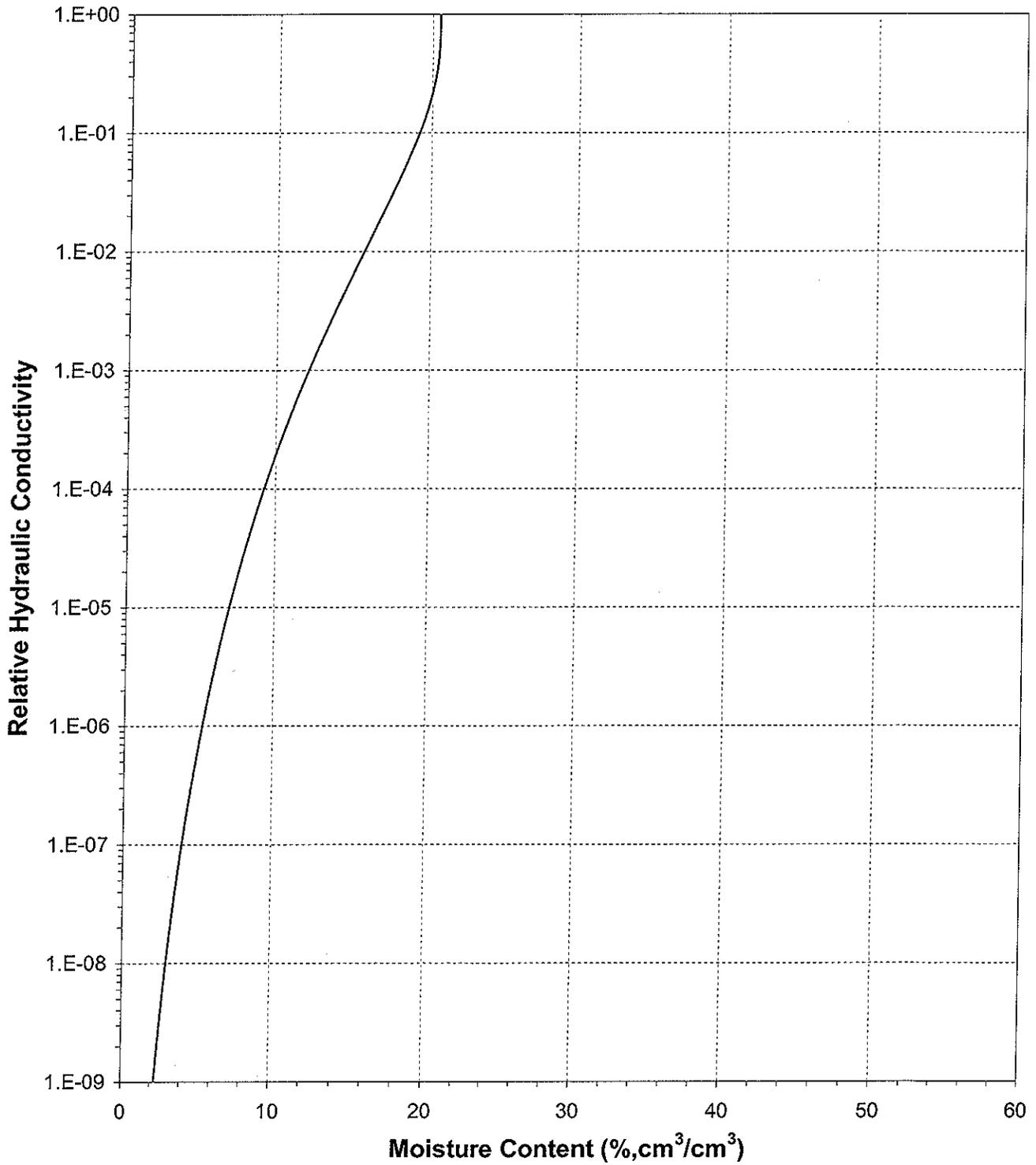




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 103.3-103.5

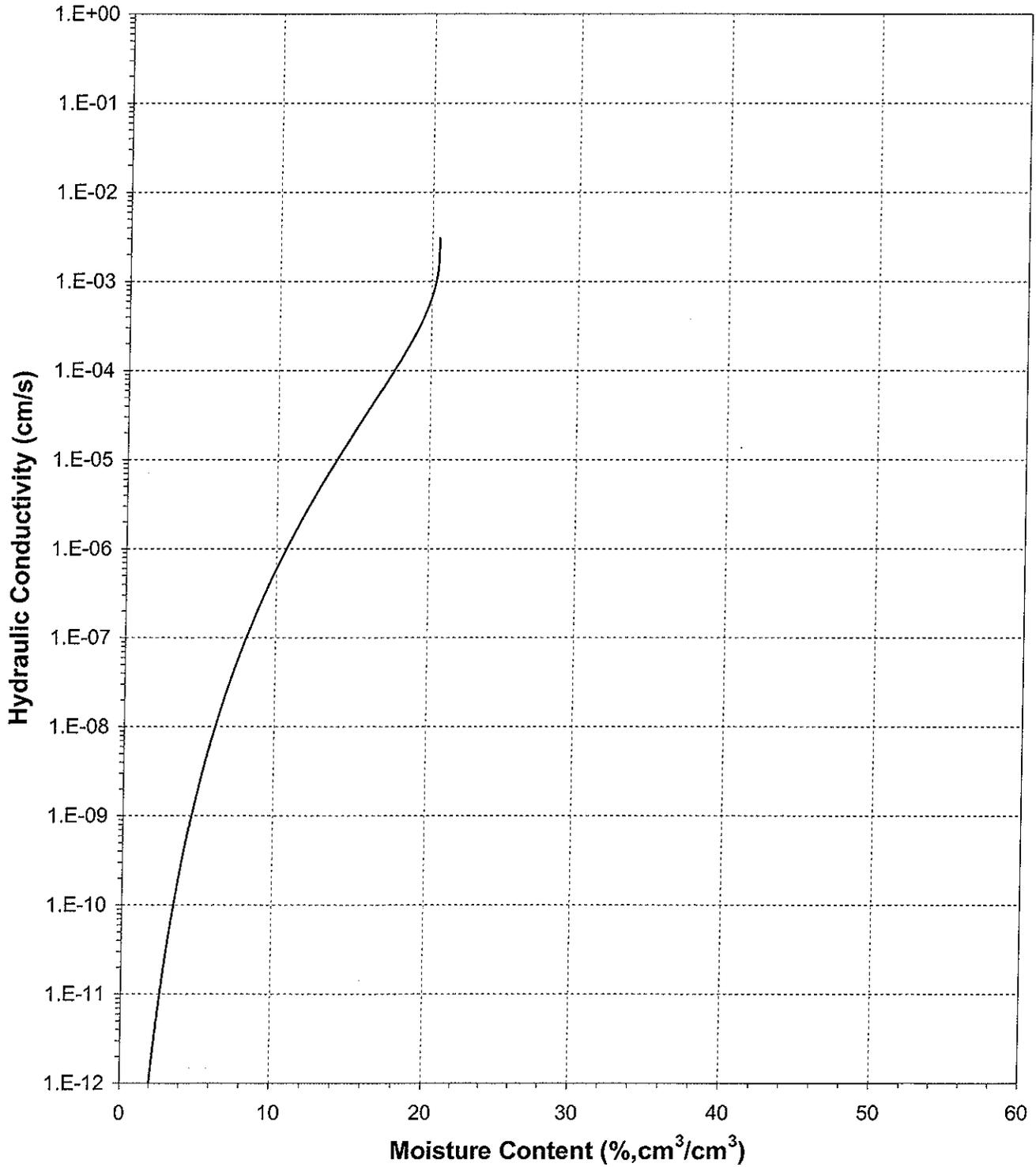




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

Sample Number: MW-23 103.3-103.5

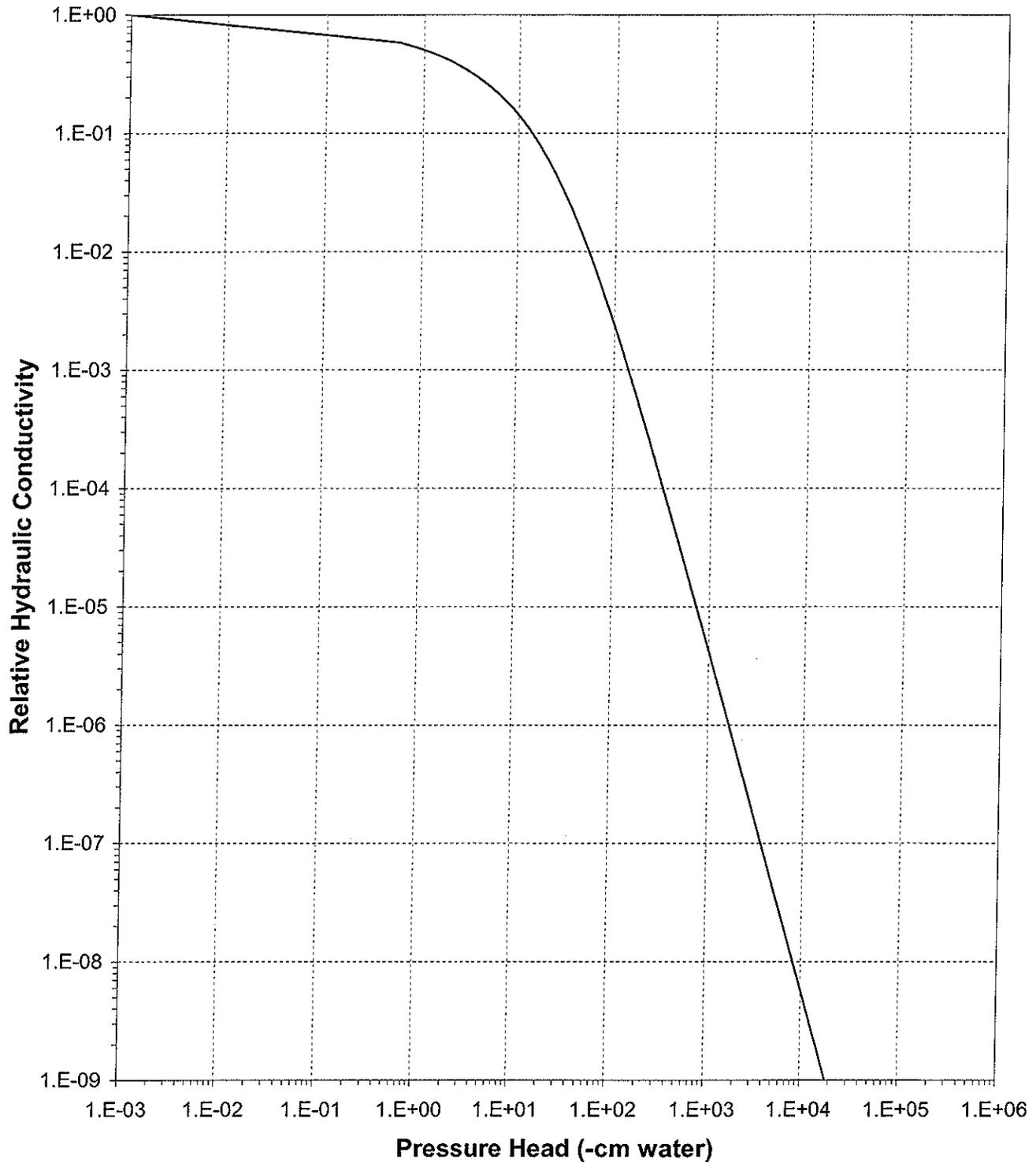




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 103.3-103.5

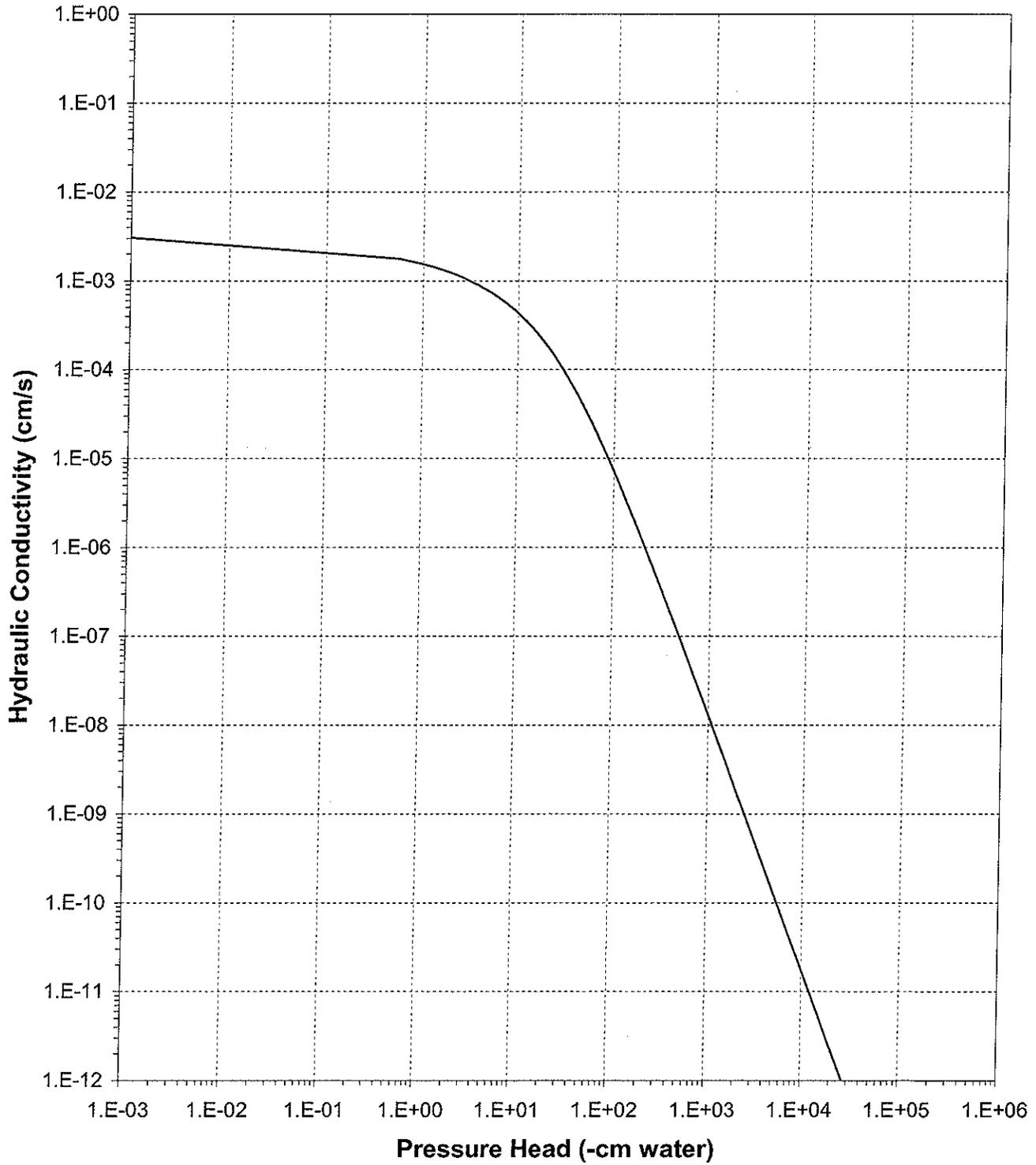




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-23 103.3-103.5





Moisture Retention Data
Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-30 35.5-36.0
Ring Number: NA
Depth: 35.5'-36.0'

Dry weight* of water activity meter sample (g): 272.00
Tare weight, jar (g): 199.26
Sample bulk density (g/cm^3): 1.98

Table with 5 columns: Date/Time, Weight* (g), Matric Potential (-cm water), Moisture Content† (% vol). Rows for Water Activity Meter on 13-Apr-07 and 12-Apr-07.

Dry weight* of relative humidity box sample (g): 57.87
Tare weight (g): 38.35
Sample bulk density (g/cm^3): 1.98

Table with 5 columns: Date/Time, Weight* (g), Matric Potential (-cm water), Moisture Content† (% vol). Row for Relative humidity box on 24-Mar-07.

Comments:

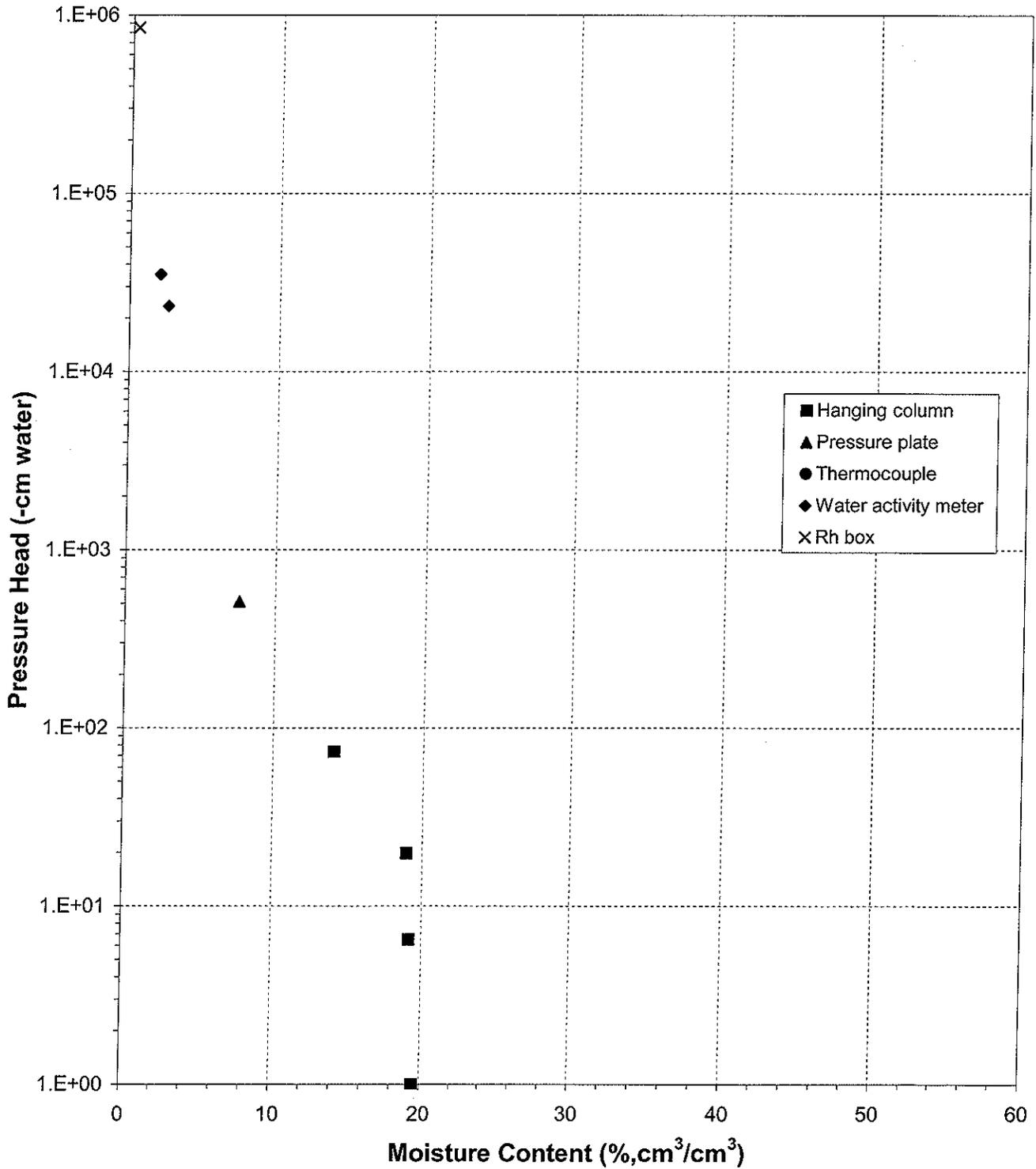
- * Weight including tares
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

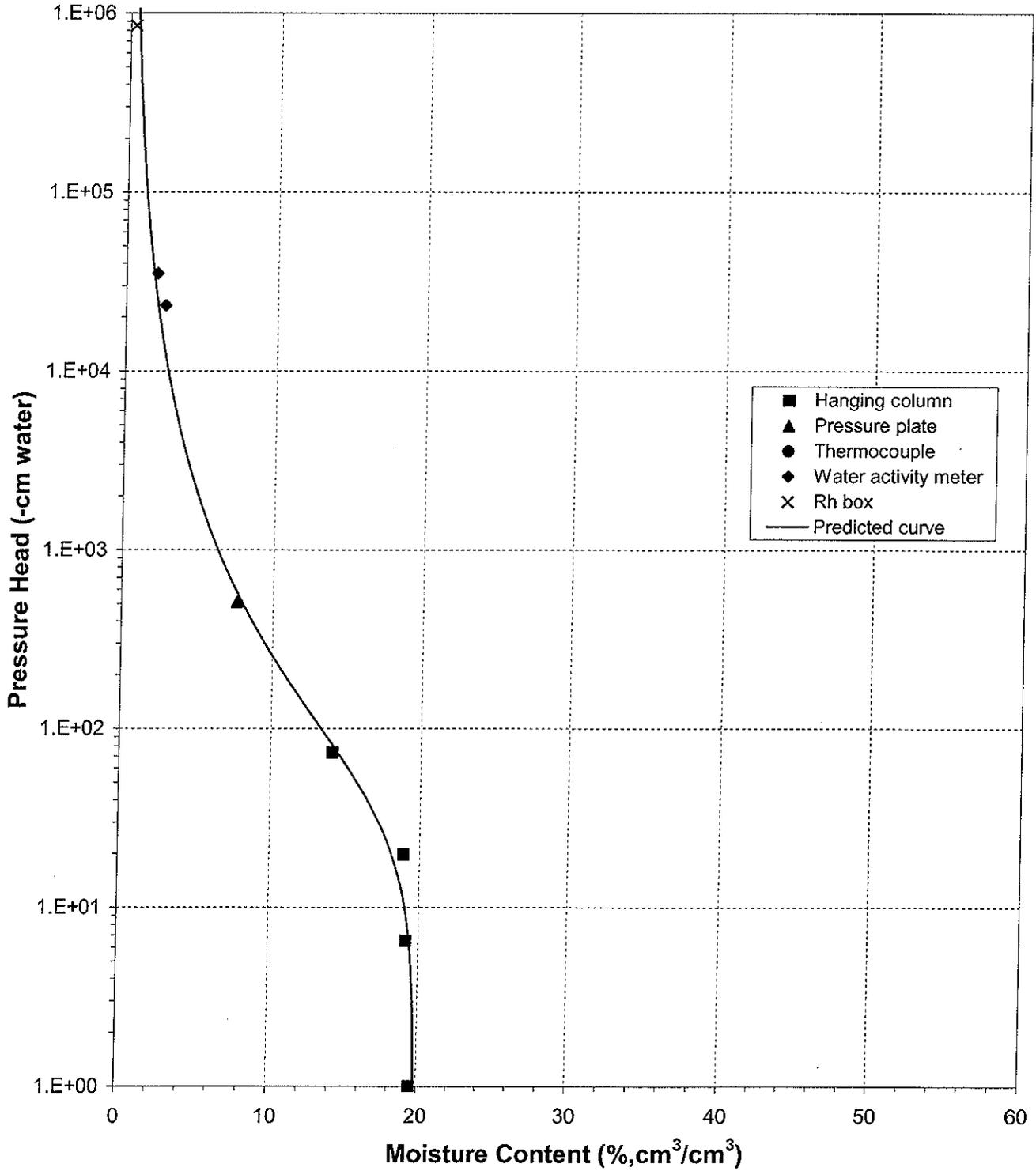
Sample Number: MW-30 35.5-36.0





Predicted Water Retention Curve and Data Points

Sample Number: MW-30 35.5-36.0

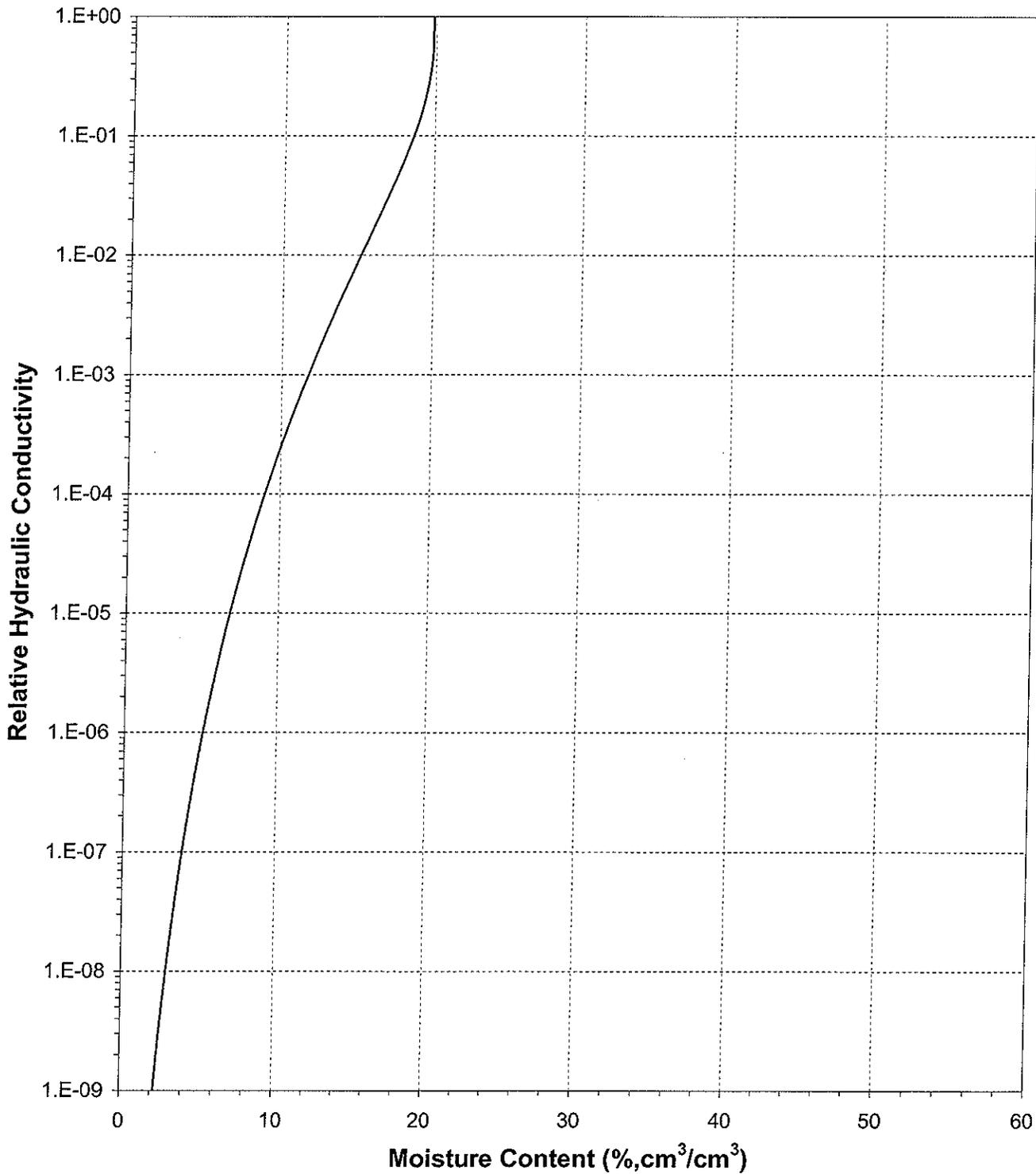




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Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-30 35.5-36.0

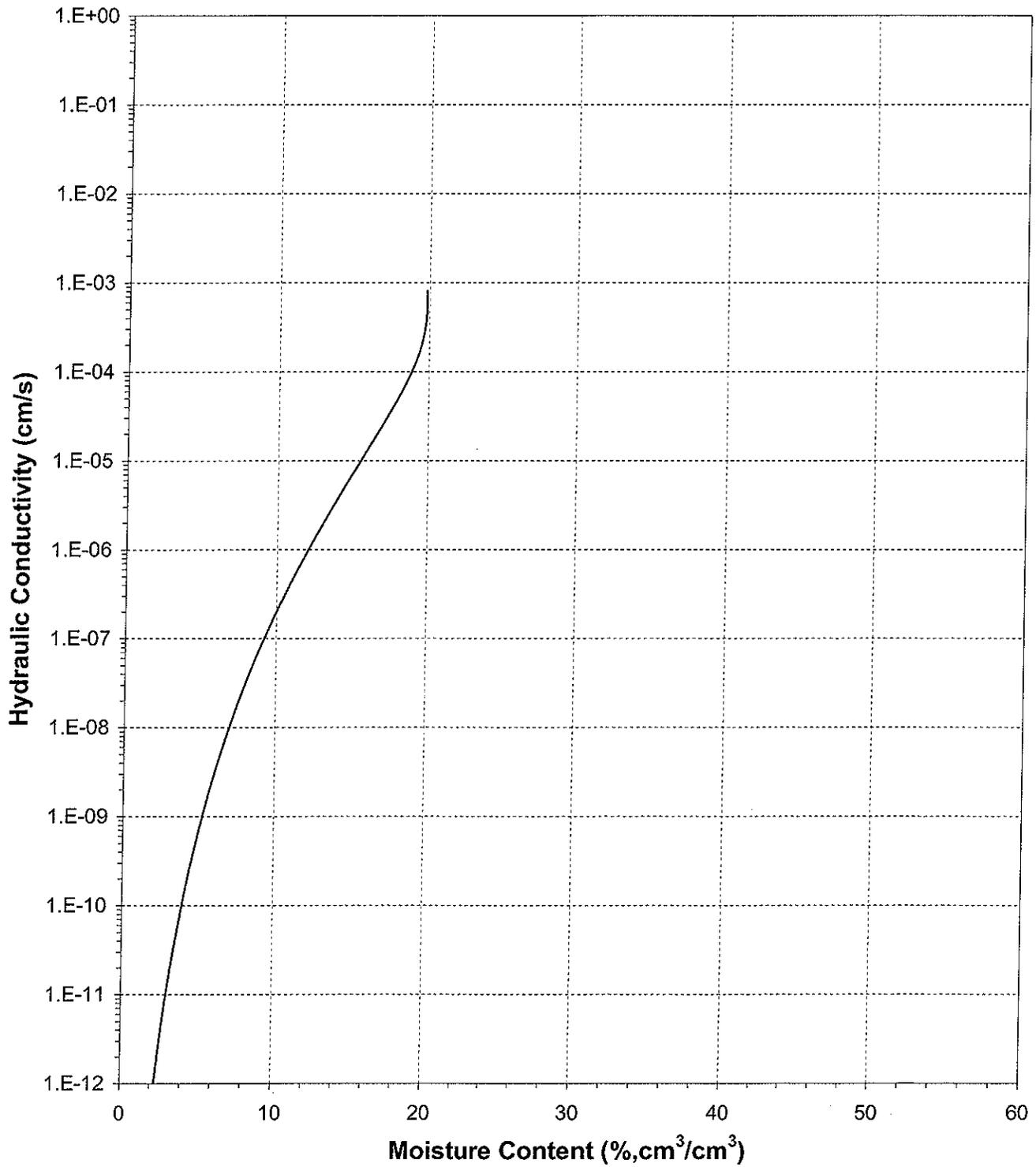




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

Sample Number: MW-30 35.5-36.0

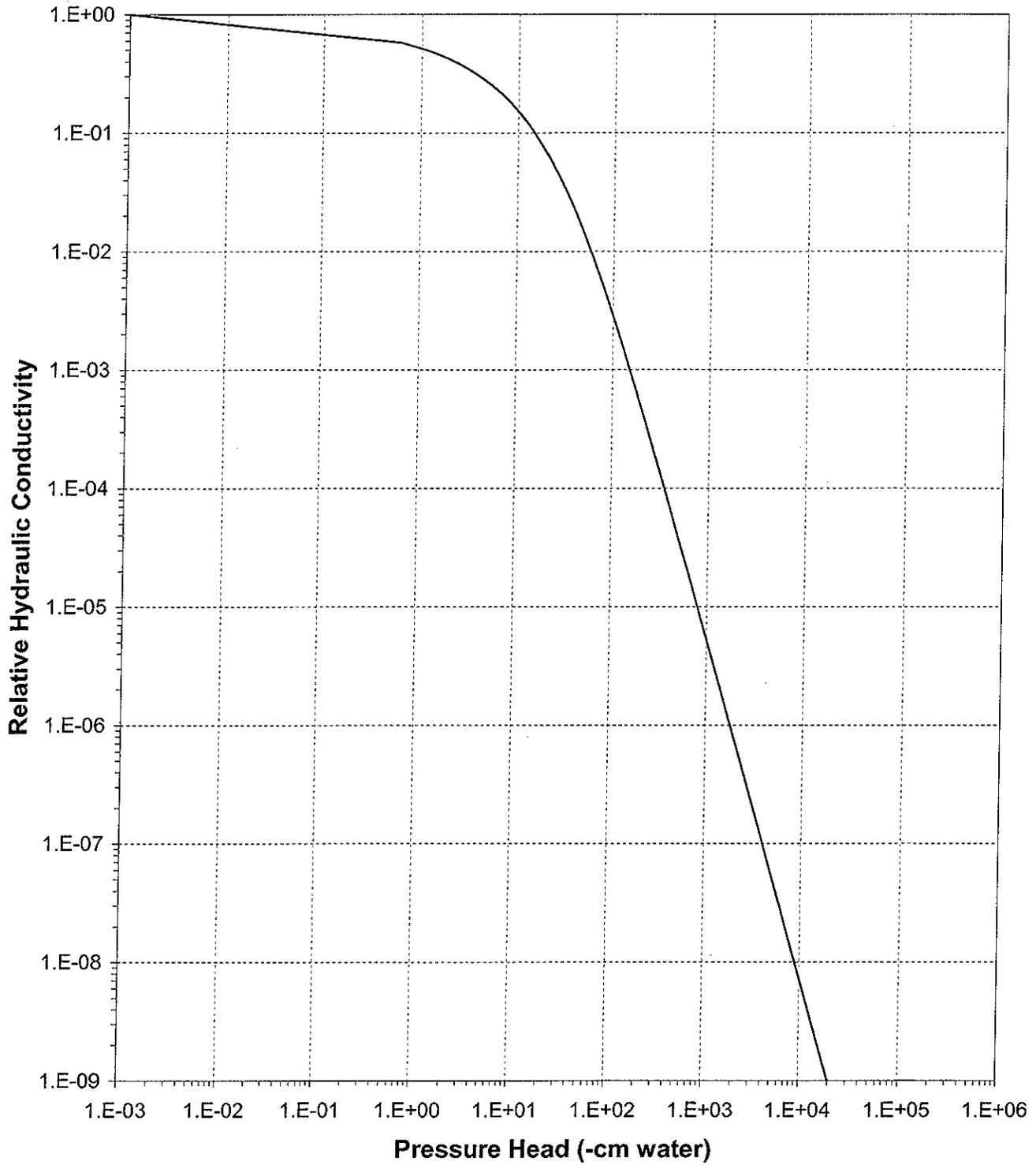




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-30 35.5-36.0

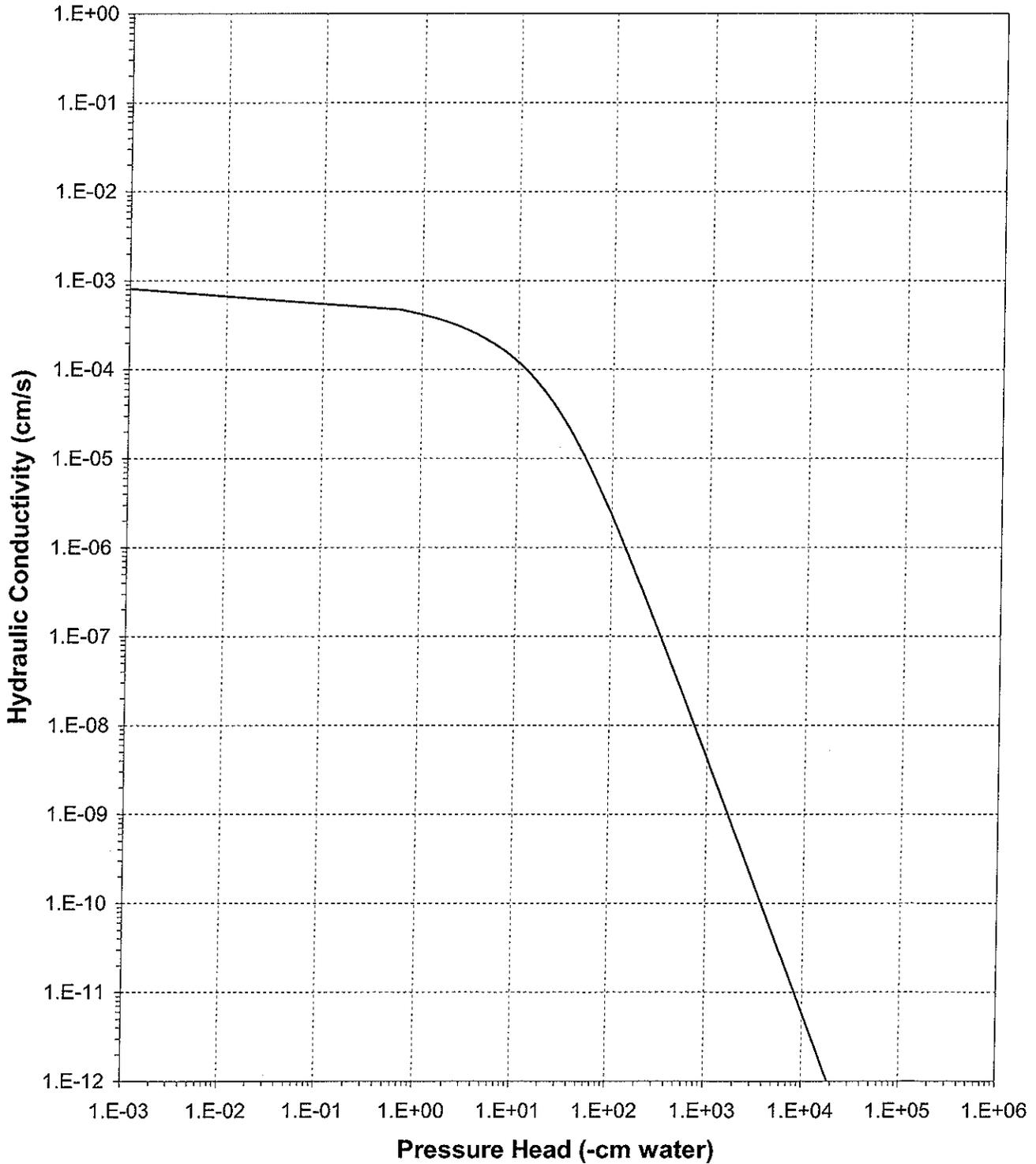




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-30 35.5-36.0





Daniel B. Stephens & Associates, Inc.

Moisture Retention Data Hanging Column/Pressure Plate/Thermocouple

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-30 44.0-44.5
Ring Number: NA
Depth: 44.0-44.5

Dry wt. of sample (g): 193.77
Tare wt., ring (g): 0.00
Tare wt., screen & clamp (g): 0.00
Sample volume (cm³): 86.88

Saturated weight* at 0 cm tension (g): 218.01
Volume of water[†] in saturated sample (cm³): 24.24
Saturated moisture content (% vol): 27.90
Sample bulk density (g/cm³): 2.23

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Hanging column:	30-Mar-07 / 08:55	218.01	0.00	27.90
	27-Mar-07 / 10:10	216.98	34.50	26.71
	05-Apr-07 / 11:40	215.27	100.50	24.75
	11-Apr-07 / 07:50	214.25	197.00	23.57
Pressure plate:	25-Apr-07 / 15:30	211.55	509.90	20.46

Comments:

* Weight including tares

† Assumed density of water is 1.0 g/cm³

Laboratory analysis by: D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Daniel B. Stephens & Associates, Inc.

Moisture Retention Data
Water Activity Meter/Relative Humidity Box

Job Name: MWH AMERICAS, INC.
Job Number: LB07.0048.00
Sample Number: MW-30 44.0-44.5
Ring Number: NA
Depth: 44.0-44.5

Dry weight* of water activity meter sample (g): 249.86
Tare weight, jar (g): 196.46
Sample bulk density (g/cm³): 2.23

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Water Activity Meter:	12-Apr-07 / 15:17	252.48	23353.4	10.94

Dry weight* of relative humidity box sample (g): 90.08
Tare weight (g): 38.03
Sample bulk density (g/cm³): 2.23

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content [†] (% vol)
Relative humidity box:	21-Mar-07 / 12:00	90.87	851293	3.38

Comments:

* Weight including tares

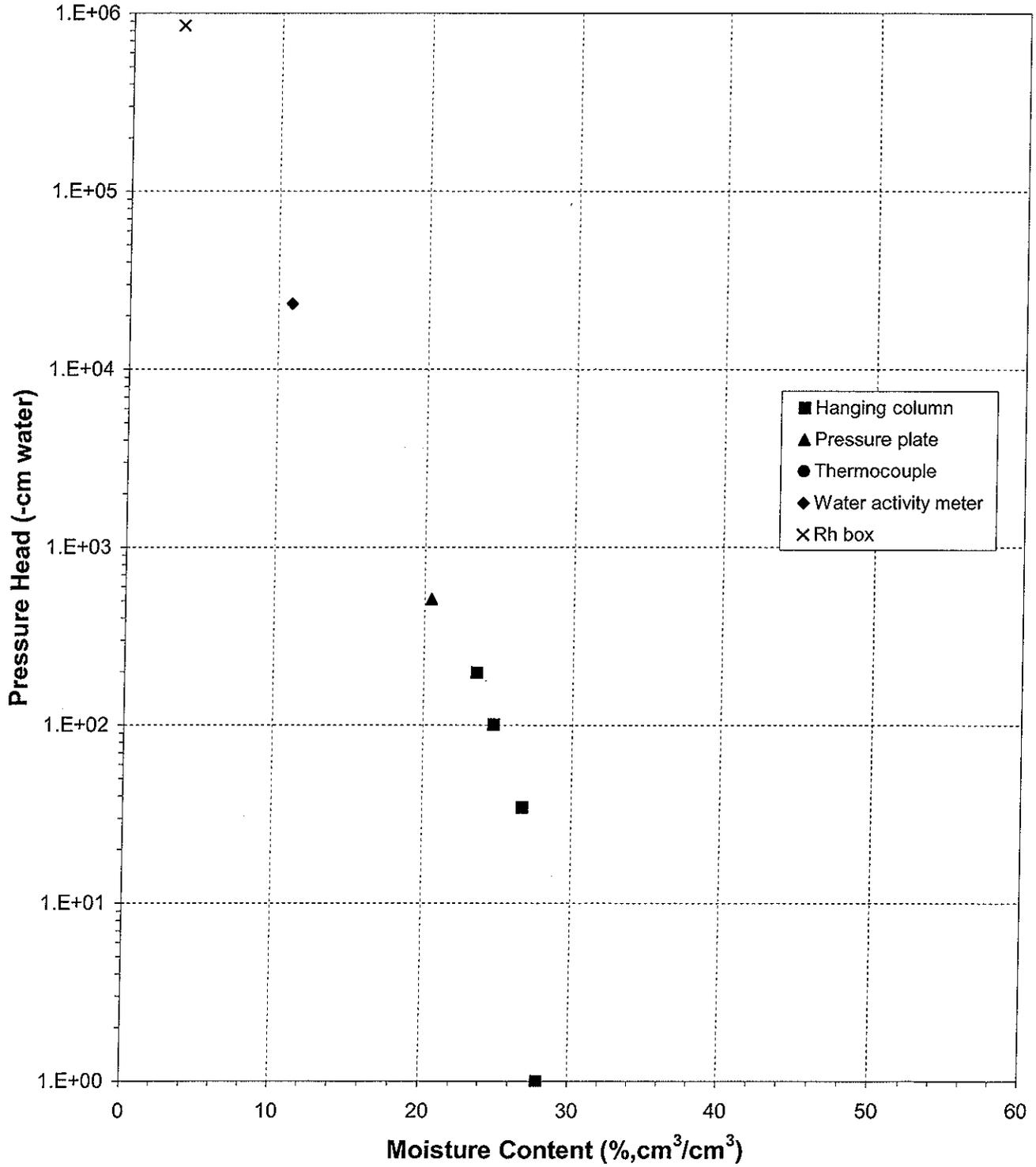
[†] Assumed density of water is 1.0 g/cm³

Laboratory analysis by: C. Krous/D. O'Dowd
Data entered by: T. Bowekaty
Checked by: J. Hines



Water Retention Data Points

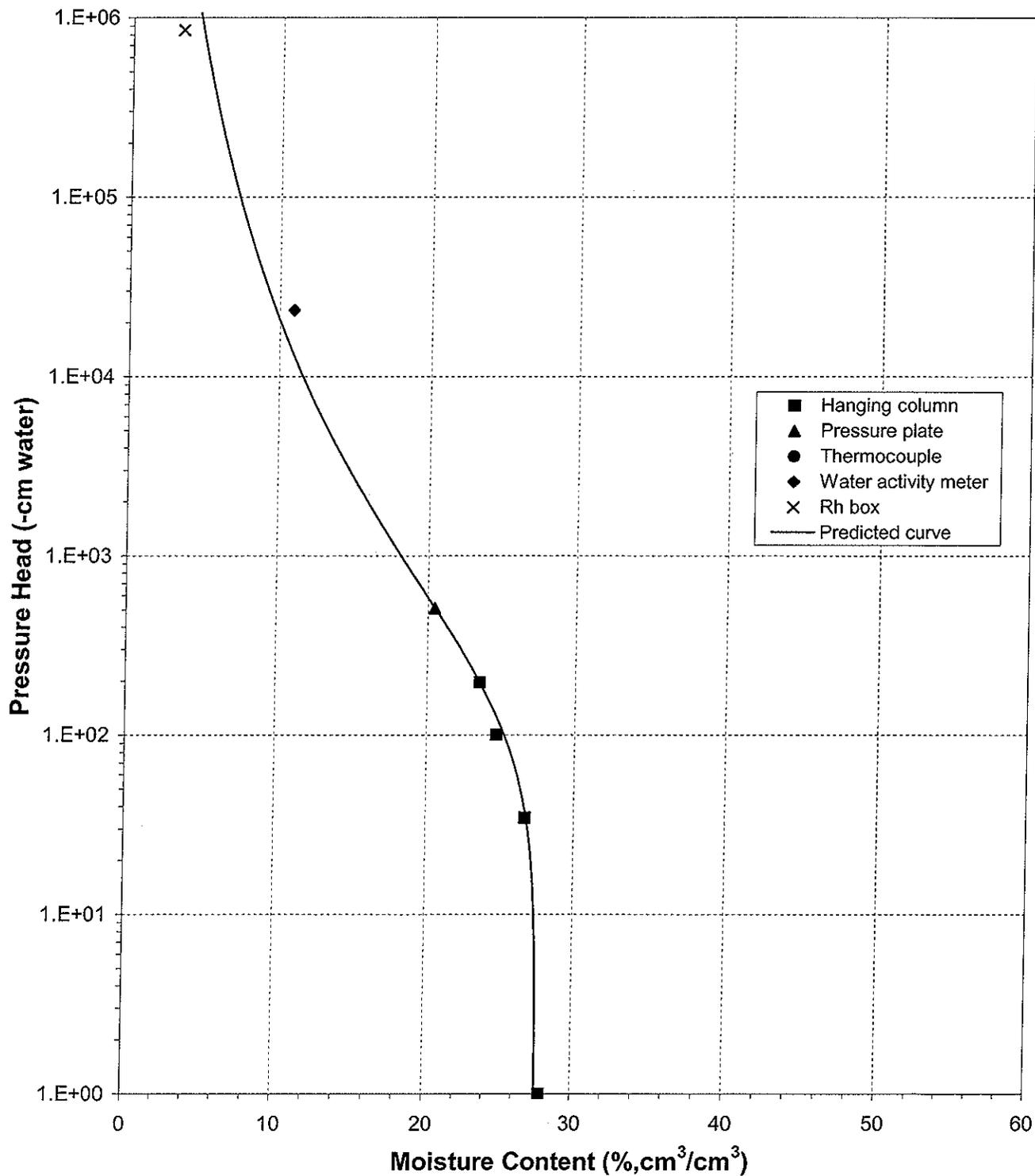
Sample Number: MW-30 44.0-44.5





Predicted Water Retention Curve and Data Points

Sample Number: MW-30 44.0-44.5

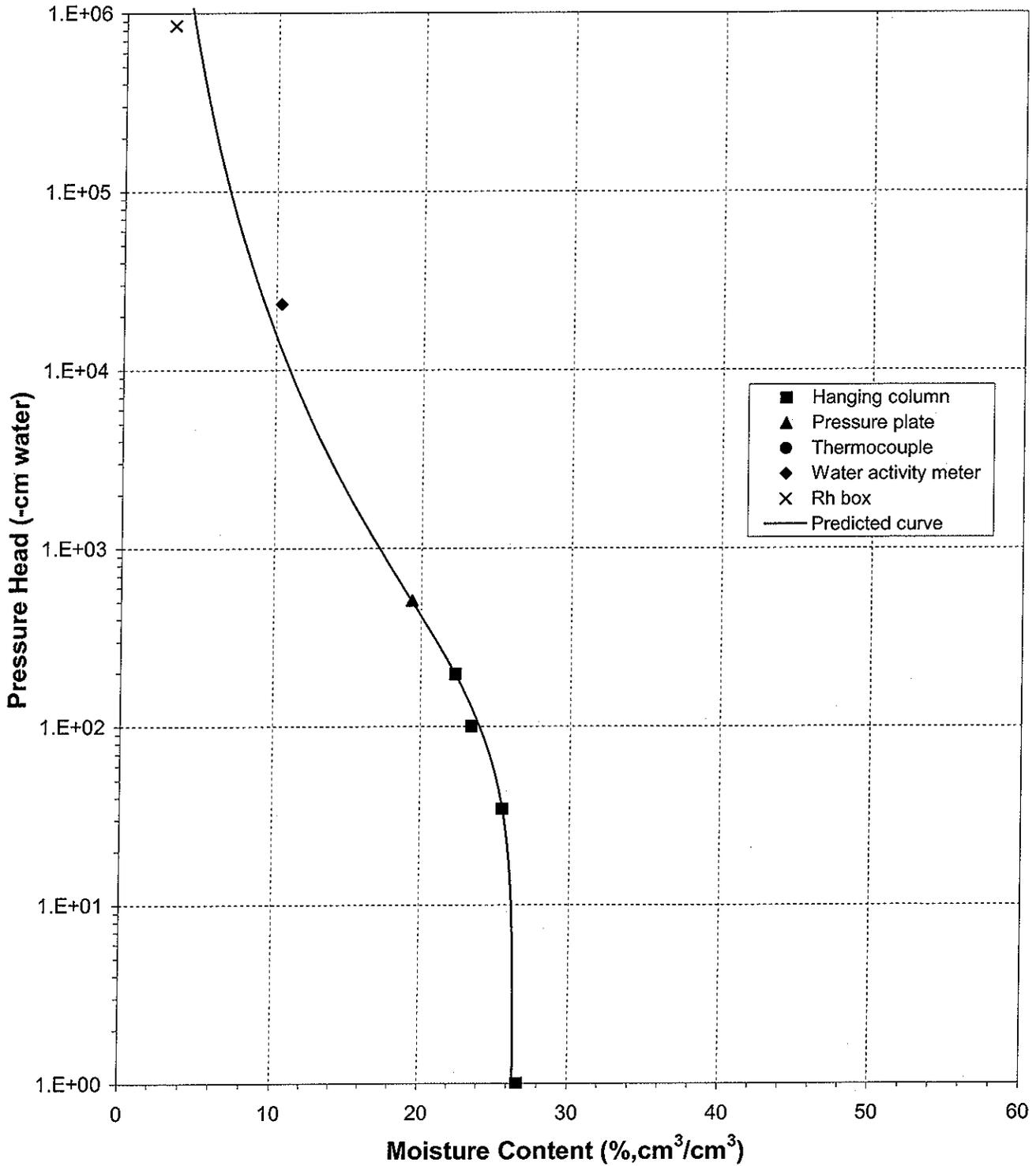




Daniel B. Stephens & Associates, Inc.

Predicted Water Retention Curve and Data Points

Sample Number: MW-30 44.0-44.5 (Volume Adjusted)

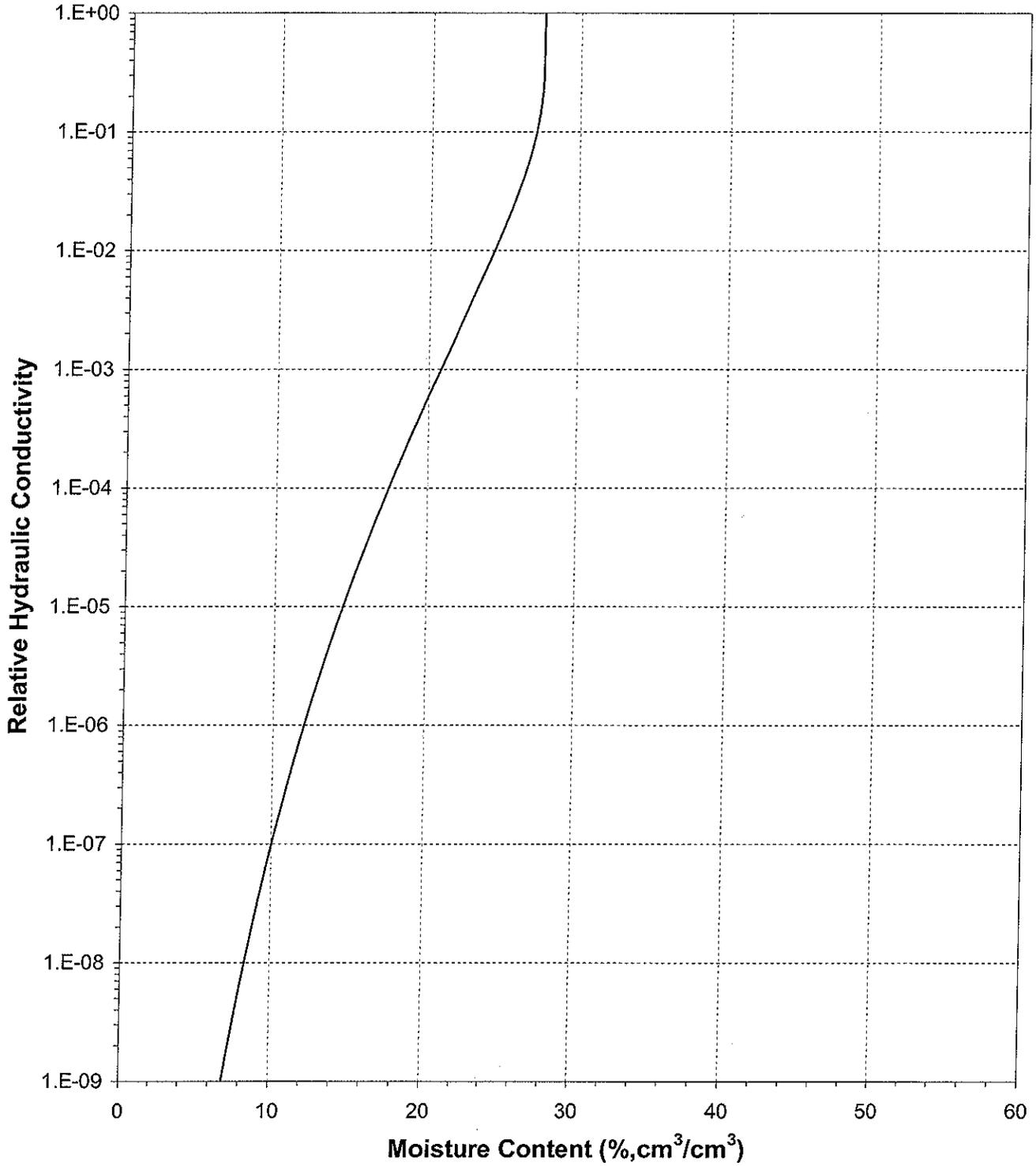




Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: MW-30 44.0-44.5

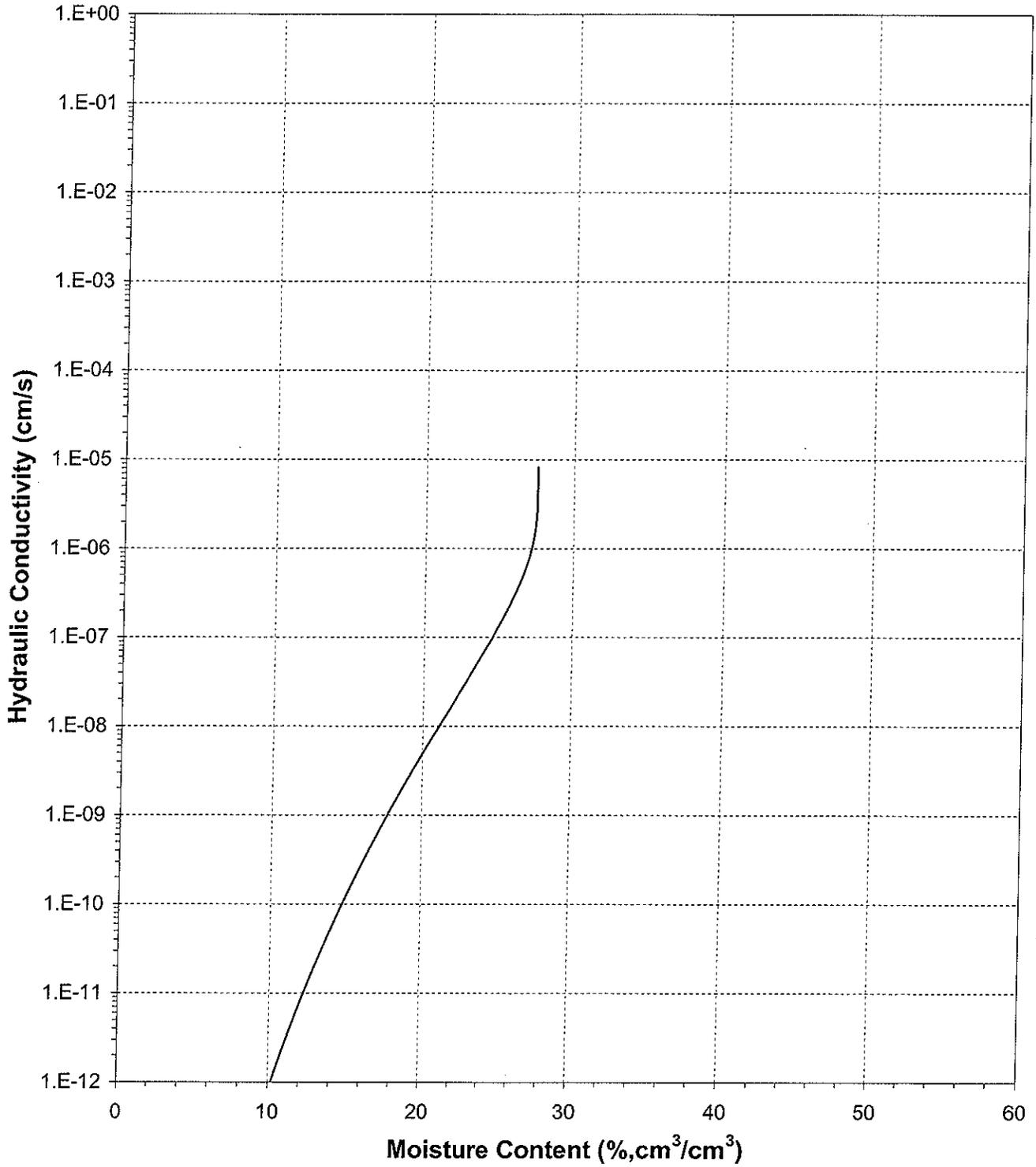




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

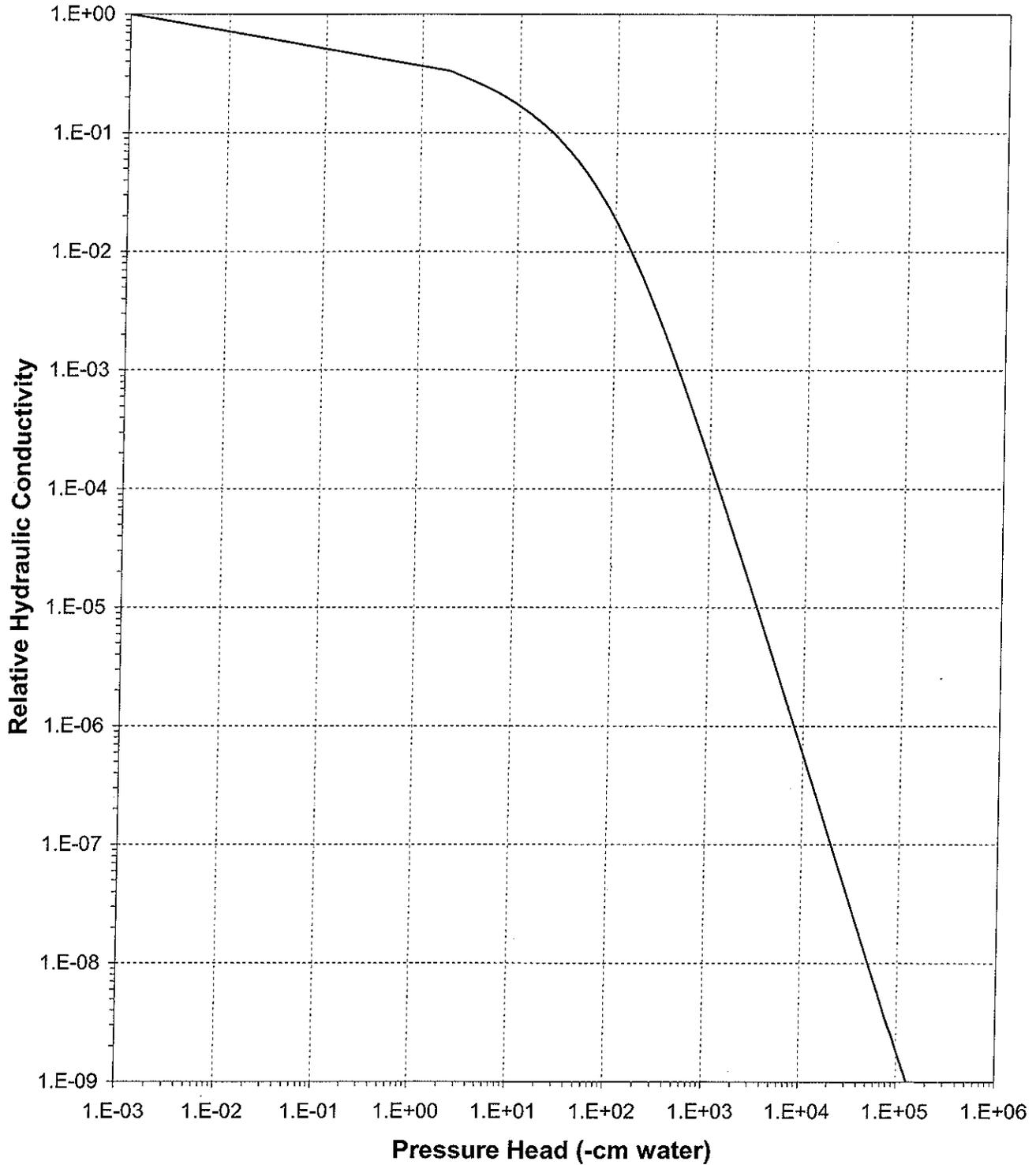
Sample Number: MW-30 44.0-44.5





Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: MW-30 44.0-44.5

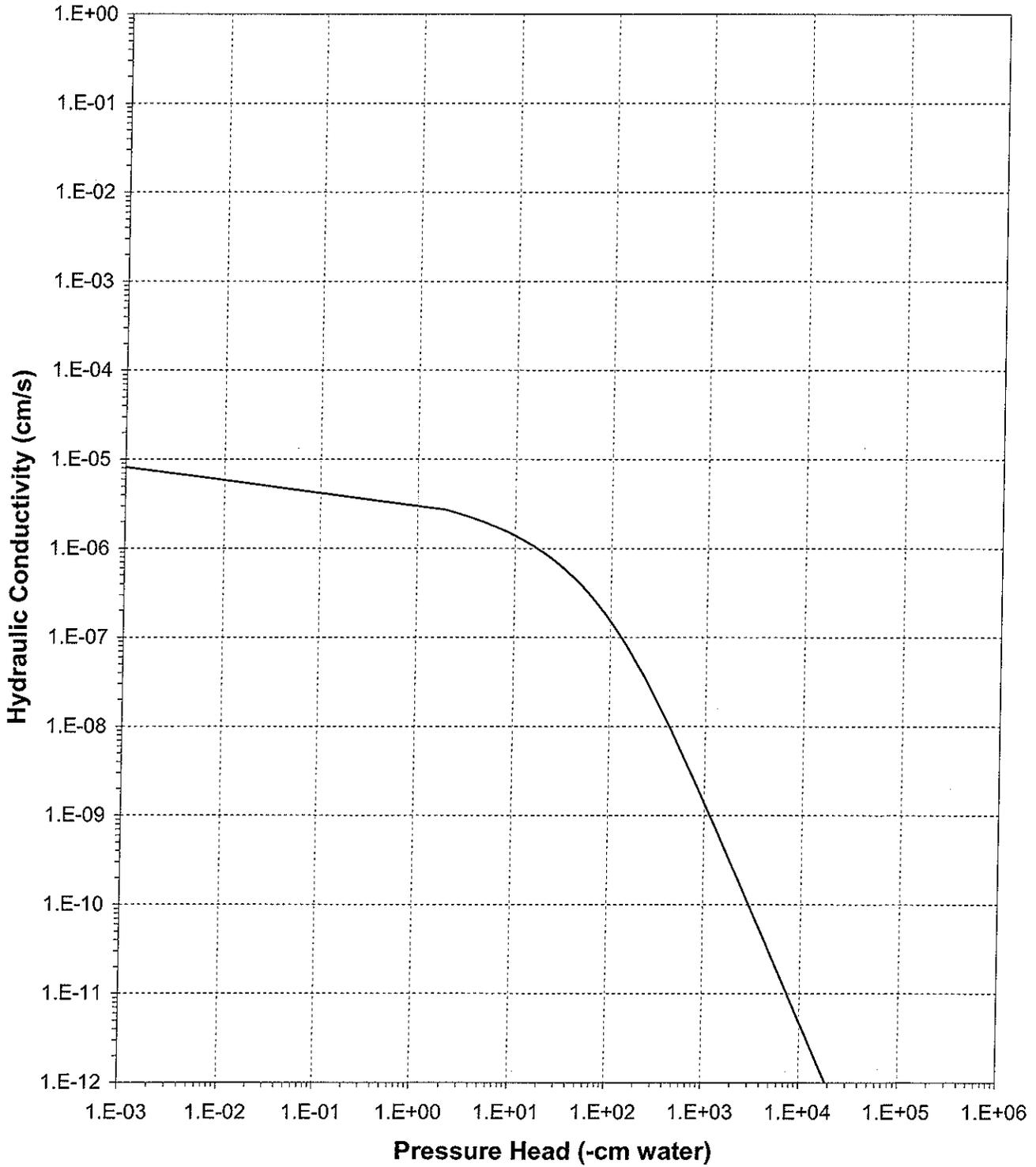




Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: MW-30 44.0-44.5





Daniel B. Stephens & Associates, Inc.

Tests and Methods

Dry Bulk Density:	ASTM D4531; ASTM D6836
Moisture Content:	ASTM D2216; ASTM D6836
Calculated Porosity:	ASTM D2435; Klute, A. 1986. Porosity. Chp.18-2.1, pp. 444-445, in A. Klute (ed.), Methods of Soil Analysis, American Society of Agronomy, Madison, WI
Saturated Hydraulic Conductivity: Falling Head Rising Tail: (Flexible Wall)	ASTM D5084
Hanging Column Method:	ASTM D6836; Klute, A. 1986. Porosity. Chp.26, in A. Klute (ed.), Methods of Soil Analysis, American Society of Agronomy, Madison, WI
Pressure Plate Method:	ASTM D6836; ASTM D2325
Water Potential (Dewpoint Potentiometer) Method:	ASTM D6836; Rawlins, S.L. and G.S. Campbell, 1986. Water Potential: Thermocouple Psychrometry. Chp. 24, pp. 597-619, in A. Klute (ed.), Methods of Soil Analysis, Part 1. American Society of Agronomy, Madison, WI.
Relative Humidity (Box) Method:	Karathanasis & Hajek. 1982. Quantitative Evaluation of Water Adsorption on Soil Clays. SSA Journal 46:1321-1325; Campbell, G. and G. Gee. 1986. Water Potential: Miscellaneous Methods. Chp. 25, pp. 631-632, in A. Klute (ed.), Methods of Soil Analysis, American Society of Agronomy, Madison, WI
Moisture Retention Characteristics & Calculated Unsaturated Hydraulic Conductivity:	ASTM D6836; van Genuchten, M.T. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. SSSAJ 44:892-898; van Genuchten, M.T., F.J. Leij, and S.R. Yates. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Ada, Oklahoma. EPA/600/2091/065. December 1991

APPENDIX C

BEDROCK SAMPLING TO CHARACTERIZE HYDRAULIC AND GEOCHEMICAL PROPERTIES OF THE VADOSE ZONE

APPENDIX C

BEDROCK SAMPLING TO CHARACTERIZE HYDRAULIC AND GEOCHEMICAL PROPERTIES OF THE VADOSE ZONE

The purpose of this appendix is to describe the approach used to collect samples of bedrock material from the vadose zone beneath (immediately adjacent to) the White Mesa Mill tailings cells for characterization of hydraulic and geochemical properties. Hydraulic properties are used to predict the flow of water through the vadose zone, while geochemical properties are used to predict water-rock chemical reactions as the tailings pore water potentially migrates beneath the tailings cells. Geochemical properties tested include mass concentrations of hydrous ferric oxide (HFO) and acid neutralization potential (ANP). The mass of ANP is used in the vadose zone reactive transport model to predict the consumption of alkalinity (neutralization front) as low-pH tailings pore water potentially migrates beneath the tailings cells, while the mass of HFO is used to predict surface complexation (adsorption) reactions. Soil water retention and unsaturated hydraulic conductivity curves are presented and used to identify hydrologic units, while a statistical analysis of the geochemical data is presented and used to identify geochemical units. Lithologic data combined with the hydrologic and geochemical data form the basis for assigning hydrogeochemical stratigraphic units within the vadose zone.

VADOSE ZONE CORE

Samples of bedrock in the vadose zone were obtained from core that is stored in core boxes in a storage shed at the White Mesa Mill. Core drilling was performed in 2005 prior to installing monitoring wells. The sample locations and depth intervals selected for characterization were based on the location with respect to the tailings cells and the availability of recovered core material. Monitoring wells that were located immediately adjacent to or between cells 2 & 3 were selected preferentially over core from more distant locations.

Availability of Core

There were five wells that had core available in the vicinity of the tailings cells: MW-23, MW-24, MW-28, MW-30, and TW4-22 (see Figure C-1 for locations). Intervals of available core are listed in Table C-1. No samples were selected from MW-28 because of the paucity of recovered core. A cross section illustrating the monitoring wells with available core and the depth intervals of samples selected for hydrogeologic and geochemical characterization is plotted in Figure C-2. Sample interval depths are measured in feet below ground surface (ft bgs). Core was not retrieved from approximately 0 to 20 ft bgs because the material consisted of native unconsolidated surficial soils, native unconsolidated windblown silt and sand, and unconsolidated soils used to construct the tailings cell berms. Recovery of core greater than this depth varied between holes. All core measured 2 inches in diameter.

Lithologic Descriptions

Rock core from wells in the vicinity of the tailings cells were logged for rock type, grain size, color, bedding/lamination, staining, and induration. Geologic logs and lithologic descriptions of samples submitted for hydrogeologic and geochemical characterization are summarized in Table C-2. Core included material from the Dakota Sandstone, Burro Canyon Formation, and Brushy Basin Member (shale) of the Morrison Formation; however, during inspection of the core material, a distinct contact between the Dakota Sandstone and Burro Canyon Formation could not be identified. Therefore, the objective of the characterization program was to select samples at appropriate intervals to quantify subsurface heterogeneity in terms of hydraulic and geochemical properties.

Geologic logs indicate that the predominate lithology between the bottom of the tailings cells (~30 ft bgs) and the top of the Brushy Basin Member shale (~103-127 ft bgs) is sandstone (Dakota Sandstone and Burro Canyon Formation) with one or two minor lenses of siltstone and conglomerate. On average, there is approximately 3 feet of siltstone and 4 feet of conglomerate (see Figure C-2). Interpretation of the geologic logs

for the monitoring wells suggests the presence of four geologic layers within the vadose zone:

- Upper sandstone (~30-56 ft bgs)
- Conglomerate or gravelly sandstone (56-60 ft bgs)
- Siltstone (60-63 ft bgs)
- Lower sandstone (63 ft bgs-bottom).

The geologic layers are included here to facilitate the statistical evaluation of the geochemical properties, and identification of hydrogeochemical stratigraphic units.

VADOSE ZONE DEPTH BENEATH THE TAILINGS CELLS

The vadose zone thickness beneath the tailings cells is tabulated in Table C-3. The vadose zone thickness is calculated by taking the difference between the bottom elevation of the cell and the distance to the water table. The minimum vadose zone thickness beneath Cells 2 & 3 and Cell 4A is approximately 42 ft and 40 ft, respectively. As a comparison, the average vadose zone thickness beneath Cell 2, Cell 3, and Cell 4A were 63 ft, 66 ft, and 56 ft. For the vadose zone transport models, the vadose zone thickness beneath Cells 2 & 3 and Cells 4A & 4B was assumed to equal 42 ft (12.8 m).

VADOSE ZONE CORE SAMPLING METHODOLOGY & LABORATORY ANALYSIS METHODS

Sampling for Geochemical Properties

Samples of the core for geochemical analysis were collected at approximately 5-foot centers beginning from approximately 30 ft bgs (selected to correspond with the approximate base of the tailings cells) and extending toward the water table. At depths

greater than about 65 ft bgs, samples were collected approximately every 7 to 10 feet. The exact spacing varied depending on availability of core and the necessity to characterize different rock types based on grain size distribution and degree of sorting. Generally, the core samples collected for geochemical characterization were 0.2 feet long. Geochemical properties, including the amount of HFO and ANP, were evaluated from laboratory analyses of 34 core intervals (34 primary samples with four duplicates for 38 total analyses reported) selected from four monitoring wells (MW-23, MW-24, MW-30, and TW4-22).

The following numbers of samples were collected and analyzed for geochemical properties from the four geologic layers observed in the cores above the Brushy Basin shale (described above):

- 18 within the upper sandstone unit
- 4 within the conglomerate unit
- 3 within the siltstone unit
- 9 within the lower sandstone unit.

The arithmetic average for each of the four sample intervals analyzed in duplicate was used in the statistical analysis. The upper sandstone unit contained more samples because of its proximity to the bottom of the tailings cells. In general, more sandstone samples were collected because this lithology was the dominant rock type, with the upper and lower sandstones having average thickness of 26 feet and greater than 37 feet, respectively, relative to the conglomerate and siltstone units which average 4 feet and 3 feet thick, respectively.

Mass of HFO. The mass of hydrous ferric oxide present in bedrock core samples was determined via chemical extraction with hydroxylamine-hydrochloride (HH) solution. The procedure consisted of subjecting samples of crushed bedrock to short-term leaching

to completely dissolve amorphous-mineral phases (e.g., ferrihydrite/hydrous ferric oxide) and partially dissolve some crystalline minerals (e.g., goethite). The solution acts as a reducing agent converting iron from the solid phase (Fe^{+3}) to an aqueous phase (Fe^{+2}). The leaching procedure used to obtain the mass of HFO was similar to the approach adopted for the Naturita UMTRA Site as prepared by the U.S. Geological Survey for the U.S. Nuclear Regulatory Commission as part of NUREG/CR-6820 (Davis and Curtis, 2003; Davis et al., 2004). The approach used in NUREG/CR-6820 to estimate the mass of HFO was also similar to an approach adopted by the U.S. EPA Environmental Research Laboratory (Loux et al., 1989).

The procedure consisted of drying the core at 34°C followed by crushing to remove material larger than 3 mm. The HH solution (100 mL) was then added to 10 grams of crushed rock in a 250 mL bottle and placed in a shaking-water bath at 50°C. Aliquots of extracted solution were withdrawn after 96 hours and filtered (<0.45 μm) prior to analysis.

The concentration of dissolved iron reported in the leachate (in milligrams per liter) was then converted to the mass of iron (in milligrams of iron per kilogram of rock) originally present in the rock sample by multiplying the solution concentration by the water to rock proportion (0.1 liter divided by 0.01 kilograms). The concentration of iron in the rock can then be converted to the concentration of HFO in the rock by multiplication of the ratio of the molecular weight of HFO divided by the molecular weight of iron (89 grams per mole divided by 55.8 grams per mole). A statistical analysis of iron concentrations in the leachate is presented as part of the results below (the original laboratory data sheets are contained within Appendix A).

HFO is the only solid phase that is credited as a potential sorption site of uranium and other trace elements, which is a conservative assumption because other phases (e.g., hematite, quartz, clays, etc.) also participate in surface complexation reactions.

Mass of ANP. The mass of acid neutralization potential (assumed to be calcite) present in the bedrock was measured directly using the methodology outlined in U.S. EPA

method M600/2-78-054. The test involves placing pulverized material into an acid bath, which is heated until the reaction ceases as noted by the absence of bubbling from the release of CO₂ gas. The neutralization potential is then determined by titrating with a base to determine how much of the acid was neutralized by fast-reacting calcium-bearing carbonate minerals. The data are reported as grams of calcite per kilogram of rock. The ANP data are considered to be representative because the test only measures fast-reacting carbonate minerals. A statistical analysis of the ANP data is included as part of the results below (the original laboratory data sheets are contained within Appendix A).

Hydraulic Properties

Five sandstone samples were analyzed for hydraulic properties. One sample, considered to represent the transition from siltstone to sandstone (MW-23 74.3-74.6 ft), was also analyzed for hydraulic properties. No conglomerate layers were analyzed for hydraulic properties because the core samples from this rock type generally consist of irregular shaped, angular pieces with variable sorting and clast sizes. Furthermore, it is likely that the conglomerate behaves hydraulically very similarly to the sandstone because the matrix is sandstone and the clasts are generally small gravel in low percentages (less than 30%). The core samples collected for hydraulic characterization varied between 0.2 to 0.5 feet long.

Soil water retention characteristics for the vadose zone samples were determined by a variety of methods including hanging column, pressure plate, water activity meter, and relative humidity box methods to cover a range of pressure heads from 0 cm (saturated water content) to -851,000 cm (residual water content). The saturated hydraulic conductivity of the samples was measured using a flexible wall permeameter. The test methods, and original laboratory report, are included in Appendix B.

VADOSE ZONE CORE SAMPLE RESULTS

Geochemical Properties

The analytical results of the geochemical test data for ANP and HFO (represented as dissolved iron concentrations in the leachate) are posted on Figures C-3 and C-4, respectively. Statistical analyses of the geochemical data for both ANP and HFO, including number of data points, minimum and maximum values, median, arithmetic average (mean), arithmetic standard deviation, geometric mean, and geometric standard deviation are tabulated in Table C-4. The statistical data are grouped by different attributes to determine whether any statistical trends can be identified. The groupings included categorization on a well-by-well basis, geologic layers, by depth assuming three arbitrary 25-foot thick zones, and for the entire population.

An analysis of the distribution of the data indicated that the geochemical properties within the vadose zone are distributed log normally. Therefore the geometric mean, rather than the arithmetic mean, should be used to guide the comparison between attribute groups. Overall, the geometric mean ANP did not vary significantly between the different attribute groups. The geometric mean HFO did vary slightly between lithologic groups and between wells with higher concentrations reported for the siltstone unit and for MW-30 and TW4-22. To simplify the conceptual model, the geometric mean of the entire population was selected as the base case value for both ANP and HFO.

To support the sensitivity analysis, and determine a range of values for the amount of ANP, the geometric mean plus one geometric standard deviation was selected as an upper bound, while the geometric mean minus one geometric standard deviation was selected as the lower bound. The geometric mean plus one geometric standard deviation of the log transformed data corresponds to approximately 68% of the observations. The amount of HFO was not included in the sensitivity analysis because the three sets of parameters were not significantly different (upper bound equal to 59.8 mg/L iron; base case equal to 55.4 mg/L iron; lower bound equal to 51.0 mg/L iron).

Hydraulic Properties

The unsaturated and saturated hydraulic properties for the vadose zone samples were estimated from laboratory measurements and through optimization. Parameter values measured in the lab on vadose zone samples included the residual water content (θ_r), saturated water content (θ_s), water contents at intermediate soil water pressures $\theta(h)$, and the saturated hydraulic conductivity in the vertical direction (K_s). Parameter values determined through optimization included the empirical fitting parameters (n and α). The fitting parameters are considered to be empirical coefficients that affect the shape of the hydraulic functions used to describe variations in water content and hydraulic conductivity for different soil water pressures. The unsaturated hydraulic properties [$\theta(h)$] and [$K(h)$] are highly nonlinear functions of the soil water pressure (h).

Unsaturated hydraulic properties (parameters θ_s , α , and n) were determined by fitting van Genuchten's (1980) analytical model to the water retention data using the RETC computer code developed by the U.S. Salinity Laboratory for the U.S. EPA (van Genuchten et al., 1991). RETC utilizes a nonlinear, least-squares parameter optimization method to estimate the unknown variables. During parameter optimization, the program is run many times in succession, each time incrementally varying the unknown variables so as to minimize the sum of squared residuals until convergence is reached and the measured data are matched. Data collected from MW-30 (44.0-44.5 ft) were not included because the core experienced swelling and cracking after the saturated hydraulic conductivity test.

A comparison between the measured and model-predicted soil water retention curves for the vadose zone samples are plotted in Figure C-5. Overall, there is good agreement between the measured and optimized parameter values used to describe $\theta(h)$. The hydraulic properties of the vadose zone samples are included in Table C-5. Justification for selection of hydrogeologic parameters for the vadose zone is discussed below.

A single set of hydraulic properties for the vadose zone assuming the properties of sandstone was used as input to the model. This assumption is considered appropriate because the saturated and unsaturated hydraulic properties of the samples are quite similar to one another (Figures C-5 and C-6) with the exception of MW-23 (74.3-74.6 ft). MW-23 (74.3-74.6 ft) had a smaller storage capacity and a slightly lower saturated hydraulic conductivity compared to the other samples. Assignment of a single set of hydrogeologic properties should not significantly affect the model results given the similarity in unsaturated hydraulic properties [$\theta(h)$] and [$K(h)$] for all samples (i.e., there were no large differences in soil water retention curves or unsaturated hydraulic conductivity curves for the materials tested). The hydraulic properties from MW-23 (55.5-56.0 ft) were used as input to the model because the hydraulic functions are intermediate as compared to the other samples. Unsaturated hydraulic conductivity of the vadose zone was not included in the sensitivity analysis because the unsaturated hydraulic conductivities vary to match flux rates under a unit hydraulic gradient.

CONCLUSIONS

The statistical evaluation of the geochemical data supports the assignment of one geochemical unit within the vadose zone. For ANP, the geometric mean of the population was used to establish the base case value, while the geometric mean plus one geometric standard deviation, and minus one geometric standard deviation, were used to establish the upper and lower bounds. For HFO, only the base case scenario will be simulated because the upper and lower bounds, calculated using the same approach as for ANP, were similar. Evaluation of the soil water retention and unsaturated hydraulic conductivity curves for the core samples indicated that the one set of parameters could be used to describe water flow through the vadose zone. Taken together, one hydrogeochemical unit will be used as input to characterize the flow and transport of solutes through the vadose zone.

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TABLE C-1. AVAILABLE INTERVALS OF CORE FOR MONITORING WELLS ADJACENT TO THE TAILINGS CELLS.				
MW-23	MW-24	MW-28	MW-30	TP4-22
49-86	20-71	54-60	27-46	20-63
87-90	73-98	78-80	50-60	68-70
96-110	99-105	84-90	-	76-80
111-132	108-120	91.5-110	-	82-100
-	-	-	-	105-115
Note: All depths are measured in feet below ground surface.				

TABLE C-2. GEOLOGIC LOGS OF SAMPLES SUBMITTED FOR HYDRAULIC AND GEOCHEMICAL CHARACTERIZATION.

Monitoring Well	Depth Interval (ft bgs)	Sample Collection Date	Rock Type	Grain Size	Sorting	Induration	Color	Comments	Analysis
MW-23	49.3-49.5	May-09	Qtz Sandstone	fine to medium	well	well	very pale brown 10YR 7/3	laminations	Chem.
MW-23	53.0-53.5	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	very pale brown 10YR 8/3	cross bedding, Fe-Mg grains 5%	Chem.
MW-23	55.5-56.0	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	very pale brown 10YR 8/3	cross bedding, Fe-Mg grains 5%	Hyd.
MW-23	59.3-59.5	May-09	Qtz Sandstone	fine to medium	well	well	very pale brown 10YR 7/3	laminations	Chem.
MW-23	63.8-64.0	May-09	Qtz Sandstone	fine to coarse	poorly	well	very pale brown 10YR 8/3	small weathered feldspar grains (5-10%), small iron stains	Chem.
MW-23	68.9-69.3	May-09	Conglomerate	fine to coarse sand and fine gravel	poorly	moderately	very pale brown 10YR 8/2	clasts of chert (qtz), weathered feldspar, and limestone (?)	Chem.
MW-23	74.0-74.3	Feb-07	Qtz Sandstone	very fine to fine	moderately	well	white 10YR 8/1	Fe-Mg grains 1%, iron staining	Chem.
MW-23	74.3-74.6	Feb-07	Qtz Sandstone	very fine to fine	moderately	well	white 10YR 8/1	Fe-Mg grains 1%, iron staining	Hyd.
MW-23	82.5-82.7	May-09	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	white 10YR 8/1	Fe-Mg grains <1%	Chem.
MW-23	82.7-82.9	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	white 10YR 8/1	Fe-Mg grains <1%	Hyd.
MW-23	89.9-90.0	May-09	Qtz Sandstone	fine to coarse sand and fine gravel	poorly sorted	moderately	very pale brown 10YR 8/2	small weathered feldspar grains (5-10%), small iron stains	Chem.
MW-23	99.8-100.0	Feb-07	Qtz Sandstone	very fine to fine	moderately	not well	very pale brown where stained 10YR 7/4 and light gray where not stained 10YR 7/2	Fe-Mg <1%, much iron staining	Chem.
MW-23	103.0-103.3	Feb-07	Qtz Sandstone	fine to medium	moderately	well	white 10YR 8/1	Fe-Mg <1%	Chem.
MW-23	103.3-103.5	Feb-07	Qtz Sandstone	fine to medium	moderately	well	white 10YR 8/1	Fe-Mg <1%	Hyd.
MW-30	31.3-31.5	May-09	Qtz Sandstone	fine to coarse	poorly	well	yellowish brown 10YR 5/4	large weathered feldspar and chert clasts (10%), matrix is 50% weathered mafics	Chem.
MW-30	35.5-36.0	Feb-07	Qtz Sandstone	fine to medium (predominately medium)	moderately	well	yellowish brown 10YR 7/4	--	Hyd.
MW-30	37.5-38.0	Feb-07	Qtz Sandstone	fine to medium (predominately medium)	moderately	well	yellowish brown 10YR 7/5	Fe-Mg grains 5%	Chem.
MW-30	43.0-43.2	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	white 10YR 8/2	Fe-Mg grains <1%, some iron staining	Chem.
MW-30	43.2-43.5	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	white 10YR 8/2	Fe-Mg grains <1%, some iron staining	Chem.

TABLE C-2. GEOLOGIC LOGS OF SAMPLES SUBMITTED FOR HYDRAULIC AND GEOCHEMICAL CHARACTERIZATION. (continued)

Monitoring Well	Depth Interval (ft bgs)	Sample Collection Date	Rock Type	Grain Size	Sorting	Induration	Color	Comments	Analysis
MW-30	44.0-44.5	Feb-07	Qtz Sandstone	fine to medium (predominately fine)	moderately	well	white 10YR 8/2	Fe-Mg grains <1%, some iron staining	Hyd.
MW-30	50.0-50.2	May-09	Qtz Sandstone	very fine w. silt	well	well	yellow 10YR 8/6	--	Chem.
MW-30	53.9-54.0	May-09	Siltstone	silt w. fine sand	--	moderately	weak red 10R 5/3	--	Chem.
MW-30	59.8-60.0	May-09	Qtz Sandstone/ Conglomerate	fine to coarse w. small clasts	poorly	well	very pale brown 10YR 7/4	chert and weathered feldspar clasts (very fine conglomerate)	Chem.
MW-24	29.7-29.9	May-09	Silty Sandstone	very fine sand w. silt	well	well	white 7.5YR 8/1 grading to reddish yellow 7.5YR 7/6	sample is iron stained and grades from white to orange	Chem.
MW-24	34.9-35.1	May-09	Qtz Sandstone	fine to medium	well	well	very pale brown 10YR 8/2	mafic grains (5-10%)	Chem.
MW-24	40.0-40.2	May-09	Qtz Sandstone	fine to coarse	poorly	well	very pale brown 10YR 8/2	weathered mafic and feldspar grains (5%)	Chem.
MW-24	44.7-44.9	May-09	Qtz Sandstone	fine to coarse	poorly	well	white 10YR 8/1	numerous large weathered feldspar grains (10%)	Chem.
MW-24	49.8-49.9	May-09	Qtz Sandstone	fine to medium	well	well	white 10YR 8/1	weathered feldspar grains (5%)	Chem.
MW-24	56.0-56.2	May-09	Siltstone	silt w. fine sand	--	well	light greenish grey 5GY 7/1	--	Chem.
MW-24	63.4-63.5	May-09	Siltstone	silt w. fine sand	--	well	pale yellow 5Y 8/3	--	Chem.
MW-24	73.0-73.2	May-09	Qtz Sandstone	fine to medium	well	well	white 10YR 8/1	small zone of poorly sorted sand to very coarse w. weathered feldspars	Chem.
MW-24	80.0-80.3	May-09	Qtz Sandstone	very fine to fine	well	moderately	white 10YR 8/1	--	Chem.
TW4-22	34.0-34.2	May-09	Qtz Sandstone	fine to medium	well	well	very pale brown 10YR 7/4	--	Chem.
TW4-22	39.4-39.6	May-09	Qtz Sandstone	fine to medium	well	well	very pale brown 10YR 7/4	prominent cross bedding (5-10 degrees)	Chem.
TW4-22	45.6-46.0	May-09	Qtz Sandstone	medium grained	well	well	very pale brown 10YR 7/4	faint cross bedding (5-10 degrees)	Chem.
TW4-22	50.0-50.3	May-09	Qtz Sandstone	medium to coarse	well	well	light yellowish brown 10YR 6/4	weathered mafic grains, faint cross bedding	Chem.
TW4-22	55.5-55.7	May-09	Qtz Sandstone/ Conglomerate	fine to coarse	poorly	well	very pale brown 10YR 8/2	large weathered feldspar clasts	Chem.
TW4-22	60.2-60.3	May-09	Qtz Sandstone/ Conglomerate	fine to medium	moderately	well	very pale brown 10YR 8/2	weathered feldspar clasts	Chem.
TW4-22	69.8-70.0	May-09	Qtz Sandstone	medium to coarse	poorly	moderately	very pale brown 10YR 7/4	weathered feldspar clasts	Chem.
TW4-22	84.0-84.3	May-09	Qtz Sandstone	fine grained/silty	poorly	poorly-moderately	pale yellow 5Y 8/3	includes silt and med-coarse sand (5-10%)	Chem.

Notes: (1) All depths are measured in feet below ground surface. (2) Samples were collected during two site visits by MWH staff: February 2007 and May 2009. (3) Qtz = quartz; Hyd. = Hydraulic Sample; Chem. = Geochemical Sample. (4) Color classified according to the Munsell soil color system.

TABLE C-3. VADOSE ZONE THICKNESS BENEATH THE TAILINGS CELLS.					
Tailings Cell	Location	Bottom Elevation of Cell (ft above MSL)	Nearest Well	Water Table Elevation (ft above MSL)	Vadose Zone Thickness (ft)
Cell 2	Cell 2 NW corner	5602	MW-24	5506	96
Cell 2	Between Cells 2&3	5592	MW-29	5511	81
Cell 2	Cell 2 N side	5595	MW-28	5541	54
Cell 2	Cell 2 NE corner	5605	TW4-20	5553	52
Cell 2	Between Cells 2&3	5582	MW-30	5535	47
Cell 2	Between Cells 2&3	5588	MW-31	5542	46
Cell 2	Cell 2 N side	5600	TW4-22	5571	29
Cell 3	Cell 3 SW corner	5585	MW-23	5495	90
Cell 3	Cell 3 S side	5585	MW-12	5500	85
Cell 3	Cell 3 S side	5577	MW-05	5502	75
Cell 3	Between Cells 2&3	5585	MW-29	5511	74
Cell 3	Cell 3 S side	5582	MW-11	5518	64
Cell 3	Cell 3 SE corner	5592	MW-25	5535	57
Cell 3	Between Cells 2&3	5585	MW-31	5542	43
Cell 3	Between Cells 2&3	5577	MW-30	5535	42
Cell 4A	Cell 4A S side	5562	MW-14	5494	68
Cell 4A	Cell 4A SW corner	5557	MW-15	5493	64
Cell 4A	Cell 4A N side	5570	MW-11	5518	52
Cell 4A	Cell 4A NE corner	5575	MW-25	5535	40
<p>Notes:</p> <ol style="list-style-type: none"> 1. Units for elevation are referenced to feet above mean sea level (ft above MSL). 2. Bottom elevations for Cells 2 & 3 from D'Appolonia (1982). 3. Bottom elevations for Cell 4A from Geosyntec (2007). 4. Average water table elevations from 2007 Water year. 5. The vadose zone thickness was calculated as the difference between the cell bottom and the water table elevation. 6. The average vadose zone thickness for Cell 2 (excluding TW4-22), Cell 3, and Cell 4A were 63 ft, 66 ft, and 56 ft, respectively. TW4-22 excluded because this well is located upgradient of Cell 1. 					

TABLE C-4. STATISTICAL ANALYSIS OF THE GEOCHEMICAL DATA BASED ON DIFFERENT ATTRIBUTES.

Mineralogical Property & Statistical Metric	MW-23	MW-24	MW-30	TW4-22	Upper Sandstone	Conglomerate	Siltstone	Lower Sandstone	29-54 ft bgs	54-79 ft bgs	79-104 ft bgs	Entire Population
ANP (g CaCO₃/kg rock)												
Count	10	9	7	8	18	4	3	9	16	12	6	34
Minimum	0.5	2	0.5	2	1	2	6	1	0.5	0.5	4	0.5
Maximum	182	27	69	36	69	182	9	27	69	182	27	182
Arithmetic Mean	22.6	7	13.1	11.1	10.1	48.5	7.7	7.7	10.3	21.3	7.8	13.8
Standard Deviation	56.1	7.7	24.9	11.4	16.6	89.0	1.5	9.1	17.7	50.9	9.4	32.4
Geometric Mean	5.7	5.2	3.7	7.5	5.0	9.7	7.6	4.3	4.8	6.4	5.5	5.4
Geometric Standard Deviation	4.3	2.1	5.4	2.5	3.2	7.5	1.2	3.2	3.4	4.2	2.2	3.4
Median	4.0	4	5	7.5	4.5	5.0	8.0	4.0	4	6	4	4.0
Geo Mean Plus 1 Geo Standard Deviation	10.0	7.2	9.1	10.0	8.2	17.1	8.8	7.5	8.1	10.5	7.7	8.8
Geo Mean Minus 1 Geo Standard Deviation	1.4	3.1	0	5.0	1.8	2.2	6.3	1.1	1.4	2.2	3.3	2.1
HFO (mg/L Fe)												
Count	10	9	7	8	18	4	3	9	16	12	6	34
Minimum	3.85	3.85	25.3	16.3	4	4	42	9	3.85	3.85	8.72	3.85
Maximum	304	226	503	509	509	276	503	109	509	503	105	509
Arithmetic Mean	93.1	44.8	179	238	163	87.3	257	48.1	170	124	49.0	132
Standard Deviation	106	71.2	183	192	168	128	232	42.5	175	153	41.1	155
Geometric Mean	43.1	18.9	102	149	70.3	30.9	169	30.8	71.3	51.8	32.4	55.4
Geometric Standard Deviation	4.2	3.8	3.3	3.3	4.9	6.1	3.5	2.8	5.1	4.6	2.9	4.4
Median	46.9	10.4	72.9	195	69.8	34.6	226	19.1	69.8	47.6	45	59.8
Geo Mean Plus 1 Geo Standard Deviation	47.3	22.7	105.7	152.4	75.1	37.1	172.3	33.7	76.4	56.3	35.3	59.9
Geo Mean Minus 1 Geo Standard Deviation	38.8	15.0	99.1	145.7	65.4	24.8	165.2	28.0	66.3	47.2	29.5	51.0
Notes: (1) ANP = acid neutralization potential; HFO = hydrous ferric oxide; ft bgs = feet below ground surface; Fe = iron; CaCO ₃ = calcite. (2) Two samples analyzed for ANP were reported at the practical quantitation limit (PQL) of 0.5 g CaCO ₃ per kilogram of rock. These values were assumed for the statistical analysis. (3) The arithmetic average for each of the 4 sample intervals analyzed in duplicate was used in the statistical analysis. (4) The conversion between milligrams of iron per liter of water in the leachate to milligrams of HFO per kilogram of rock is described in the text.												

TABLE C-5. SUMMARY OF UNSATURATED AND SATURATED HYDRAULIC PROPERTIES OF BEDROCK VADOSE ZONE CORE SAMPLES.						
Well ID and Core Interval (ft bgs)	Residual soil water content θ_r (% vol)	Saturated soil Water content θ_s (% vol)	Curve fitting parameters in the soil water retention function ^a		Saturated hydraulic conductivity in the vertical direction K_{sat} (cm/d)	Dry Bulk Density P_b (g/cm ³)
			α (cm ⁻¹)	n (-)		
MW-30 35.5-36.0	0.004	0.199	0.0266	1.348	69.9	1.98
MW-23 55.5-56.0	0.003	0.184	0.0103	1.386	9.37	2.03
MW-23 74.3-74.6	0.016	0.122	0.0003	1.354	2.47	2.33
MW-23 82.7-82.9	0.003	0.160	0.0069	1.336	14.9	2.10
MW-23 103.3-103.5	0.006	0.205	0.0287	1.349	263	1.84
MW-30 44.0-44.5 ^b	0.032 ^b	0.264 ^b	0.0081 ^b	1.201 ^b	0.707	2.23

Notes:
All depths are measured in feet below ground surface (ft bgs).
^aThe van Genuchten-Mualem single-porosity soil-hydraulic-property model was selected to characterize the soil-hydraulic properties.
^bWater retention parameters based on volume adjusted values because core cracked and swelled after conductivity testing.

Figure C-1. Monitoring well and test well locations near the tailings cells 2 and 3 with core available. Locations include MW-23, MW-24, MW-28, MW-30, and TW4-22.

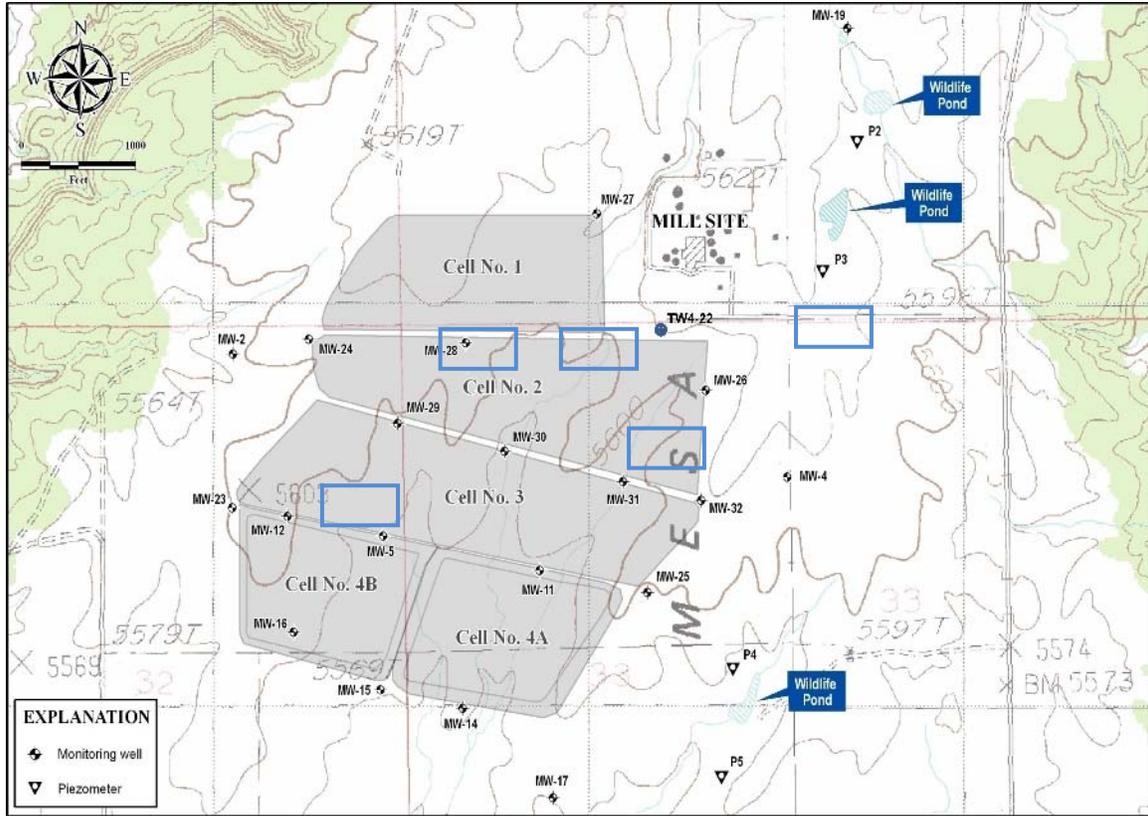


Figure C-2. Generalized cross section of monitoring wells and available core in the vicinity of the tailings cells. Lithologic information and sample intervals selected for geochemical and hydraulic characterization are also identified.

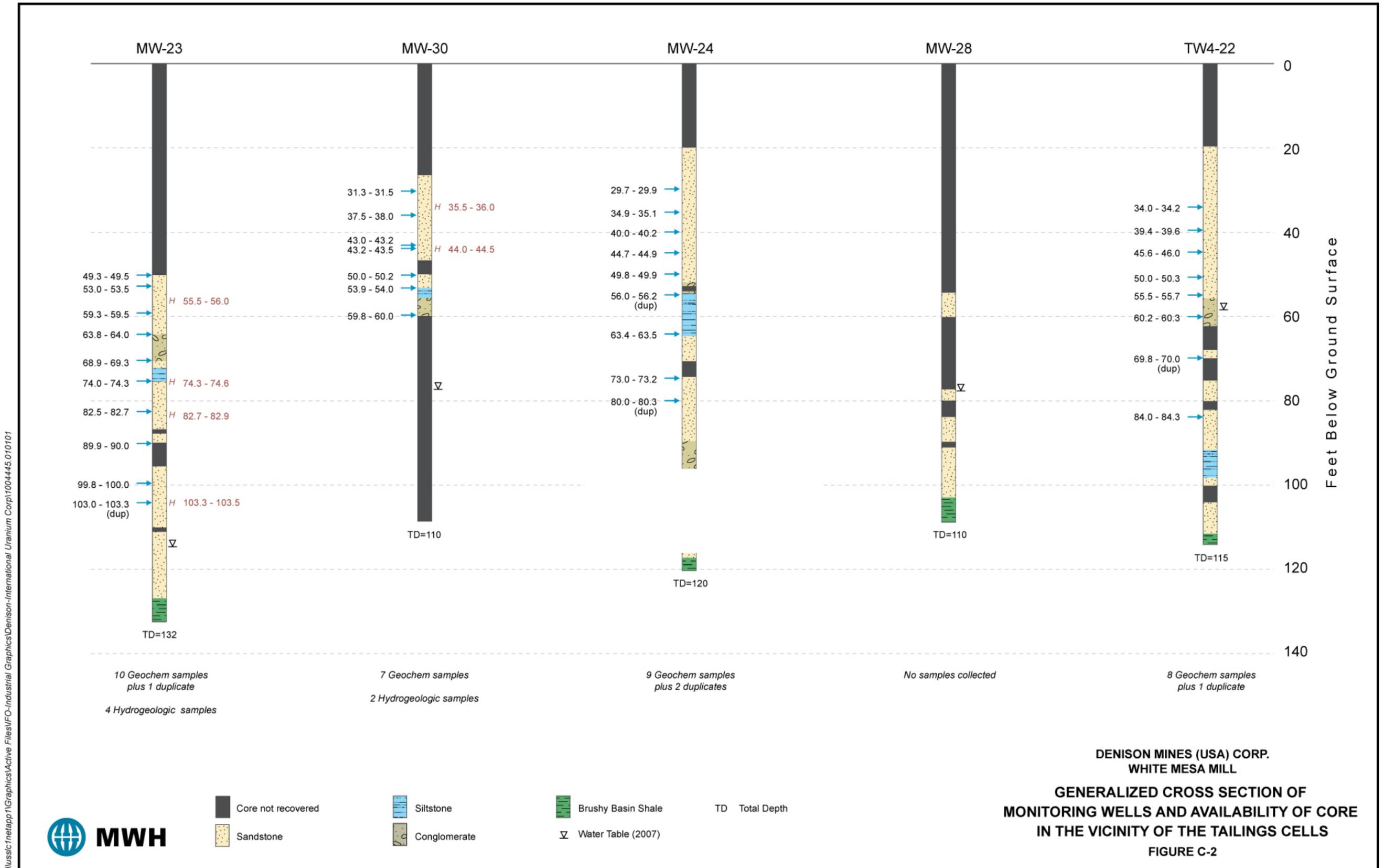
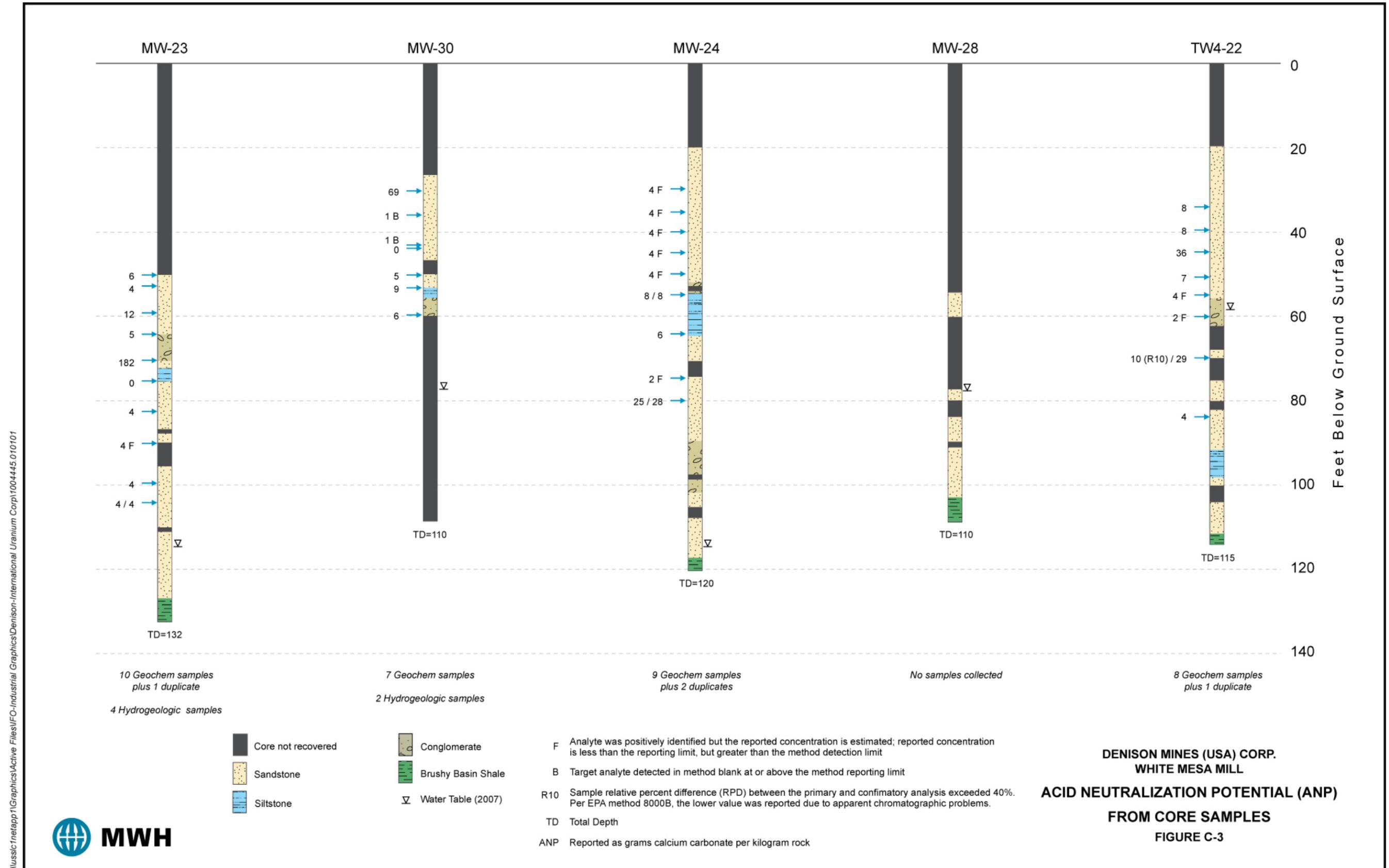


Figure C-3. Acid neutralization potential (ANP) results from core samples.



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Figure C-4. Amount of hydrous ferric oxide (HFO) from core samples (represented as dissolved iron concentrations in the leachate).

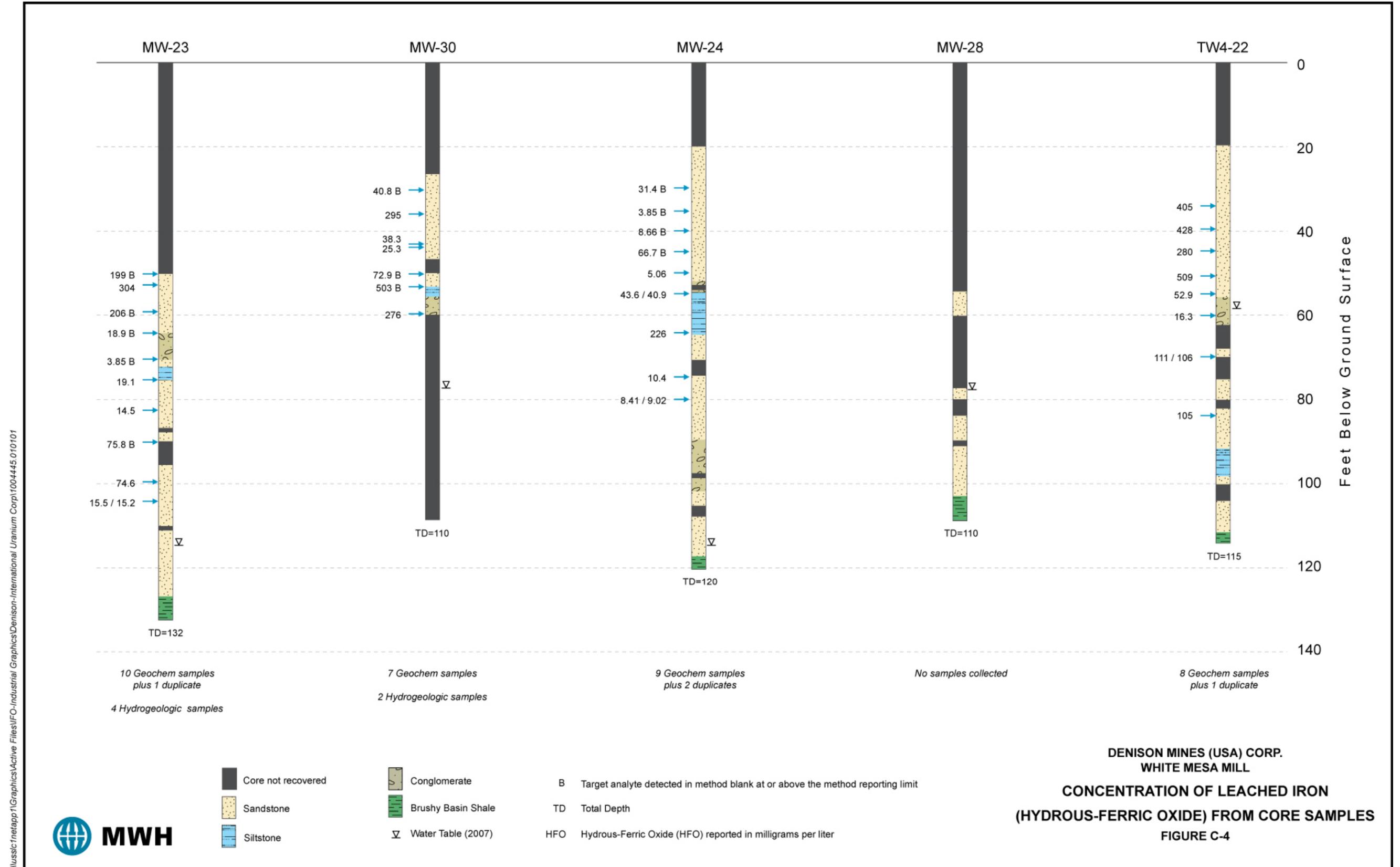


Figure C-5. Comparison between the measured and model-predicted soil water retention curves for the vadose zone samples.

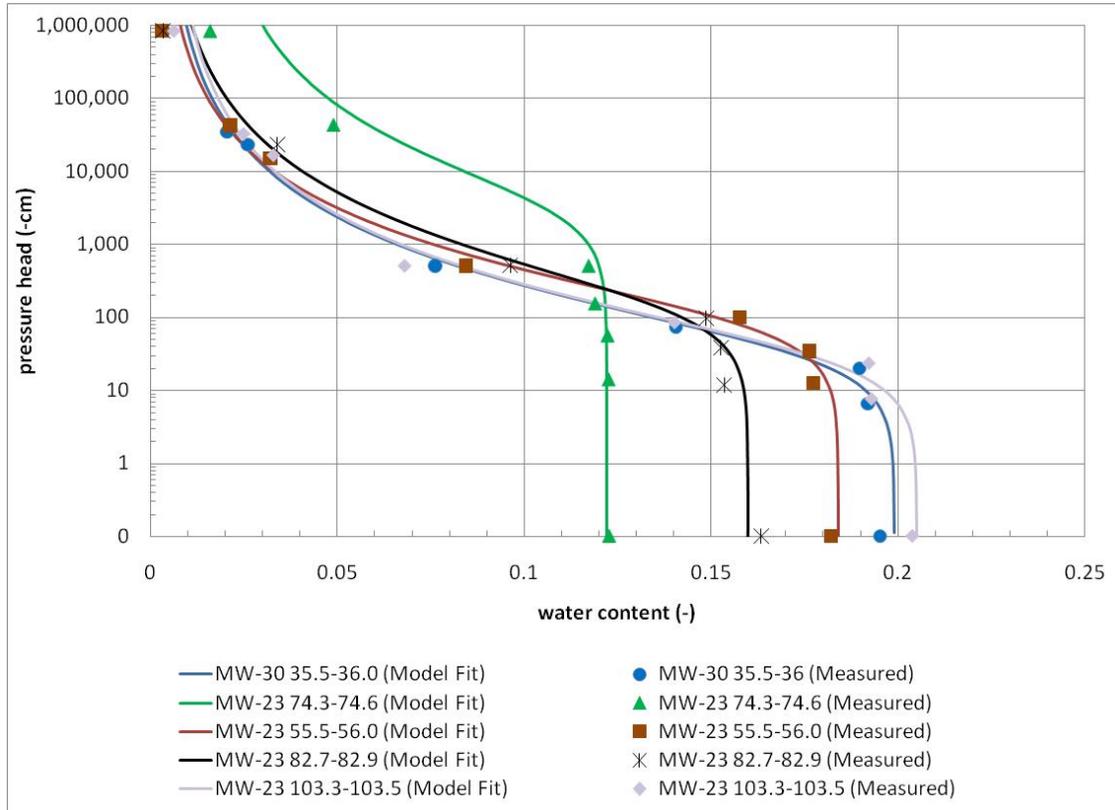
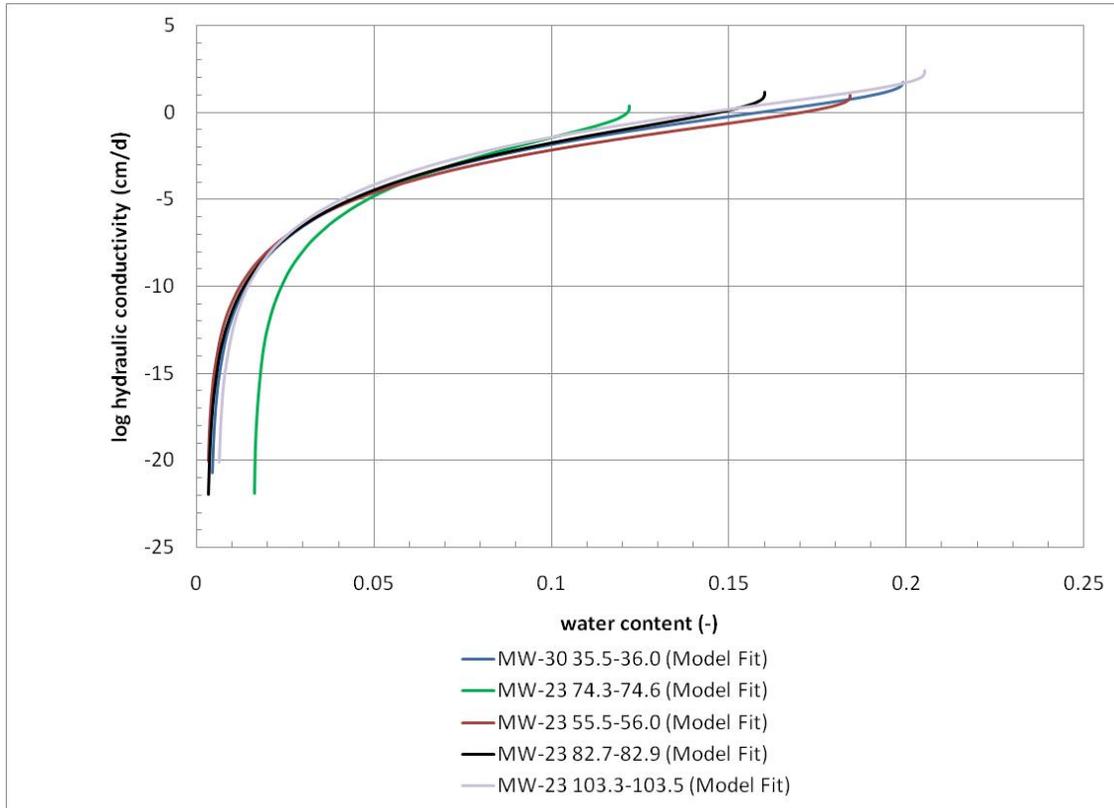


Figure C-6. Log hydraulic conductivity as a function of water content for the vadose zone samples.



APPENDIX D

**VEGETATION EVALUATION FOR THE
EVAPOTRANSPIRATION COVER**

APPENDIX D

VEGETATION EVALUATION FOR THE EVAPOTRANSPIRATION COVER

This appendix provides an evaluation of vegetation that would be used as an integral part of an evapotranspiration (ET) cover proposed for reclamation of tailing cells at the White Mesa Mill Site. A critical component of an ET cover is the plant community that will be established on the cover and will function over the long term to provide protection from wind and water erosion and assist in removing water through the process of transpiration. In this appendix, issues related to the short-term establishment and long-term sustainability of vegetation proposed as part of the ET cover are addressed. These issues include: plant species selection, ecological characteristics of species (i.e., longevity, sustainability, compatibility, competition, rooting depth and root distribution), characteristics of the established plant community (i.e., percent plant cover and leaf area index [LAI]), and soil requirements for sustained plant growth.

Empirical data regarding the ecological characteristics of the species mix (rooting depth and root distribution) and established plant community (percent cover) are summarized from the literature and nearby lysimeter studies to develop a conceptual model of the vegetation component for the ET cover system. The empirical data were used to parameterize the numerical model and predict the ET cover's performance over the long term. A range of parameter values intended to correspond to a base case (anticipated or expected) scenario and a worst case scenario is presented. These values were used in the predictive simulations performed using HYDRUS. The range in data values are included to determine which parameters may be more sensitive in predicting flow through the cover. Results of model simulations are presented in Appendix G.

PROPOSED SPECIES FOR ET COVER RECLAMATION

The following 12 species (10 grasses and 2 forbs) are proposed for the ET cover system at the White Mesa Mill Site. These species were selected for their adaptability to site conditions, compatibility, and long-term sustainability. Species were also selected based

on the assumption that institutional controls will prohibit grazing by domestic livestock.

The proposed species are:

- Western wheatgrass, variety Arriba (*Pascopyrum smithii*)
- Bluebunch wheatgrass, variety Goldar (*Pseudoroegneria spicata*)
- Slender wheatgrass, variety San Luis (*Elymus trachycaulus*)
- Streambank wheatgrass, variety Sodar (*Elymus lanceolatus* ssp. *psammophilus*)
- Pubescent wheatgrass, variety Luna (*Thinopyrum intermedium* ssp. *barbulatum*)
- Indian ricegrass, variety Paloma (*Achnatherum hymenoides*)
- Sandberg bluegrass, variety Canbar (*Poa secunda*)
- Sheep fescue, variety Covar (*Festuca ovina*)
- Squirreltail, variety Toe Jam Creek (*Elymus elymoides*)
- Blue grama, variety Hachita (*Bouteloua gracilis*)
- Common yarrow, no variety (*Achillea millefolium*)
- White sage, variety Summit (*Artemisia ludoviciana*).

These species are described in more detail later in this appendix.

PROPOSED SEEDING RATES

Given a mixture of the species listed above, Table D-1 presents broadcast seeding rates for each species. Seeding rates were developed based on the objective of establishing a

permanent cover of grasses and forbs in a mixture that would promote compatibility among species and minimize competitive exclusion or loss of species over time. The proposed seeding rate is based on pounds of pure live seed per acre (lbs PLS/acre).

ECOLOGICAL CHARACTERISTICS OF PROPOSED SPECIES AND ESTABLISHED PLANT COMMUNITY

Longevity and Sustainability

All of the species proposed for reclamation of the tailings cells are long-lived, except for slender wheatgrass (*Elymus trachycaulus*) and squirreltail (*Elymus elymoides*). Slender wheatgrass is a perennial bunchgrass that is short-lived (5 to 10 years) but has the ability to reseed and spread vegetatively with rhizomes. Squirreltail is also a short-lived perennial but has the ability to establish quickly and is highly effective in competing with undesirable annual grasses. Both of these species are included in the proposed seed mixture because of their ability to provide quick cover for erosion protection and to effectively compete with annual and biennial species that cannot be relied upon to provide consistent and sustainable plant cover. The use of these species will facilitate the establishment of the remaining long-lived perennials that have been documented to be highly adapted to the elevation, climate, and soil conditions found at the White Mesa Mill Site (Monsen et al., 2004; Alderson and Sharp, 1994; Wasser, 1982; Thornburg, 1982).

The perennial grasses and forbs in the proposed seed mixture include species that develop individual plants that are long lived (30 years or more) and are able to reproduce either by seed or vegetative plant parts like rhizomes and tillers. The use of these species in reclamation of the tailing cells will ensure a permanent or sustainable plant cover because of the highly adapted nature of these species to existing site conditions, their tolerance to environmental stresses such as drought, fire, and herbivory, and their ability to effectively reproduce over time.

The use of a mixture of species for the ET cover also contributes to longevity and sustainability. The establishment of a diverse community has many advantages over a

monoculture for sustained plant growth. The use of a variety of species ensures that diverse microsites that may exist over a seeded site are properly matched with species that are adapted to those specific environmental conditions. In addition, a mixture of species reverses the loss of plant diversity and enhances natural recovery processes following impacts from insects, disease organisms, and adverse climatic events. Finally, mixtures provide improved ground cover and surface stability, along with reducing weed invasion by fully utilizing plant resources such as water, nutrients, sunlight and space. Weeds in this context are typically annual or biennial plants considered to be undesirable or troublesome, especially growing where they are not wanted.

Compatibility

Reclamation research and its application have been ongoing in the U.S. since the early 1900s. First with the reseeding of millions of acres following the dust bowl of the 1930s. Then, improvements of large tracts of arid and semiarid rangelands between the 1960s and 1980s following more than a half a century of rangeland exploitation through overgrazing. In 1985 the U.S. Department of Agriculture Conservation Reserve Program was implemented which resulted in the conversion of more than 40 million acres of marginal farm land to permanent grasslands through an extensive seeding program. Finally, there have been tens of thousands of acres of mined lands reclaimed across the U.S. with the implementation of federal and state rules and regulations governing mine land reclamation. Over this time period, there have been thousands of reclamation publications in the form of books, scientific journal articles, symposium proceedings, and government publications. Many publications have reported on the performance of individual species and mixtures of species under semiarid conditions similar to southeastern Utah (e.g., Plummer et al., 1968; Monsen et al., 2004). All of this work has led to a knowledge base about species compatibility. Species that are seeded together in mixtures must be compatible as young, developing plants or certain individuals will succeed and others will fail. The species proposed for the ET cover at the White Mesa Mill Site are all compatible with each other and seeding rates will be used to prevent overseeding species that may be aggressive [e.g., pubescent wheatgrass (*Thinopyrum*

intermedium)] and could potentially dominate the site (Monsen et al., 2004). These species are commonly seeded together and many studies have shown excellent interspecies compatibility (e.g., DePuit et al., 1978; DePuit, 1982; Redente et al., 1984; Sydnor and Redente, 2000; Newman and Redente, 2001). Finally, to increase compatibility and to reduce competition among seeded species, sites would be broadcast seeded as opposed to drill seeded. According to Monsen et al. (2004), drill seeding causes species in a mixture to be placed in potentially competitive situations, while broadcasted seeds are not placed in as close contact with each other as with drilling and therefore are less likely to be negatively impacted from competition.

Competition

There are two ways to view competition. In the context of establishing an ET cover on the tailing cells, the use of seeded species to compete with weeds or woody plants is a desirable attribute. However, competition among seeded species with the potential loss of any of these species is undesirable. Therefore, as stated earlier, the proposed seed mixtures is comprised of species that can coexist and also fully utilize plant resources to keep weeds or woody species from colonizing and excluding seeded species. The establishment of weeds, especially invasives (i.e., non-native species whose introduction causes economic and environmental harm) is unacceptable because of the potential loss of seeded perennial species and the subsequent reduction in species diversity, plant cover, and overall sustainability. The establishment of deep rooted woody plants is unacceptable because of the potential for bioinvasion through the cover and into the tailings material. Once established, the proposed seed mixture will produce a grass-forb community of highly adapted and productive species that will effectively compete with undesirable species, including shrubs native to the area. Paschke et al. (2003) present a literature review on shrub establishment on mined lands and conclude that one of the primary reasons that shrub establishment does not occur in mined land reclamation is because of competition from herbaceous species. This finding is also supported by DePuit et al. (1980), DePuit (1988), Munshower (1994), and Monsen et al. (2004). Because of the highly adapted and competitive nature of the species that will be seeded,

the invasion of indigenous woody species will be inhibited, and intrusion into the cover below the water storage layer (top 4 feet of the cover) from their roots is not anticipated to occur. Woody species in this environment are slow-growing and not nearly as competitive for water and nutrients as the proposed grass and forb species (Monsen et al., 2004). In addition, species like sagebrush, piñon pine, and Utah juniper have become dominant components of the regional flora primarily because of decades of overgrazing that has removed more palatable grasses and forbs and allowed less palatable woody species to establish and expand their range (Dames and Moore, 1978; Ellison, 1960). This process is referred to as retrogression (Holechek et al., 1998). These conditions will not occur on the tailing cells cover and therefore will not be a factor favoring the establishment of woody species.

Percent Plant Cover and Leaf Area Index

Monitoring of an alternative cover at the Monticello, Utah, Uranium Mill Tailings Disposal Site showed that the plant cover performed well over a seven year period. Plant cover ranged from 5.5% during the first growing season to nearly 46% in the seventh growing season (Waugh et al., 2008). A total of 18 species were seeded at the Monticello Site and of these 18 species, eight species contributed 70% of the total plant cover. Approximately one half of the species proposed for the White Mesa Site were seeded at Monticello and of the eight best-performing species, four of these species are in the White Mesa mixture. High performing species used at Monticello that are not proposed for White Mesa include three introduced species that can be highly competitive (i.e. smooth brome, crested wheatgrass, and alfalfa) and were not considered acceptable for the White Mesa Site. Based on these results and the similarity in environmental conditions between Monticello and White Mesa, a plant cover estimate of 40% was determined to be a reasonable estimate for a long-term average, while a percent plant cover of 30% was assigned as a worst case scenario under drought conditions. The percent vegetative cover at White Mesa is expected to be slightly less than what would be found at Monticello because the average annual precipitation at White Mesa is approximately 13 inches compared to 15 inches at Monticello and the average annual

maximum/minimum air temperatures are 64/37°F for White Mesa and 59/33°F for Monticello. The slightly greater precipitation and lower temperatures at Monticello are due to its slightly higher elevation of 7,000 feet compared to 5,600 feet at White Mesa.

Long-term average plant cover for the tailing cells along with monthly leaf area index (LAI) values were estimated for the proposed ET cover at the White Mesa Site. Three primary publications were used to estimate monthly LAI for the ET cover, including: Groeneveld (1997), Scurlock et al. (2001), and Fang et al. (2008). Table D-2 presents a compilation of LAI values based on North American data sets that were focused on semiarid herbaceous plant communities. Months with a LAI of zero were assigned a transpiration rate of zero, and only evaporation was simulated in the HYDRUS-1D model. It is important to note that the proposed species for the ET cover include both cool- and warm-season species. This combination of species will maximize the length of the growing season and transpiration from early spring to late fall. Cool-season species are more productive and use more water during the cooler times of the growing season, while warm-season species are more productive and use more water during the warmest period of the year.

The formation of desert pavement and potential impact on plant cover has been raised as an issue for discussion. Desert pavements are armored surfaces composed of angular or rounded rock fragments, usually one or two stones thick, set on or in a matrix of finer material (Cooke and Warren, 1973). These surfaces form on arid soils through deflation of fine material by wind or water erosion due to a lack of protection by surface vegetation (Cooke and Warren, 1973). Desert pavements are not common in semiarid regions and do not occur where either wind or water erosion are controlled by plant cover (Hendricks, 1991), as would be the case for the White Mesa cover system. In addition, there is no evidence of desert pavement formation either on the White Mesa Site or areas surrounding the site. Even with the use of a topsoil layer amended with gravel, there is no supporting evidence to indicate a potential for desert pavement formation or an associated decrease in plant cover over the long term.

Rooting Depth and Distribution

The effective rooting depth would be 3.5 feet (107 cm). Six primary publications were used to estimate root densities by depth for the plant community that would establish on the ET cover, including: Hopkins (1953), Bartos and Sims (1974), Sims and Singh (1978), Lee and Lauenroth (1994), Jackson et al. (1996), and Gill et al. (1999). Table D-3 and Figure D-1 present an estimate of effective root densities by depth for the ET cover system proposed for the White Mesa tailing cell cover. Root densities are presented for anticipated and worst case scenarios. The root densities were interpolated at depth in order to parameterize the HYDRUS-1D model (e.g., 0 to 15 cm interpolated from 0 to 1.9 grams/cm³). Rooting depths for species included in the proposed seed mixture for the White Mesa site are presented in Table D-4.

BIOINTRUSION

Based on a review of the wildlife survey data from the 1978 Environmental Report produced for the White Mesa site (Dames and Moore, 1978), and a thorough literature review of burrowing depths and biointrusion studies, the maximum depth of on-site burrowing would be approximately one meter or slightly over three feet. Wildlife survey data for the site indicate that burrowing mammals include deer mice, kangaroo rats, chipmunks, desert cottontails, blacktailed jackrabbits, and prairie dogs. Other burrowing mammals, such as pocket gophers and badgers have not been observed in the area of the White Mesa site (Dames and Moore, 1978). Of the list of burrowing mammals that may occur on the site, the prairie dog is the species capable of burrowing to the greatest depth. Studies by Shuman and Whicker (1986) and Cline et al. (1982) conducted in southeast Wyoming, Grand Junction, Colorado and Hanford, Washington, document maximum burrowing depths of prairie dogs between 2.0 and 3.2 feet. Based on this empirical data and the potential species that may use the site as habitat, any burrowing activity that may occur would be limited to about three feet below ground surface. Burrowing animals would not significantly perturb the surface of the cover, and thus would not encourage growth of undesirable species. The effects of biointrusion on water flow and radon transport through the ET cover was evaluated as part of the sensitivity analysis for the

infiltration model (see Appendix G), as well as the radon attenuation model (see Appendix H).

SOIL REQUIREMENTS FOR SUSTAINABLE PLANT GROWTH

There are two key components to establishing an ET cover with a sustainable plant community. The first is to select long-lived species that are adapted to the environmental conditions of the site. The second is to provide a cover soil that will function as an effective plant growth medium over the long term by supplying plants with adequate amounts of water, nutrients and rooting volume.

There are a number of soil characteristics that are particularly important to achieve long-term sustainability in semiarid environments and include the following: pH, electrical conductivity (EC), sodium levels, percent organic matter, texture, bulk density, cation exchange capacity, macronutrient concentrations, available water holding capacity, and soil microorganisms. Table D-5 presents levels for most of these soil properties that are considered necessary for long-term sustained plant growth. In addition, the table includes soil property levels from soil samples of potential cover soil collected from stock piles at the White Mesa Site in May 2009.

The soil properties of the potential cover soil that are acceptable for sustaining long-term plant growth include: pH, EC, sodium adsorption ratio (SAR), percent clay content, and extractable phosphorus. Those soil properties that appear to be deficient and would need improvement include: percent organic matter, total nitrogen, and extractable potassium.

Cation exchange capacity was not measured in the potential cover soil, but it is believed that the cover soil will have an acceptable level for sustained plant growth based on the percent clay content and a recommendation that an organic matter amendment be added to the soil during the reclamation process. Bulk density of the emplaced cover material will be specified in the cover design and will be controlled during the construction process to be within the sustainability range shown in Table D-5.

In order for the potential cover soil to function as a normal soil and provide long-term sustainable support for the vegetation component of the ET cover, it will be amended to improve organic matter content, nitrogen and potassium levels. An organic matter amendment will also improve available water holding capacity and cation exchange capacity. The source of organic matter will depend upon availability in the region and could either be composted biosolids or a combination of manure and hay to provide a material that has the appropriate carbon to nitrogen ratio for sustained plant growth. Such an organic matter amendment will also provide a source of soil microorganisms that will function to cycle nutrients over time and ensure sustainable plant growth.

UPDATED RECLAMATION PLAN AND ENGINEERING SPECIFICATIONS

Upon Executive Secretary approval of the Infiltration and Contaminant Transport Modeling (ICTM) Report, and proposed conceptual cover design included as part of this report, the Reclamation Plan would be modified to accommodate necessary changes to protect public health and the environment. The Reclamation Plan would include most of the details presented within this appendix, as well as vegetative design criteria that must be met (e.g., percent cover, exclusion of woody and invasive species). The Engineering Cover Design will include material specifications and a comparison to the data used to support the modeling presented in the ICTM Report.

ECOLOGICAL CHARACTERISTICS OF PROPOSED SPECIES

Important ecological characteristics for each species proposed for reclamation are provided in the paragraphs that follow. Species information was obtained from Monsen et al. (2004), Alderson and Sharp (1994), Wasser (1982), and Thornburg (1982). The proposed species are adapted to the elevation (5,600 feet), precipitation (13 inches per year on average), and soil textural ranges (loam to sandy clay) that are well within the environmental conditions of the White Mesa Site. Table D-4 presents a summary of the ecological characteristics discussed in the following paragraphs.

Western wheatgrass, variety Arriba (*Pascopyrum smithii*)

Western wheatgrass is a native, rhizomatous, long-lived perennial cool season grass. It grows well in a 10 to 14 inch mean annual precipitation zone and is adapted to a wide range of soil textural classes at elevation ranges up to 9,000 feet. Western wheatgrass has been an important species for restoring mining related disturbances, for erosion control and for critical area stabilization in semiarid regions because of its ease of establishment and ability to grow successfully in pure or mixed stands of both warm and cool season species. Western wheatgrass is fire tolerant and regenerates readily following burning. The variety of Arriba is known for rapidly establishing seedlings and high seed production. The combination of its ability to spread vegetatively and reproduce by seed ensures long-term sustainability of this species.

Bluebunch wheatgrass, variety Goldar (*Pseudoroegneria spicata*)

Bluebunch wheatgrass is a native, cool season perennial bunch grass. Bluebunch wheatgrass grows on soils that vary in texture, depth and parent material. It is one of the most important and productive grasses found in sagebrush communities in the intermountain west. Bluebunch wheatgrass is fire tolerant and regenerates vegetatively following burning. This species is well adapted to a 12 to 14 inch mean annual precipitation range and is considered to be highly drought resistant. Bluebunch wheatgrass performs well in mixtures with other species and grows at elevations up to 10,000 feet.

Slender wheatgrass, variety San Luis (*Elymus trachycaulus*)

Slender wheatgrass is a native, cool season, perennial bunch grass that occasionally produces rhizomes. It is a short-lived species (5 to 10 years) but it reseeds and spreads well by natural seeding, exceeding most other wheatgrasses in this characteristic. Slender wheatgrass can serve as an important pioneer species; its seedlings are vigorous and capable of establishing on harsh sites. In addition, it is able to establish and compete with weedy species. Slender wheatgrass is commonly

seeded in mixtures with other grasses and forbs to restore disturbances and rehabilitate native communities. It is adapted to a wide variety of sites and is moderately drought tolerant. It performs best at sites with an annual precipitation of 15 inches or more, but can grow on sites with precipitation levels as low as 13 inches.

Streambank wheatgrass, variety Sodar (*Elymus lanceolatus* ssp. *psammophilus*)

Streambank wheatgrass is considered to be part of the thickspike wheatgrass (*Elymus lanceolatus* ssp. *lanceolatus*) taxa. Variety Sodar is a native, perennial sod grass that is highly rhizomatous and adapted to the western intermountain area. It is highly drought tolerant and performs well in mean annual precipitation ranges between 11 and 18 inches. It grows on a wide range of soil textures, from sandy to clayey. Streambank wheatgrass is commonly used in mine land reclamation and is best known for its ability to control erosion and compete with annual weeds. Its highly rhizomatous nature ensures long-term sustainability of this species.

Pubescent wheatgrass, variety Luna (*Thinopyrum intermedium* ssp. *barbulatum*)

Pubescent wheatgrass is a long-lived sod forming perennial introduced from Eurasia. It is highly drought tolerant and grows where the mean annual precipitation is 12 inches or more. It is adapted to a wide range of soil textures, from sand to clay. Pubescent wheatgrass is a highly persistent species, should be seeded at low densities to avoid competition with native species and has been found to be effective in reducing the establishment of woody plants.

Indian ricegrass, variety Paloma (*Achnatherum hymenoides*)

Indian ricegrass is a native, cool season, perennial bunchgrass with a highly fibrous root system. Indian ricegrass is one of the most common grasses on semiarid lands in the west and is one of the most drought tolerant species used in mine land reclamation. It generally occurs on sandy soils, but is found on soils ranging from sandy to heavy clays. It grows from 2,000 to 10,000 feet in areas where the mean

annual precipitation is 6 to 16 inches. Indian ricegrass is slow to establish, but highly persistent once it becomes established.

Sandberg bluegrass, variety Canbar (*Poa secunda*)

Sandberg bluegrass is a native, cool season perennial bunchgrass that is adapted to all soil textures and is highly resistant to fire damage. Sandberg bluegrass is one of the more common early-season bunchgrasses in the Intermountain area. It grows at elevations from 1,000 to 12,000 feet and can be successfully established in areas with a mean annual precipitation of 12 inches or more. Established plants are not overly competitive, and therefore highly compatible with other native species.

Sheep fescue, variety Covar (*Festuca ovina*)

Sheep fescue is a short, mat-forming native perennial that grows well on infertile soils in areas with a mean annual precipitation of 10 to 14 inches. It is long-lived and highly drought tolerant. Sheep fescue is a cool season species that greens up early in the spring. The proposed variety, Covar, was introduced from Turkey and is commonly used in mine land reclamation for long-term stabilization and erosion control. This variety was selected because plants are persistent, winter hardy, and drought tolerant.

Squirreltail, variety Toe Jam Creek (*Elymus elymoides*)

Squirreltail is a short-lived perennial that is selected for its ability to establish quickly and to effectively compete with undesirable annual grasses. It grows along an elevation range from 2,000 to 11,000 feet and on all soil textures in mean annual precipitation zones of 8 to 15 inches. Squirreltail is fairly tolerant of fire because of its small size.

Blue grama, variety Hachita (*Bouteloua gracilis*)

Blue grama is a low-growing perennial warm season bunchgrass. Blue grama produces an efficient, widely spreading root system that is mostly concentrated near the soil surface. Blue grama is adapted to a variety of soil types, but does best on well-drained soils and once established, is highly drought tolerant. This species is commonly found with cool-season species and is highly compatible with other native perennials.

Common yarrow (*Achillea millefolium*)

Yarrow is a common native forb species that is rhizomatous and found growing from valley bottoms to timberline. It is commonly used in mine land reclamation, establishes easily from seed and is highly persistent. It grows on a variety of soil textures and found in a mean annual precipitation range between 13 and 18 inches.

White sage, variety Summit (*Artemisia ludoviciana*)

White sage is considered to be a pioneer rhizomatous forb species that establishes quickly on disturbed sites and is highly compatible with perennial grasses. It does best on well-drained soils, but can be found growing on a wide range of soil textures. It is adapted to sites above 5,000 feet in elevation and to sites with a mean annual precipitation above 12 inches.

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Table D-1. Species and seeding rates proposed for ET cover at the White Mesa Mill Site.

Scientific Name	Common Name	Variety	Native/ Introduced	Seeding Rate (lbs PLS/acre) [†]
Grasses				
<i>Pascopyrum smithii</i>	Western wheatgrass	Arriba	Native	3.0
<i>Pseudoroegneria spicata</i>	Bluebunch wheatgrass	Goldar	Native	3.0
<i>Elymus trachycaulus</i>	Slender wheatgrass	San Luis	Native	2.0
<i>Elymus lanceolatus</i>	Streambank wheatgrass	Sodar	Native	2.0
<i>Elymus elymoides</i>	Squirreltail	Toe Jam	Native	2.0
<i>Thinopyrum intermedium</i>	Pubescent wheatgrass	Luna	Introduced [‡]	1.0
<i>Achnatherum hymenoides</i>	Indian ricegrass	Paloma	Native	4.0
<i>Poa secunda</i>	Sandberg bluegrass	Canbar	Native	1.0
<i>Festuca ovina</i>	Sheep fescue	Covar	Native	2.0
<i>Bouteloua gracilis</i>	Blue grama	Hachita	Native	1.0
Forbs				
<i>Achillea millefolium</i>	Common yarrow	No variety	Native	6.0
<i>Artemisia ludoviciana</i>	White sage	Summit	Native	3.0
Total				30.0

[†] Seeding rate is for broadcast seed and presented as pounds of pure live seed per acre (lbs PLS/acre).

[‡] Introduced refers to species that have been ‘introduced’ from another geographic region, typically outside of North America. Also referred to as ‘exotic’ species.

Table D-2. Leaf area index for the ET Cover at White Mesa Mill Site.

Month											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	0	0.3	0.7	0.6	0.6	1.8	2.4	2.6	0.8	0.1	0

Table D-3. Root densities (anticipated case and worst case) for the White Mesa Mill Site.

Depth (cm)	Root Density (grams cm ⁻³)	Root Density (grams cm ⁻³)
	Anticipated Case	Worst Case
0-15	1.9	1.3
15-30	6.2	4.3
30-45	1.7	0.8
45-60	0.8	0.5
60-75	0.6	0.3 [†]
75-90	0.6	0.0
90-107	0.4	0.0

[†]Maximum rooting depth under worst case scenario would be 68 cm.

Table D-4. Summary of ecological characteristics of plant species proposed for the ET cover at the White Mesa Mill Site.

Species	Origin	Annual or Perennial	Method of Spread	Ease of Establishment ^a	Compatibility with Other Species ^a	Longevity ^a	Annual Precipitation Range (inches)	Elevation Range (feet)	Soil Texture ^b	Rooting Depth (cm)	Soil Stabilization ^a	Drought Tolerance ^a	Fire Tolerance ^a
Western wheatgrass	Native	Perennial	Vegetative	4	3	4	10-14	≤9,000	S,C,L	109 ^d	4	4	4
Bluebunch wheatgrass	Native	Perennial	Seed	4	4	4	12-14	≤10,000	S,C,L	122 ^e	4	4	4
Slender wheatgrass	Native	Perennial	Seed	4	4	2	13-18	≤10,000	S,C,L	109 ^d	2	2	2
Streambank wheatgrass	Native	Perennial	Vegetative	4	4	4	11-18	≤10,000	S,C,L	165 ^f	4	4	3
Pubescent wheatgrass	Introduced	Perennial	Vegetative	4	2	4	12-18	≤10,000	S,C,L	185 ^d	4	4	3
Indian ricegrass	Native	Perennial	Seed	3	4	4	6-16	≤10,000	S,L	84 ^g	2	4	2
Sandberg bluegrass	Native	Perennial	Seed	4	4	4	12-18	≤12,000	S,C,L	45 ^h	2	3	4
Sheep fescue	Native	Perennial	Seed	4	2	4	10-14	≤11,000	S,C,L	56 ^e	3	4	2
Squirreltail	Native	Perennial	Seed	3	4	3	8-15	≤11,000	S,C,L	30 ^{c,i}	2	4	3
Blue grama	Native	Perennial	Vegetative	2	4	4	10-16	≤10,000	S,L	119 ^g	4	4	4
Common yarrow	Native	Perennial	Vegetative	4	3	4	13-18	≤11,000	S,C,L	105 ^h	4	3	2
White sage	Native	Perennial	Vegetative	4	4	4	12-18	≥5,000	S,C,L	20 ^{c,i}	3	3	2

^aKey to Ratings—4 = Excellent, 3 = Good, 2 = Fair, 1 = Poor

^bSoil Texture Codes—S = Sand, C = Clay, L = Loam

^cDepth represents minimum depth; no information in the literature on average or maximum depth could be found

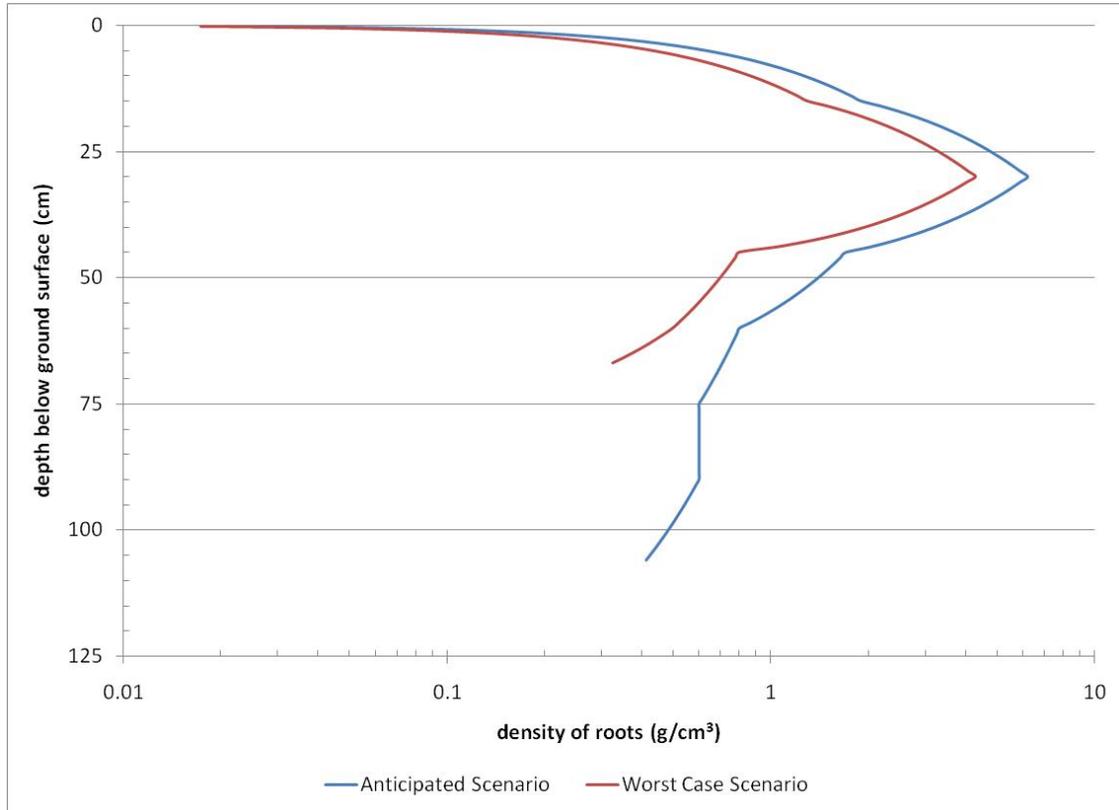
^dWyatt et al., 1980; ^eWeaver and Clements, 1938; ^fCoupland and Johnson, 1965; ^gFoxx and Tierney, 1987; ^hSpence, 1937; ⁱUSDA, 2009

Table D-5. Soil properties and their range of values important for sustainable plant growth, along with analytical results of soil available for ET cover construction at the White Mesa Mill Site.

Soil Property	Level for Sustainability	Reference	Levels for On-Site Soil
pH (units)	6.6 to 8.4	Munshower (1994)	7.7 to 8.1
EC (mmhos/cm)	≤4.0	Munshower (1994)	<1.5
Sodium adsorption ratio	≤12	Munshower (1994)	<0.5
Organic matter (%)	1.5 to 3.0	Brady (1974)	0 to 0.4
Texture (%)	35 to 50% clay	Brady (1974)	36 to 50% clay
Bulk density (g/cm ³)	1.2 to 1.8	Brady (1974)	1.59 to 1.99 [†]
Water holding capacity (cm H ₂ O/cm soil)	0.08 to 0.16	Brady (1974)	0.084-0.14 [†]
Cation exchange capacity (meq/100g)	5 to 30	Munshower (1994)	Not measured
Total nitrogen (%)	0.05 to 0.5	Harding (1954)	0.02 to 0.05
Extractable phosphorus (mg/kg)	6 to 11	Ludwick and Rogers (1976)	10 to 57
Extractable potassium (mg/kg)	60 to 120	Ludwick and Rogers (1976)	11 to 36

[†] Calculated values

Figure D-1. Root density profile for a semiarid grassland community for the White Mesa ET cover.



APPENDIX E

COMPARISON OF COVER DESIGNS BASED ON INFILTRATION MODELING

APPENDIX E

COMPARISON OF COVER DESIGNS BASED ON INFILTRATION MODELING

To compare the potential performance of different conceptual cover designs, infiltration modeling with HYDRUS was performed to predict infiltration rates through the tailing cell cover for each design. Four cover designs were evaluated and included one rock cover and three evapotranspiration (ET) covers of variable thicknesses and layering. The material thicknesses for the different cover designs were based on the results of radon attenuation modeling to achieve the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Results of the radon attenuation model are presented in Appendix H. Rates of model-predicted water flux entering the tailings cells were compared between the various simulations and used as the basis to guide the selection of a cover design for the White Mesa tailings cells.

As specified in the Groundwater Discharge Permit (Part I.H.2.f), the Permittee may include supplemental information to justify modification of certain Permit requirements, including tailings cell cover system engineering design and construction specifications. Upon Executive Secretary approval of the ICTM report and proposed conceptual cover design included as part of this report, the Reclamation Plan would be modified to accommodate necessary changes to protect public health and the environment.

CONCEPTUAL COVER DESIGNS

Four different cover designs were simulated with the HYDRUS infiltration model to evaluate the range in model-predicted water flux rates expected to flow into the tailings. The four conceptual cover designs simulated were:

1. Monolithic ET cover design
2. ET cover design with a compacted clay layer
3. ET cover design with a gravel capillary break layer
4. Conventional rock cover design with a compacted clay layer.

Cover 1 is a 2.84-m (9.3-ft) thick monolithic ET cover that consists from top to bottom of:

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil placed at 85% of Standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer
- 162 cm (5.3 ft) of random fill soil comprised of 2.8 feet random fill compacted to 95% of Standard Proctor dry density over 2.5 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

The first cover is based on a monolithic ET cover design with a water storage layer thickness that would provide sufficient soil volume to allow the establishment of vegetation and protection against intrusion by burrowing animals (see Appendix D). Based on empirical data published in the literature, and the potential species that may use the site as habitat, any burrowing activity that may occur would be limited to the upper one meter of the cover, with the remainder of the cover (1.84 m) not impacted. Previously, TITAN Environmental (1996) completed a freeze/thaw evaluation based on site-specific conditions which indicated that the anticipated maximum depth of frost penetration was 6.8 inches (0.6 ft). Therefore, the entire soil-gravel admixture layer and upper few centimeters of the underlying water storage layer will provide adequate protection against frost penetration. The lower platform fill is based on the assumption that a minimum of 3 feet of random fill has already been placed above Cell 2 and that the lower 2.5 feet was placed at 80% while the upper 0.5 feet of that material will be compacted along with 2.3 feet of additional random fill to 95%.

Cover 2 is a 2.72-m (8.9-ft) thick ET cover design with a compacted clay layer that consists from top to bottom of:

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil placed at 85% of Standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer
- 31 cm (1 ft) of compacted clay compacted to 90% of Modified Proctor dry density to serve as a radon attenuation layer
- 119 cm (3.9 ft) of random fill soil comprised of 1.4 feet random fill compacted to 95% of Standard Proctor dry density over 2.5 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

The second cover is based on an ET cover design that contains a compacted clay layer meant to provide added protection to minimize radon fluxes. Cover 2 differs from Cover 1 in that it includes a clay layer between the water storage layer and the platform fill layers. The lower platform fill is based on the assumption that a minimum of 3 feet of random fill has already been placed above Cell 2 and that the lower 2.5 feet was placed at 80% while the upper 0.5 feet of that material will be compacted along with 0.9 feet of additional random fill to 95%.

Cover 3 is a 3.14-m (10.3-ft) thick ET cover design with a gravel layer that consists from top to bottom of:

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil placed at 85% of Standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer

- 31 cm (1 ft) of gravel to serve as a capillary break to inhibit vertical migration of water
- 162 cm (5.3 ft) of random fill soil comprised of 2.8 feet random fill compacted to 95% of Standard Proctor dry density over 2.5 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

The third cover is based on an ET cover design that contains a gravel layer. Cover 3 differs from Cover 1 in that it includes a gravel layer between the water storage and platform fill layers to create a capillary break. The lower platform fill is based on the assumption that a minimum of 3 feet of random fill has already been placed above Cell 2 and that the lower 2.5 feet was placed at 80% while the upper 0.5 feet of that material will be compacted along with 2.3 feet of additional random fill to 95%.

Cover 4 is a 1.91-m (6.25-ft) thick rock cover design with a compacted clay layer that consists from top to bottom of:

- 8 cm (0.25 ft) of rock to serve as armor/riprap to provide for long-term surface resistance (layer not included in numerical model)
- 61 cm (2 ft) of random fill soil compacted to 95% of Standard Proctor dry density to serve as a frost barrier and radon attenuation layer
- 31 cm (1 ft) of compacted clay compacted to 90% of Modified Proctor dry density to serve as a radon attenuation layer
- 92 cm (3 ft) of random fill soil comprised of 1 foot random fill compacted to 95% of Standard Proctor dry density over 2 feet of random fill placed at 80% of Standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

The fourth cover design (IUC, 2000; Denison Mines, 2009) is based on the currently permitted cover design. The rock cover design with a compacted clay layer was based on technology previously recommended by the U.S. Nuclear Regulatory Commission (NRC). However, recent advances in cover design technology have emphasized the construction of vegetated, monolithic ET covers for minimizing infiltration through engineered cover systems, particularly in arid and semiarid regions. The presence of vegetation in an ET cover is expected to enhance evapotranspiration and to significantly reduce infiltration of water into the tailings. The rock cover is not anticipated to become vegetated; therefore infiltration is expected to be much higher for the rock cover compared to the ET cover designs.

The conceptual model designs and hydraulic properties for the different cover materials used to parameterize the HYDRUS models are summarized in Table E-1. The soil water retention and hydraulic conductivity curves for the different cover materials are plotted in Figures E-1 and E-2. Original laboratory datasheets used to support the hydraulic and geotechnical properties are tabulated in Attachment E-1.

INFILTRATION MODEL CONFIGURATION

Grid Spacing

The finite element nodes were discretized in the vertical direction to simulate layers in the different cover systems. Construction of the finite element mesh is dependent on surface and bottom boundary conditions and represented lithologic heterogeneities due to stratigraphic layering (Simunek et al., 2009). As a result, node spacing was finer than the material layers in order to simulate steep hydraulic gradients which result from transient wetting (precipitation and infiltration) and drying (evapotranspiration) fronts. Fine grid spacing was necessary to accurately simulate water flow through the unsaturated zone because hydraulic properties vary significantly as a function of moisture content and pressure head. Because hydraulic properties vary much faster and on a finer scale near the land surface due to rapid changes in atmospheric conditions (daily variations in precipitation and evapotranspiration were modeled), the node spacing varied between 0.1

and 1 cm near the top of the domain representing the cover system. Due to the large contrast in hydraulic conductivity for the compacted clay and gravel layers, the node spacing immediately above and below these layers decreased in a step-wise manner to 0.35 cm. In order to reduce errors due to numerical dispersion, the ratio between neighboring elements did not exceed 1.5 (Simunek et al., 2009).

Initial Conditions

Initial conditions for the infiltration model were determined separately for each scenario. The initial pressure head distribution was determined by evaluating a long-term (114-year) simulation that used the concatenated atmospheric input file as an upper boundary condition (i.e., the 57-year climate record repeated twice). The pressure head distribution for the final time step of the 114-year simulation (Figure E-3) was used as the initial condition for the transient simulations used to predict water infiltration rates through the cover. The model was then rerun using these initial conditions, and the long-term water infiltration rates were averaged during a second 114-year simulation. The methodology implemented to establish the initial conditions for the site is a commonly accepted approach for solving hydrogeologic modeling problems.

Boundary Conditions

The upper surface of the model domain was simulated with an atmospheric boundary condition, while the lower boundary of the cover system was simulated as a unit gradient. The amount of precipitation was based on the 57-year climate record 1932-1988. Development of the climate record for the site is discussed in detail within the main body of the report. All model simulations assumed an anticipated scenario with a maximum rooting depth of 107-cm and an anticipated root density distribution, as supported by data presented in Appendix D. Concatenation of the atmospheric boundary file considered an anticipated scenario assuming 40% vegetative cover. The winter months that included December, January, and February were assigned a transpiration rate of zero, and only evaporation was simulated in the HYDRUS-1D models. Cover 4 was the only model that did not simulate transpiration; only evaporation was simulated because this cover design

is not expected to become vegetated. The sensitivity of the infiltration modeling results to the parameter values assigned to represent the vegetation, reduced performance due to biointrusion, and the amount of precipitation that may occur at the site, was evaluated as part of Appendix G.

The HYDRUS models did not include runoff and 100% of the precipitation was allowed to evaporate or infiltrate into the top layer of the cover. Each scenario was modeled with daily precipitation and ET input using the 57-year climate record. The use of daily rather than hourly input yields nearly identical results, as evaluated in Appendix F.

INFILTRATION MODEL RESULTS

Water Flux

The model-predicted water flux rate through the four different tailings cell covers during a typical 57-year climate record are plotted in Figure E-4. The model-predicted flux rates are plotted on linear and semilog scales to illustrate differences in infiltration rates between the four different cover designs. The infiltration rates plotted on the linear scale demonstrate significantly improved performance of the three ET covers as compared to the currently permitted rock-cover design. The infiltration rates plotted on the semilog scale demonstrate that all three ET covers were predicted to behave in a similar manner, with only nominal differences in model-predicted flux rates between designs. The average infiltration rate predicted to enter the top of the tailings cells for all four simulations is summarized in Table E-2. Overall, the three infiltration models for the ET covers showed significantly improved performance compared to the currently permitted rock cover design. For example, the average model-predicted long-term infiltration rates were reduced from 9.2×10^{-3} centimeters per day (cm/d) for the original rock cover design (Model 4) to 1.2×10^{-4} cm/d for the monolithic ET cover design (Model 1) and 3.1×10^{-5} cm/d for the ET cover design with a capillary break (Model 3), a reduction of 75 to 300x, respectively. The increased performance and reduction of infiltration for the ET covers is attributed to the presence of vegetation and associated transpiration. Simulations for the three ET covers produced two instances that resulted in temporary short-term surface

ponding, while simulations of the fourth cover design (due to decreased saturated hydraulic conductivity of the surface layer and increased subsurface moisture contents) produced many instances in which surface ponding occurred; however, as noted above, runoff was not simulated so that estimates of infiltration through the cover, via surface ponding, would be representative of the expected flat nature (0.2% slope) of the surface. For all HYDRUS simulations the water mass balance errors did not exceed 1%. As a general rule-of-thumb, mass balance errors that do not exceed 3% are considered acceptable.

SELECTION OF PREFERRED COVER DESIGN

The fourth cover design can be eliminated as a design possibility because the model predicted much higher rates of infiltration; furthermore, because the three ET cover designs (Models 1, 2, and 3) contain a soil-gravel admixture layer to minimize long-term surface erosion, the construction of a rock cover to cap the tailings is not advantageous and would lead to increased rates of water flow through the tailings.

Comparison of Model 1 and Model 2 indicates that the inclusion of a compacted clay layer does not significantly reduce infiltration rates compared to the monolithic cover. Furthermore, performance of the second cover design does not account for reduced performance of the compacted clay layer. Reduced performance of the compacted clay layer could occur as a result of shrinking and swelling of the clay particles due to repeated wetting and drying, or desiccation and cracking during installation. Cracking within the clay layer could lead to desiccation thereby affecting long-term moisture contents and the materials effectiveness as a radon attenuation barrier. Cracking could also lead to preferential flow and increased rates of infiltration comparable to results predicted for the first cover design. The clay layer is not necessary for radon attenuation (see Appendix H). Uncertainty of the materials performance, and potential similarity to infiltration rates as compared to the monolithic ET cover (assuming reduced performance), effectively eliminates consideration of the second cover design.

Comparison of Model 1 and Model 3 indicates that the inclusion of a capillary break results in a moderate reduction of infiltration compared to the monolithic cover. However, performance of the third cover design does not account for reduced performance of the gravel layer. Reduced performance of the gravel layer could occur if fines migrate into the material. Plugging of pore spaces would tend to produce a material type more similar to the overlying soil and lead to increased rates of infiltration somewhat comparable to results predicted for the first cover design (assuming reduced performance). The potential migration of fines could be minimized by the inclusion of different filtering media (soil layers); however, inclusion of such materials would significantly increase the difficulty to construct and lead to uncertainty in performance. Given the simplicity, the monolithic ET cover can be constructed with greater certainty and quality assurance. The difference in performance between the covers is nominal, and the addition of any filtering media only adds more complexity and increased uncertainty with only a minimal amount of potential benefit.

Therefore, the design and construction of a monolithic ET cover is the preferred alternative for infiltration control. The model-predicted water flux through the monolithic ET cover indicates that the available storage capacity of the cover should be sufficient to significantly reduce infiltration, and the ET cover should function properly as designed. The transport of water below the rooting zone and into the tailings material would occur when the storage capacity of the overlying soil materials is exceeded; for example, during multi-consecutive years or longer that receive above average amounts of annual or winter precipitation. For the monolithic ET cover (Model 1), breakthrough of water through the bottom of the cover, beginning at about year 48, resulted from the occurrence of three consecutive years that received above average amounts of winter precipitation followed by another seven years that received above average amounts of annual precipitation.

Moisture Contents for the Preferred Cover Design

Moisture content variations at five depth intervals (50, 100, 150, 200, and 284 cm) during a typical 57-year climate record are plotted in Figure E-5 for the monolithic ET cover.

Within the rooting zone, at 50-cm and 100-cm depths, the model-predicted volumetric water content varies from a low of roughly 11% up to a high of 36%; while below the rooting zone, at 150-cm and 284-cm depths, the model-predicted volumetric water content varies from a low of roughly 14% up to a high of 25%. Throughout the year, within the rooting zone, the amount of moisture increases during the winter months because the amount of precipitation generally exceeds the amount of evapotranspiration; and then, during spring and summer, the amount of moisture decreases in response to increased evapotranspirative fluxes. The time series plots verify that within the rooting zone the moisture content has large year-to-year variability, and that below the rooting zone the amount of moisture does not significantly vary through time due to efficient root water uptake within the water storage layer. Overall, the amount of moisture in the cover predicted by the infiltration model generally exceeds the amount of moisture used in the radon attenuation model (12.6%). Therefore, the design and construction of a monolithic ET cover is the preferred alternative for radon control.

CONCLUSIONS

The construction of a monolithic ET cover is the preferred alternative to minimize infiltration and meet the radon attenuation standard. The proposed cover design will be sufficient to provide adequate thickness to protect against frost penetration, provide adequate water storage capacity to minimize the rate of infiltration into the underlying tailings, and provide long-term moisture within the cover to attenuate radon fluxes.

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TABLE E-1. COVER MODEL DESIGNS AND HYDRAULIC PROPERTIES USED TO PARAMETERIZE THE HYDRUS MODELS								
Model Layer	Purpose	Thickness (cm)	Residual soil water content θ_r (% vol)	Saturated soil water content θ_s (% vol)	Curve fitting parameters in the soil water retention function ^a		Saturated hydraulic conductivity in the vertical direction K_{sat} (cm/d)	Source
					α (cm ⁻¹)	n (-)		
Model 1: Monolithic ET Cover^b								
1	Erosion Protection	15	0.045	0.254	0.0145	1.406	5.6	1
2	Water Storage & Radon Attenuation	107	0.055	0.404	0.0145	1.406	7.4	2
3	Upper Platform Fill (High Compaction) Radon Attenuation	86	0.046	0.334	0.0229	1.261	3.6	2
4	Lower Platform Fill (Base Grade) Radon Attenuation	76	0.059	0.439	0.0125	1.461	10.4	2
Model 2: ET Cover with a Compacted Clay Layer^b								
1	Erosion Protection	15	0.045	0.254	0.0145	1.406	5.6	1
2	Water Storage & Radon Attenuation	107	0.055	0.404	0.0145	1.406	7.4	2
3	Clay Radon Attenuation	31	0.08	0.391	0.0122	1.386	0.032	3
4	Upper Platform Fill (High Compaction) Radon Attenuation	43	0.046	0.334	0.0229	1.261	3.6	2
5	Lower Platform Fill (Base Grade) Radon Attenuation	76	0.059	0.439	0.0125	1.461	10.4	2
Model 3: ET Cover with a Gravel Capillary Break Layer^b								
1	Erosion Protection	15	0.045	0.254	0.0145	1.406	5.6	1
2	Water Storage & Radon Attenuation	107	0.055	0.404	0.0145	1.406	7.4	2
3	Capillary Break	31	0.03	0.33	2.8	2.5	112,300	4
4	Upper Platform Fill (High Compaction) Radon Attenuation	86	0.046	0.334	0.0229	1.261	3.6	2
5	Lower Platform Fill (Base Grade) Radon Attenuation	76	0.059	0.439	0.0125	1.461	10.4	2
Model 4: Conventional Rock Cover with a Compacted Clay Layer^c								
1	Frost Barrier & Radon Attenuation	61	0.046	0.334	0.0229	1.261	3.6	2
2	Clay Radon Attenuation	31	0.08	0.391	0.0122	1.386	0.032	3
3	Upper Platform Fill (High Compaction) Radon Attenuation	31	0.046	0.334	0.0229	1.261	3.6	2
4	Lower Platform Fill (Base Grade) Radon Attenuation	61	0.059	0.439	0.0125	1.461	10.4	2

(continued on next page)

Footnotes:

- a. The van Genuchten-Mualem single-porosity soil-hydraulic-property model was selected to characterize the soil-hydraulic properties.
- b. The terminal rooting depth was located at 107-cm depth below ground surface.
- c. Original cover design. No transpiration was simulated. Only evaporation was assumed to occur.

Sources:

1. Erosion protection layer hydraulic properties were estimated by correcting for the volume and mass of gravel added to the random fill material. The residual water content was corrected on a volume basis, while the saturated hydraulic conductivity was corrected on a mass basis. The hydraulic parameter values for the soil were adjusted assuming the gravel-soil mixture was composed of 25% gravel by weight, and that the soil dry bulk density with no gravel was 1.59 g/cm^3 while the gravel density of solids was 2.65 g/cm^3 . The calculated volume percent of gravel, assuming no rock porosity, was 19%. The saturated water content was adjusted to correspond to values used in the radon attenuation model (porosity equal to one minus ratio of in-place dry bulk density to density of solids). The density of solids was assumed to equal 2.67 g/cm^3 .
2. Hydraulic properties of the water storage (placed at 85% Standard Proctor), upper platform fill (compacted to 95% Standard Proctor), and lower platform fill (placed at 80% Standard Proctor) layers were predicted using the soil-properties database in HYDRUS. The average grain size distribution of stockpiled random fill (loam to sandy clay) from 32 samples was 44% sand, 36% silt, and 20% clay, while the maximum Standard Proctor dry bulk density was 1.87 g/cm^3 (Attachment E-1). The in-place dry bulk density was taken as a percentage of the maximum density for each layer. The saturated water contents were then adjusted to correspond to values used in the radon attenuation model (porosity equal to one minus ratio of in-place dry bulk density to density of solids). The density of solids was assumed to equal 2.67 g/cm^3 .
3. Compacted clay (90% Modified Proctor) hydraulic properties were predicted using the soil-properties database in HYDRUS. The average grain size distribution of 16 samples obtained from the clay source identified at Section 16 was 28% sand, 37% silt, and 35% clay, while the maximum Modified Proctor dry bulk density (from 4 samples) was 1.71 g/cm^3 (Attachment E-1). Samples collected from 0 to 5 feet depth below ground surface were not included as part of the averaging because the material was slightly more sandy. The in-place dry bulk density was taken as a percentage of the maximum density. The saturated water content was then adjusted to correspond to values used in the radon attenuation model (porosity equal to one minus ratio of in-place dry bulk density to density of solids). The density of solids was assumed to equal 2.53 g/cm^3 . The saturated hydraulic conductivity was assumed to equal $3.7 \times 10^{-7} \text{ cm/s}$.
4. Gravel hydraulic properties were taken from measurements of pea gravel reported by Dwyer (2003).

TABLE E-2. AVERAGE INFILTRATION RATE PREDICTED TO ENTER THE TOP OF THE TAILINGS CELLS FOR THE FOUR COVER DESIGNS MODELED					
Model	Cover Design	Water Flux (cm/d)	Water Flux (mm/yr)	Water Flux (% of Average Annual Precipitation)	Amount of water entering tailings after 200 years
Model 1	Monolithic ET cover	1.2×10^{-4}	0.45	0.14%	0.09 m (0.29 ft)
Model 2	ET cover with a compacted clay layer	5.4×10^{-5}	0.20	0.062%	0.04 m (0.13 ft)
Model 3	ET cover with a gravel layer	3.1×10^{-5}	0.11	0.036%	0.02 m (0.066 ft)
Model 4	Rock cover with a compacted clay layer	9.2×10^{-3}	34	11%	6.7 m (22 ft)

Note: The average annual precipitation for the 57-year climate record was recorded 1932-1988.

Figure E-1. Semilog plot of the soil water retention curves (pressure head as a function of water content) for the different cover materials. The placement or compaction density for the random fill (RF) as a percentage of the Standard Proctor (SP) maximum dry density is noted for clarification.

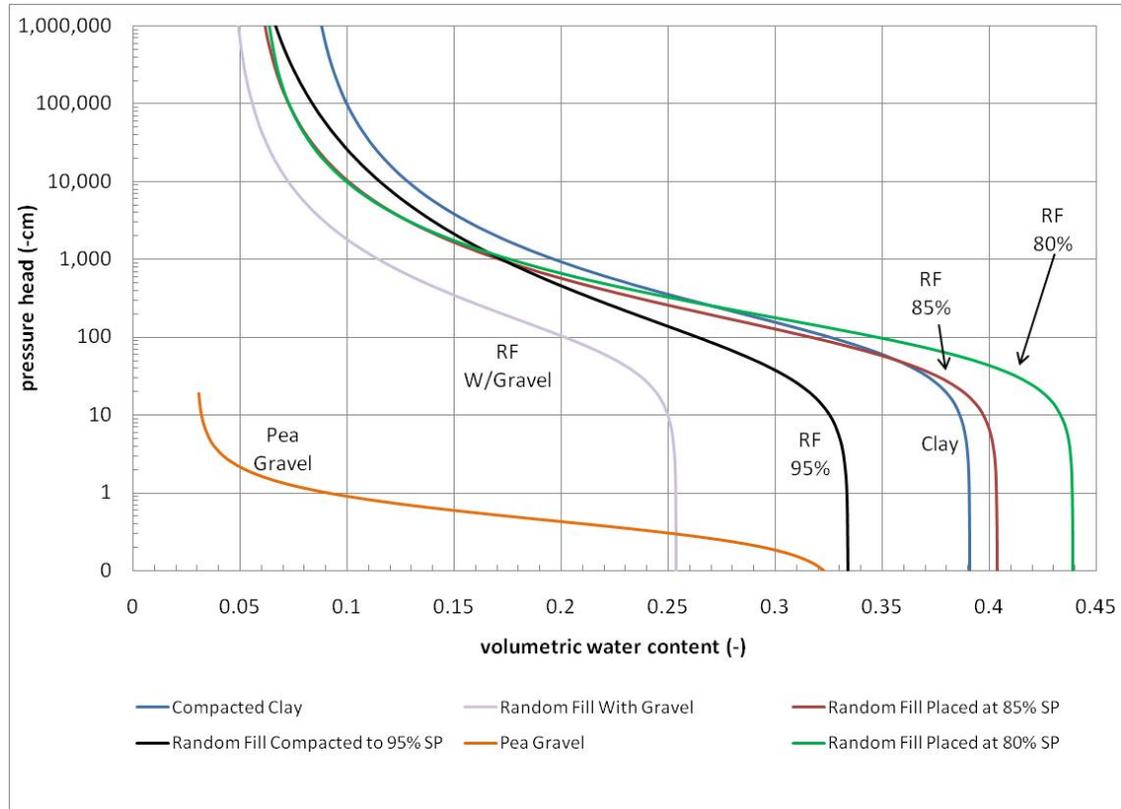


Figure E-2. Semilog plot of the unsaturated hydraulic conductivity curves (log hydraulic conductivity as a function of water content) for the different cover materials. The placement or compaction density for the random fill (RF) as a percentage of the Standard Proctor (SP) maximum dry density is noted for clarification.

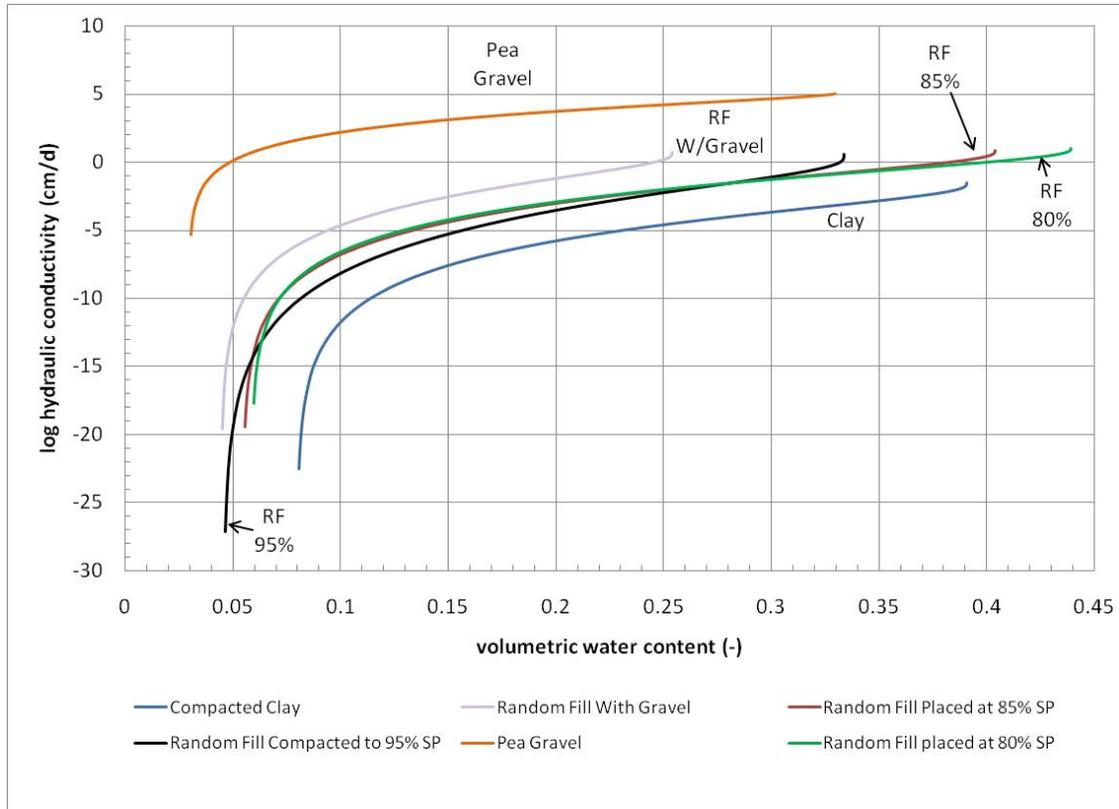


Figure E-3. Initial pressure head distributions for the four tailings cell cover designs.

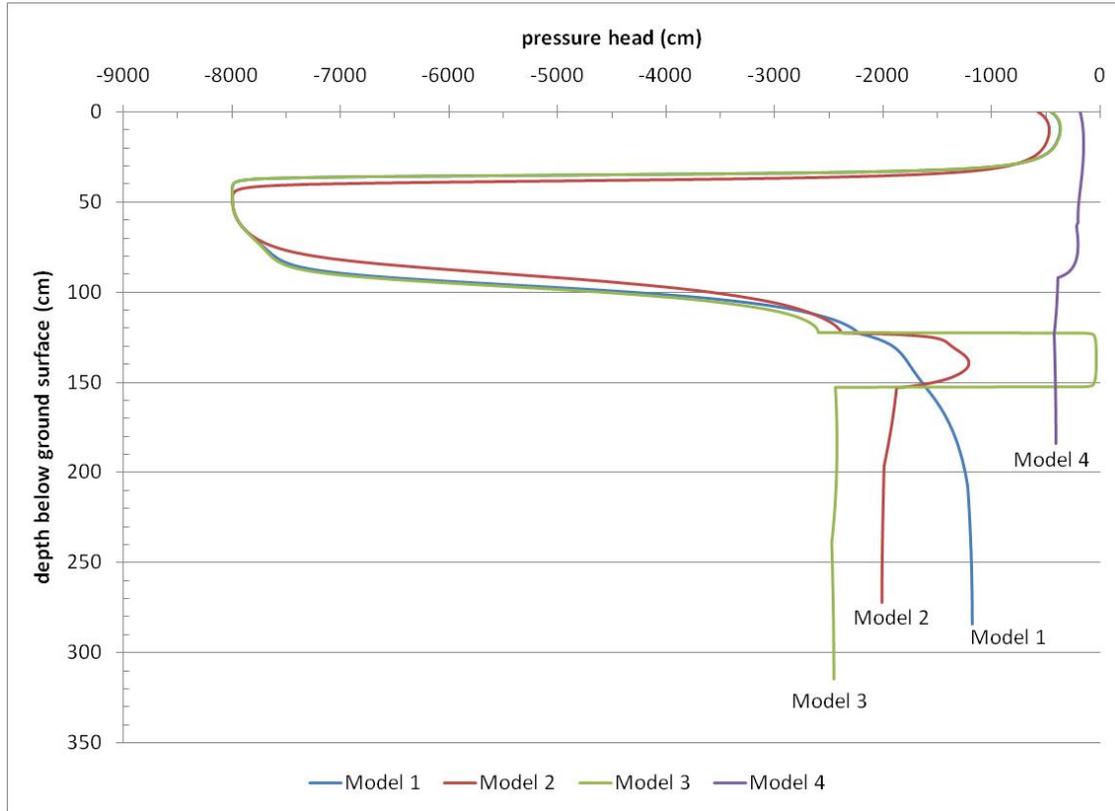


Figure E-4. Model-predicted water flux rates through the four tailings cell cover designs during a typical 57-year climate record. The model-predicted flux rates are plotted on linear (upper figure) and semilog (lower figure) scales to illustrate differences in infiltration rates between the different cover designs.

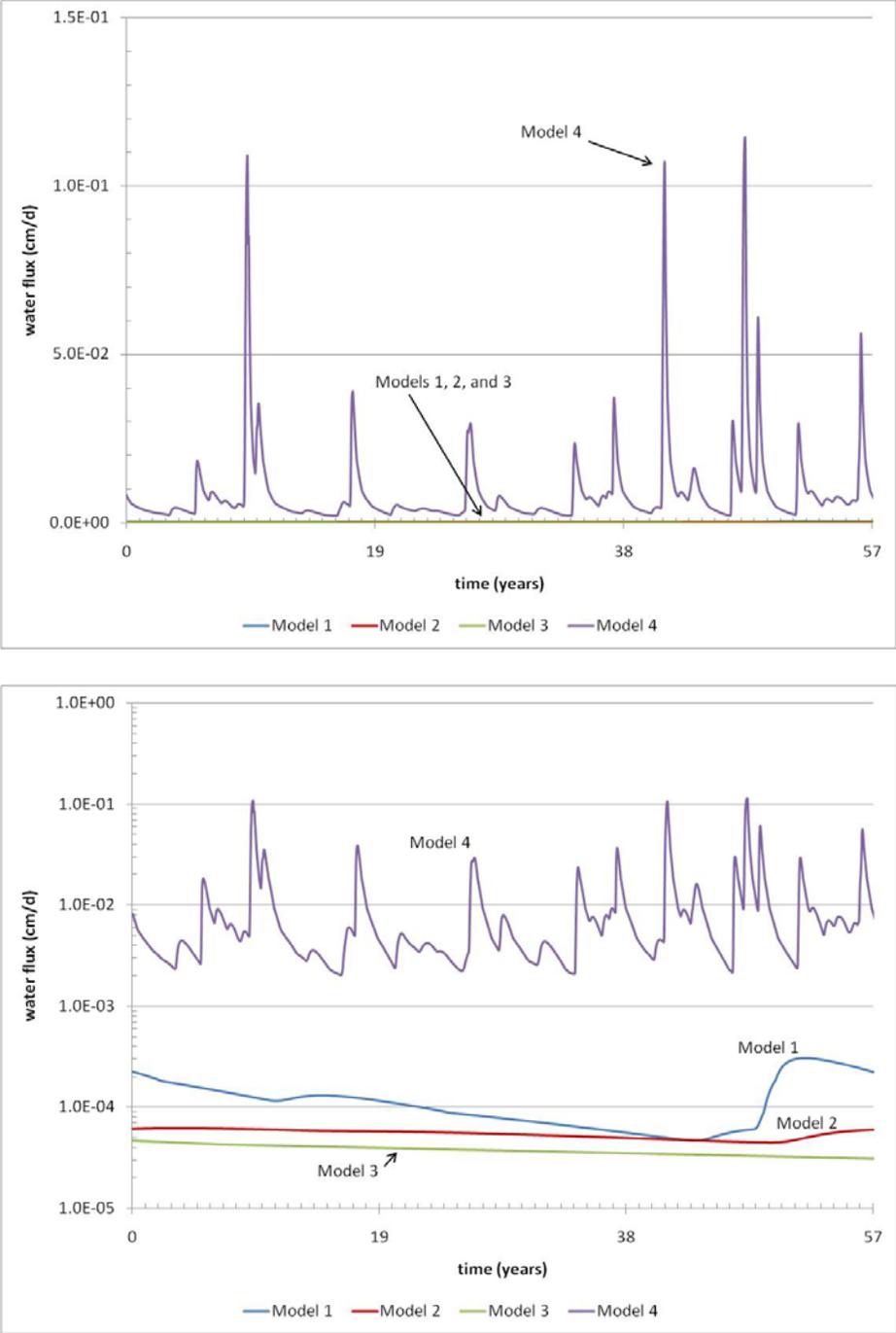
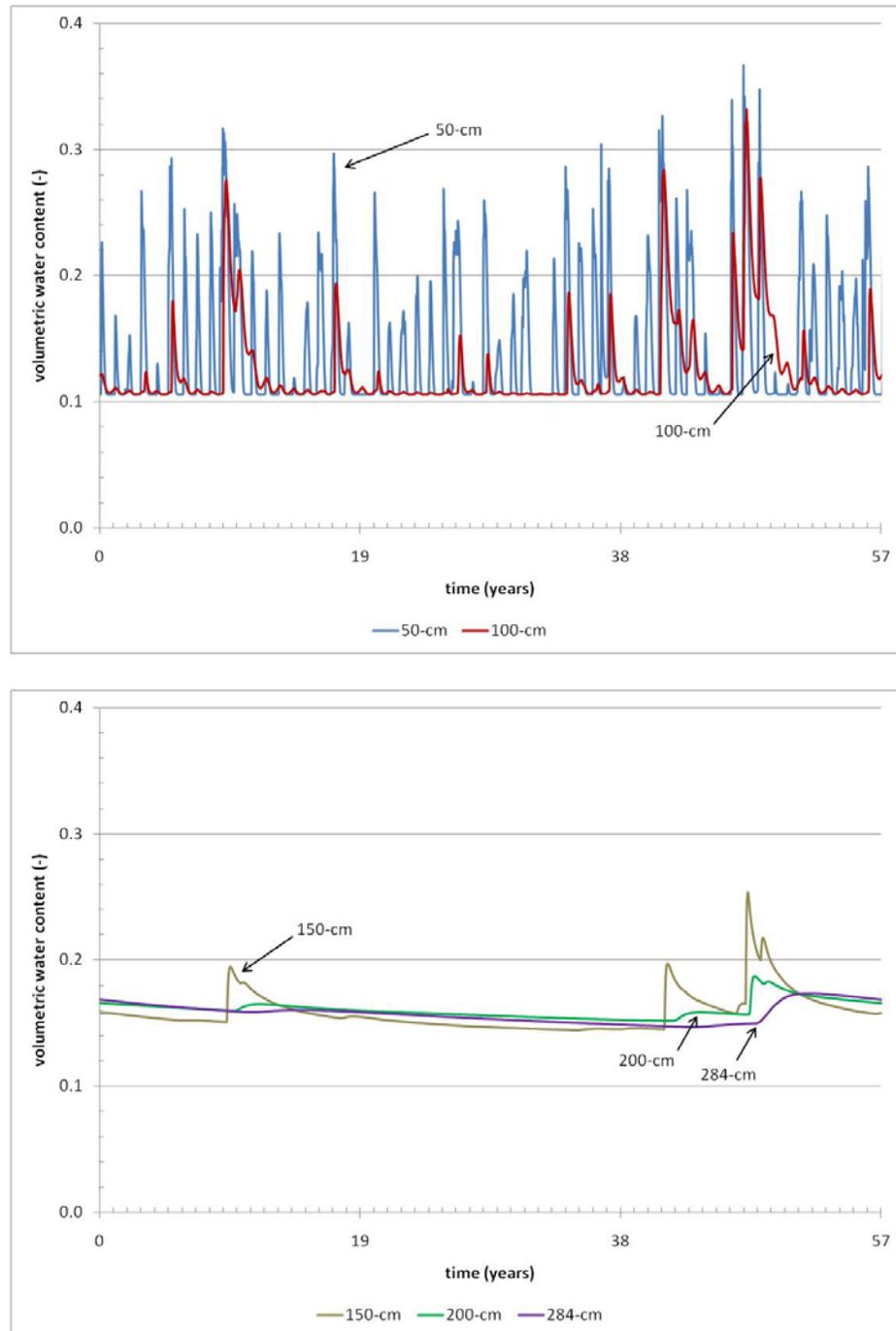


Figure E-5. Moisture content at nested intervals within the monolithic ET cover (Model 1) during a typical 57-year climate record. Water content variations within the rooting zone (**upper figure**) and below the rooting zone (**lower figure**) are plotted. The bottom of the rooting zone is located at 107-cm depth, while the bottom of the cover corresponds to 284-cm depth.



APPENDIX F

EVALUATION OF THE EFFECTS OF STORM INTENSITY ON INFILTRATION THROUGH EVAPOTRANSPIRATION COVER

APPENDIX F

EVALUATION OF THE EFFECTS OF STORM INTENSITY ON INFILTRATION THROUGH EVAPOTRANSPIRATION COVER

The purpose of this appendix is to evaluate the sensitivity of the infiltration modeling results to storm intensity and ponding of water on the monolithic evapotranspiration (ET) cover surface. In the modeling presented in the Infiltration and Contaminant Transport Modeling (ICTM) Report, precipitation was input on a daily basis, thus ignoring storm intensity. However, summer monsoon precipitation events are characterized by severe thunderstorms of short duration. To test the importance of simulating storm intensity and ponding, the HYDRUS model of the monolithic ET cover was run using both hourly and daily precipitation rates. Model-predicted soil moisture content and water flux within the proposed monolithic ET cover were compared for the simulations using hourly versus daily precipitation data as input.

To evaluate the effect of storm intensity on infiltration, two scenarios were modeled:

- a 10-day period with a single intense storm event of 4.4 cm
- a 92-day period representing the summer monsoon season (July 1 through September 30) with 19.2 cm of precipitation (recorded in 1987), the greatest recorded precipitation for the period July 1 through September 30.

The hourly scenarios were modeled with hourly precipitation and ET input, while the daily scenarios were modeled with daily precipitation and ET input. The July 1 through September 30 time period was simulated because severe thunderstorms occur most commonly during this period (summer monsoon).

CONCEPTUAL COVER DESIGN

The proposed conceptual cover design consists of a 2.84-m (9.3-ft) thick monolithic ET cover as described in Appendix E.

INFILTRATION MODEL CONFIGURATION

The hydraulic properties of the cover material, and grid spacing of the HYDRUS-1D model, are summarized in Appendix E.

Initial Conditions

The initial water content within the cover material was taken from the base case model simulation (i.e., assuming 40% vegetative cover, anticipated rooting depth/distribution, and anticipated climate). The initial water content for the top 50-cm portion of the cover is plotted in Figure F-1. The change in water content at a depth of 15 cm is a result of the abrupt change in material properties between the erosion control layer and water storage layer.

Boundary Conditions

The upper surface of the model domain was simulated with an atmospheric boundary condition. The lower boundary of the cover system was simulated as a unit gradient. The HYDRUS models did not include runoff and 100% of the precipitation was allowed to evaporate or infiltrate into the top layer of the cover.

Generally, surface ponding and runoff would be expected to occur for conditions in which the precipitation rate exceeds the infiltration capacity (e.g., saturated hydraulic conductivity) of the surface soil. If water accumulates on the surface of the ET cover (i.e., ponding), evaporative losses from the surface layer are accounted for by applying a net infiltration rate, and the flux of water along the boundary is governed by the hydraulic

potential until all the water infiltrates. Runoff was not simulated, but would act to reduce infiltration.

Precipitation. For the 10-day time series, one precipitation extreme was considered which corresponded to the 100-year average recurrence interval (ARI) for a precipitation event lasting 1-hour. For the Blanding, Utah, weather station, this amounted to 4.4 cm of precipitation distributed during a 1-hour storm. Precipitation frequency estimates were obtained from the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Design Studies Center Web site (<http://www.nws.noaa.gov/oh/hdsc/index.html>). The maximum amount of precipitation recorded on any given day at the Blanding weather station during the period-of-record (1904-2005) from July through September only exceeded 4.4 cm on three occasions. The 10-day simulation that used hourly input data assumed that all of the precipitation (4.4 cm) fell between 13:00 and 14:00 on the first day, which was aimed at reproducing a severe rain event. The base case simulation had precipitation input on a daily basis for the first day (4.4 cm for the day). The remaining days were assumed to lack precipitation.

For the 92-day time series, precipitation data from 1987, the year with the greatest recorded amount of monsoon season precipitation (19.2 cm from July 1 through September 30) were used as model input. For the 92-day simulations that used hourly input data, all precipitation was assumed to occur between 13:00 and 14:00 for each day. Daily precipitation for the 1987 monsoon season is plotted in Figure F-2. There were three storm events that received 2 to 4 cm of precipitation and four storm events that received 1 to 2 cm of precipitation. The maximum amount of precipitation received on any given day during the 1987 season was approximately 4 cm, which corresponded to a 50-year ARI 1-hour duration precipitation event. The maximum precipitation event of 3.99 cm occurred on August 23 (day 54), the day after a 1.57-cm event and was followed by 2.51-cm and 0.89-cm events, which amounts to nearly 50% of the precipitation received during the entire 1987 monsoon season.

Precipitation data recorded during 15-minute increments were obtained for the 1987 monsoon season from the NOAA National Climatic Data Center Web site (<http://www.ncdc.noaa.gov/oa/ncdc.html>) for the Blanding weather station. The 15-minute precipitation data were obtained in order to compare the actual and modeled (hourly input) storm intensities. The modeled storm intensities using hourly input generally exceeded the actual storm event intensities. Furthermore, the finer-resolution precipitation data revealed that the afternoon storm events that occurred between 12:00 and 16:00 generally consisted of a handful of short-duration storms in which approximately 0.3 to 0.8 cm of water were distributed during 15 and 30 minutes, respectively, at intermittent times throughout the day. The maximum precipitation event of 3.99 cm received nearly 90% of the rainfall throughout a 1.75-hour storm. As a result, modeling with hourly input of precipitation rates, which assumed that all of the precipitation occurred during a 60-minute storm event, simulated more intense storms compared to what was actually recorded during the 1987 monsoon season.

Evapotranspiration. Simulations with hourly input data required a finer temporal resolution of potential evaporation (PE) and potential transpiration (PT) than the values used in which precipitation was input on a daily basis. The cumulative potential evapotranspiration (PET) for any given day during July, August, and September was 0.65, 0.52, and 0.40 cm, respectively. The hourly variation in PET for the monsoon season is plotted in Figure F-3. The amount of PE and PT during the hours 0:00-6:00 and 18:00-24:00 was assumed to represent 1% of the total daily value. The rates of PE and PT between the hours of 6:00 and 18:00 were simulated as a step-increasing function with a maximum value occurring at 12:00. The rate of PE and PT was not varied during the 10-day time frame, and was assumed equal to the rate determined for July.

INFILTRATION MODEL RESULTS

Ten-day Period

The daily precipitation input example did not produce any surface ponding because the precipitation intensity did not exceed the capacity of the soil to transmit the water. The

saturated hydraulic conductivity of the surface layer of the ET cover used in all model simulations was 6.5×10^{-5} cm/sec (5.6 cm/day; 0.23 cm/hr), which is greater than the amount of precipitation input on a daily basis (4.4 cm/day). However, the hourly precipitation input example did result in temporary ponding for a 10-hour period between 13:02-23:00 with a maximum ponding depth of 3.2 cm. The formation of ponding for the hourly precipitation input example was expected because the saturated hydraulic conductivity of the ET cover surface (5.6 cm/day; 0.23 cm/hr) was about twenty times lower than the precipitation rate (4.4 cm/hr).

Differences in subsurface soil moisture and water flux were compared for the daily and hourly input examples to yield insight into potential differences that may arise by simulating infiltration through the cover with daily input data rather than hourly data. The moisture content distribution within the upper 50-cm of the cover after day two and day six is plotted in Figure F-4. The water content between the two simulations are similar, with the soil profile being slightly more wet on day two for the simulation that used hourly input data. The difference is attributed to the ponding which would transmit slightly more water deeper into the profile as compared to a scenario that does not lead to ponding. However, after day six, the differences in water content diminished (Figure F-4) and the instantaneous water flux within the cover for the simulations using hourly and daily input were nearly identical (Figure F-5). The infiltration pulse from the precipitation event was not transmitted below 50-cm depth, which demonstrates that the approach using daily or hourly input data would yield similar flux rates through the cover system into the underlying tailings cell. Based on this evaluation, the model simplification of using daily input rather than hourly input does not affect the predictive results.

Monsoon Season

Model predicted water content at 30-cm and 50-cm depths during the 1987 summer monsoon season (19.2 cm of precipitation) using daily and hourly input data are plotted in Figure F-6. The simulation using hourly input data produced eight instances in which temporary ponding occurred. The maximum surface pressure head (i.e., ponding depth)

was 2.8 cm, and saturated conditions at the surface remained for approximately 8 hours following the August 23 storm event of 3.99 cm. Runoff was not included in the simulations in order to be conservative. A similar change in water content was noted at 30-cm and 50-cm depths for the simulations that used daily and hourly input data, which suggests that despite greater variations in water content within the shallow subsurface (e.g., the top 10 cm), using daily or hourly input data result in the same flux rates following back-to-back, high-intensity rainstorm events. Little variation in water content occurred beneath 75-cm depth for the daily and hourly input. Therefore, the method of modeling storm events through daily or hourly input has little effect on the prediction of infiltration through the ET cover (Figure F-7).

CONCLUSIONS

The results of the sensitivity analysis provide justification that daily inputs of precipitation predict conditions that are representative of field conditions that would occur during high-intensity monsoon rainstorm events (as modeled using hourly input data). Hourly input allows for surface ponding, which leads to differences in the distribution of soil moisture in the short term in the upper 50 cm of the cover relative to the modeling with daily input. However, little variation in water content and water flux occurred deeper in the ET cover between the simulations using daily and hourly input. This was true for both the 10-day scenario in which a single 100-year ARI storm of 4.4 cm was simulated and the 92-day scenario in which the precipitation input was set based on the maximum recorded monsoon season of 1987 in which 19.2 cm of precipitation occurred between July 1 and September 30. Based on this evaluation, the model simplification of using daily input rather than hourly input does not affect the predictive results. The exclusion of runoff, and simulation with a one-dimensional model, results in representative estimates of infiltration through the cover.

Figure F-1. Initial water content for the top 50-cm portion of the monolithic evapotranspiration (ET) cover.

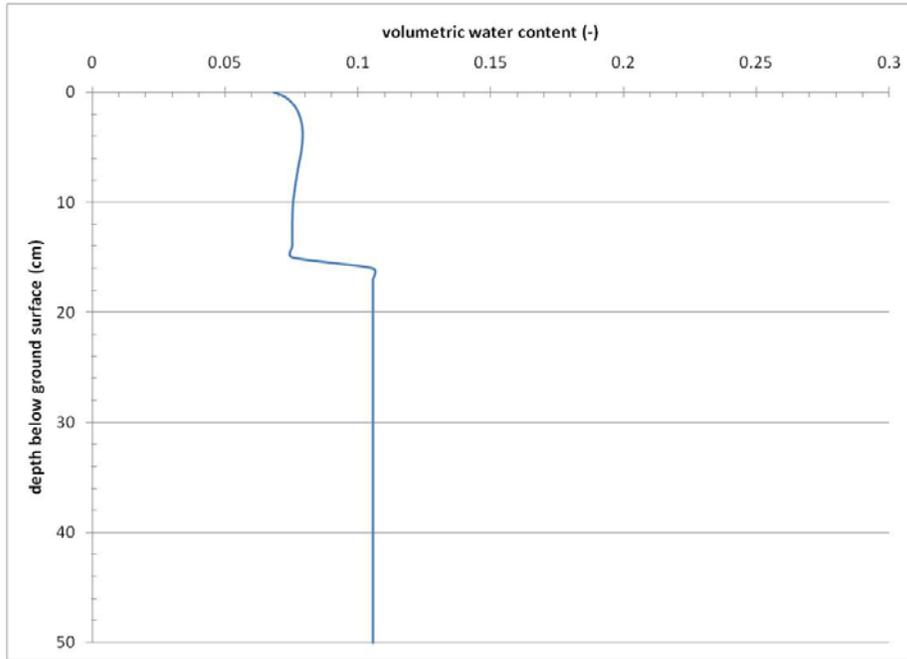


Figure F-2. Precipitation recorded during 1987 monsoon season (July 1 through September 30). The 1987 monsoon season recorded the maximum amount of summertime precipitation (19.2 cm).

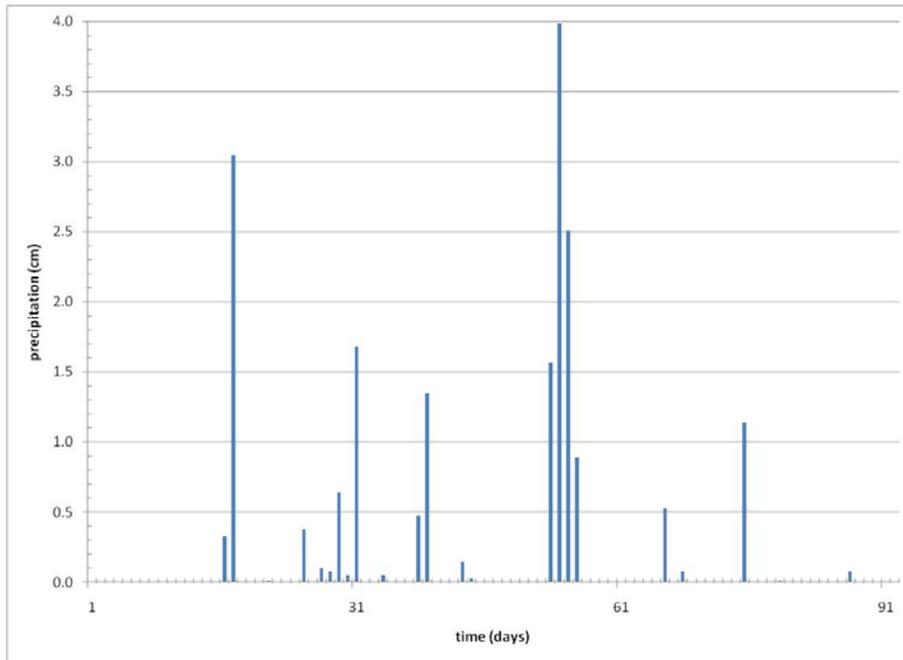


Figure F-3. Atmospheric boundary condition representing daily values of potential evapotranspiration (PET) during July, August, and September. The amount of potential evaporation (PE) and potential transpiration (PT) were calculated assuming 40% vegetative cover.

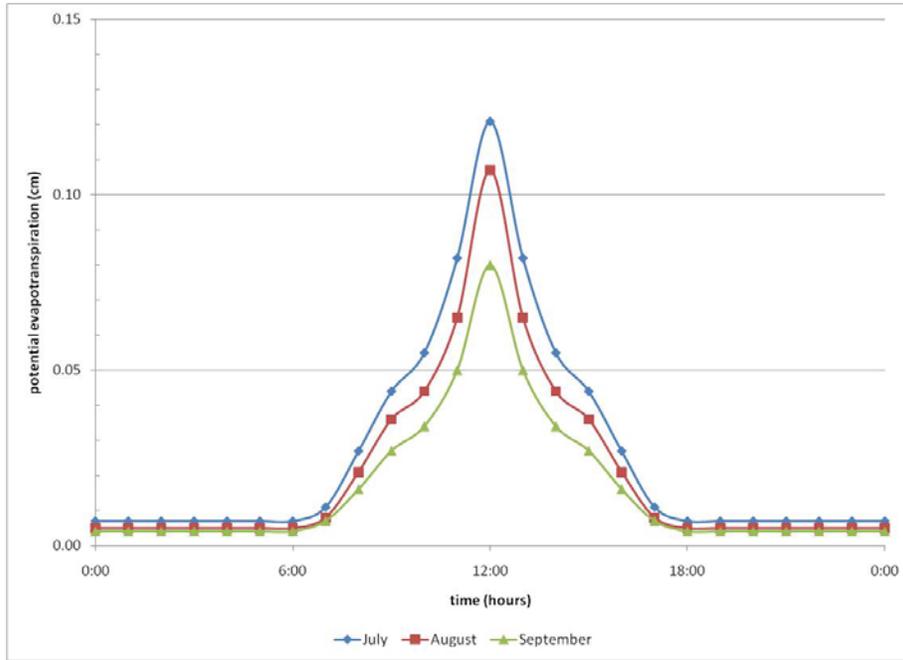


Figure F-4. Water content within the upper 50-cm of the cover system after day two (**upper figure**) and day six (**lower figure**) for the simulations that used hourly and daily input. Both simulations reproduced a 100-year average recurrence interval 1-hour long precipitation event.

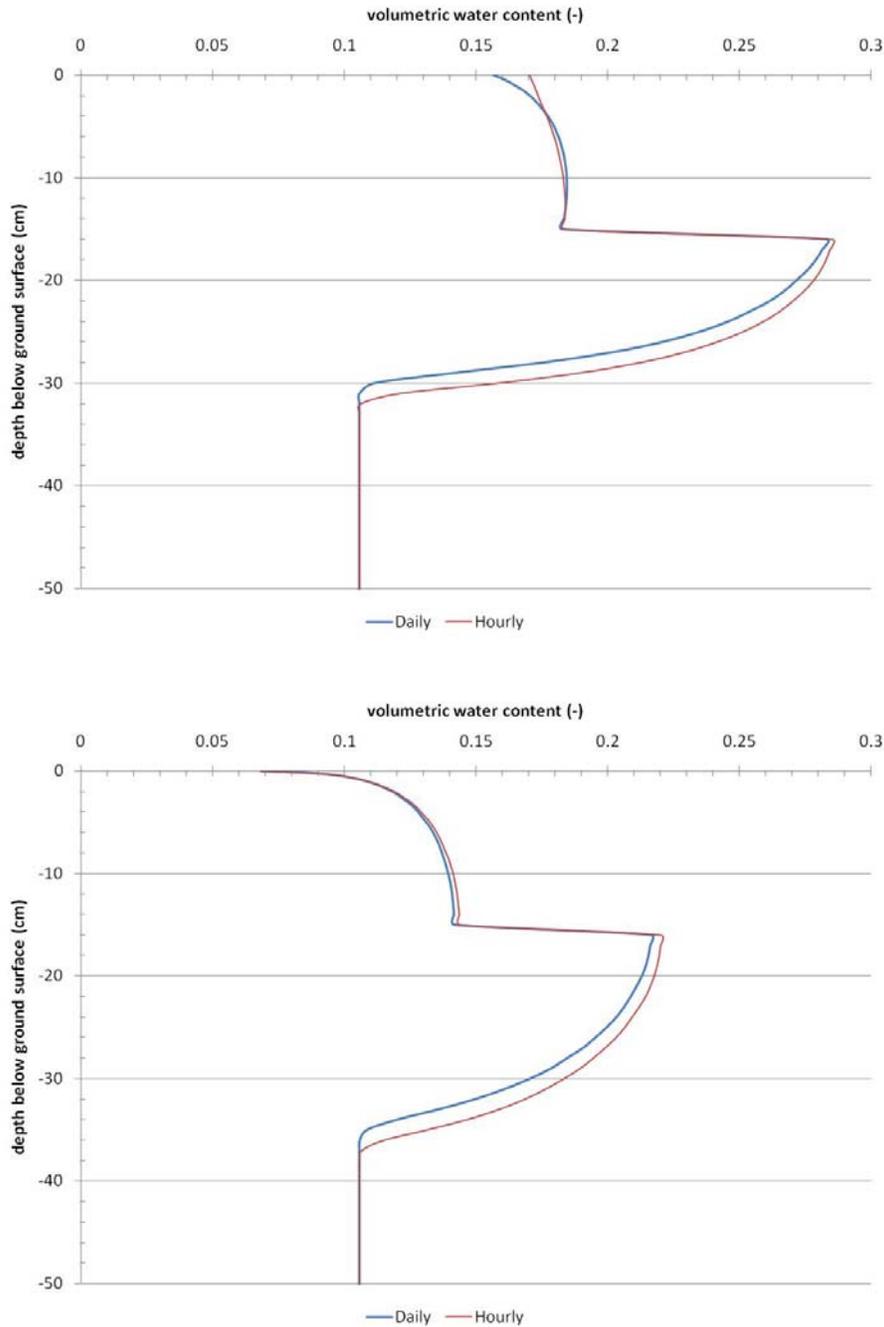


Figure F-5. Water flux within the upper 50-cm of the cover system after day two (**upper figure**) and day six (**lower figure**) for the simulations that used hourly and daily input. Both simulations reproduced a 100-year average recurrence interval 1-hour long precipitation event. Negative and positive water flux rates correspond to the downward and upward movement of water, respectively. Note the change in scale for flux between the two plots.

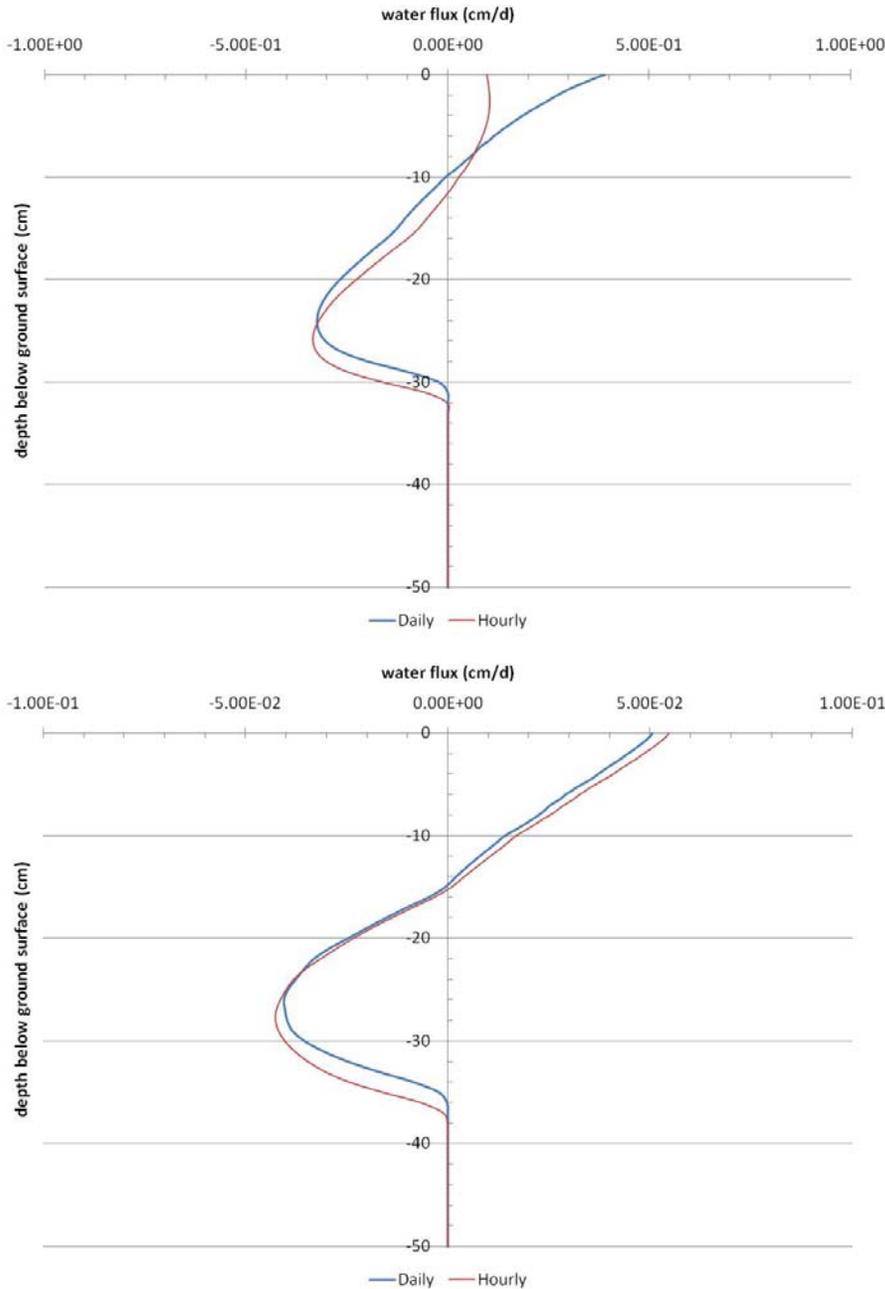


Figure F-6. Model predicted water content at 30-cm and 50-cm depths during the 1987 monsoon season (July 1 through September 30), which recorded the maximum amount of summertime precipitation (19.2 cm), for the simulations that used daily and hourly input.

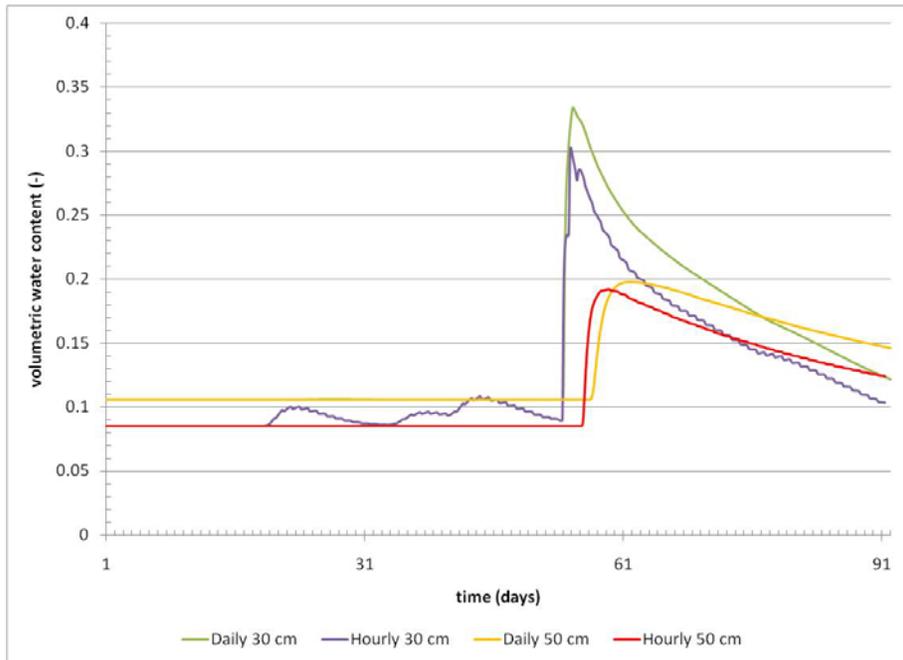
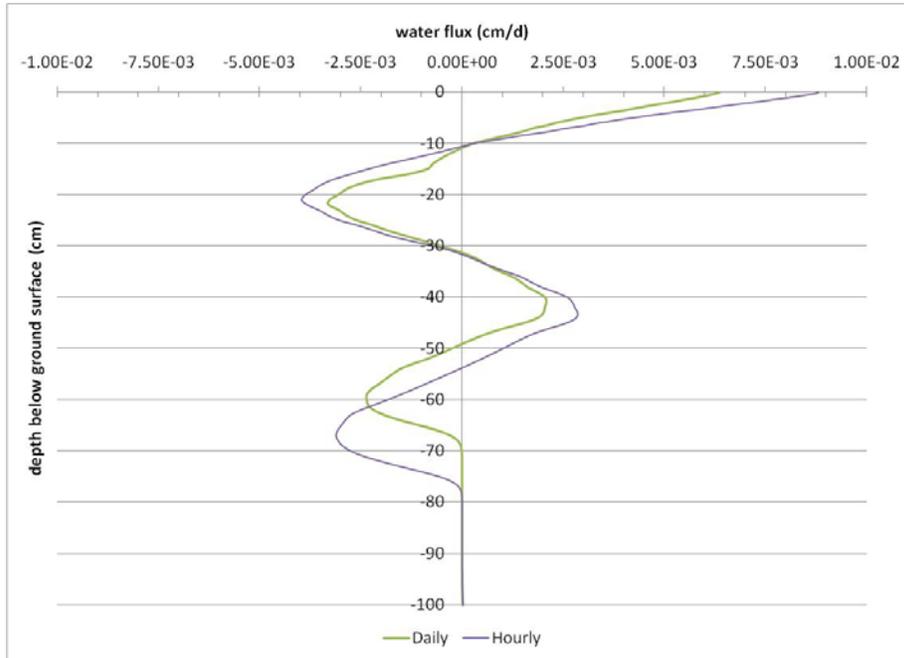


Figure F-7. Water flux within the upper 100-cm of the cover system at the end of the 1987 monsoon season for the simulations that used daily and hourly input. Negative and positive water flux rates correspond to the downward and upward movement of water, respectively.



APPENDIX G

SENSITIVITY ANALYSIS COMPARING INFILTRATION RATES THROUGH THE EVAPOTRANSPIRATION COVER BASED ON COVER VEGETATION, BIOINTRUSION, AND PRECIPITATION

APPENDIX G

SENSITIVITY ANALYSIS COMPARING INFILTRATION RATES THROUGH THE EVAPOTRANSPIRATION COVER BASED ON COVER VEGETATION, BIOINTRUSION, AND PRECIPITATION

To test the importance of simulating reduced performance of the vegetative component of the cover system, and how increased precipitation could influence the transport of water through the monolithic evapotranspiration (ET) cover, the HYDRUS model was run using different assumptions aimed at characterizing an anticipated scenario and reduced performance scenarios. The reduced performance scenarios were based on conservative assumptions that are expected to over predict the potential impacts (e.g., lead to increased fluxes for water flow); while the anticipated scenarios were based on professional judgment that reflect assumptions considered to be representative of expected conditions. Rates of model-predicted water flux entering the tailings cells were compared between simulations using different input assumptions. The effects on moisture content by the parameters used to assess establishment of vegetation and root water uptake are evaluated in this appendix to determine whether moisture contents that are input into the radon model are conservative. Impacts to hydraulic properties of cover material and water infiltration rates due to biointrusion of animals were also evaluated.

SENSITIVITY ANALYSES

Vegetation Establishment

Percent Cover and Rooting Depth/Distribution. Empirical data used as model input for the HYDRUS model regarding the ecological characteristics of the vegetation (rooting depth and root distribution) and established plant community (percent cover) were obtained from the literature and nearby lysimeter studies (Monticello) Background information that supports the empirical data and are included as part of Appendix D.

To evaluate the effect of vegetation establishment, four scenarios were modeled:

- an anticipated scenario with a maximum rooting depth of 107-cm and an anticipated root density distribution
- a reduced performance scenario with a maximum rooting depth of 68-cm and a reduced root density distribution
- an anticipated scenario assuming 40% vegetative cover
- a reduced performance scenario assuming 30% vegetative cover.

The two rooting depths and root density distributions are illustrated in Figure G-1. A larger percent cover results in a higher rate of partitioned transpiration relative to evaporation, while a smaller percent cover results in a lower rate of partitioned transpiration relative to evaporation. A lower percent cover results in less root water uptake (i.e., transpiration) and more evaporation, relatively speaking, which would lead to increased fluxes and increased moisture contents. In regard to rooting depth and root density distribution, a greater rooting depth and distribution function results in more root water uptake (i.e., transpiration), which would lead to reduced fluxes and reduced moisture contents within the rooting zone.

Root Water Uptake and Evaporation. Root water uptake will vary as a function of the soil water pressure head within the rooting zone, the plant root distribution function (i.e., density of roots and rooting depth), and the rate of potential transpiration (PT). The rate of PT is assigned as part of the atmospheric upper boundary condition, which HYDRUS then uses to compute the actual transpiration (AT) rate as a function of time and space within the rooting zone. For example, when conditions are extremely dry (i.e., less than the wilting point) or extremely wet (i.e., near saturation) plants cease to uptake water, and the AT would be zero. At intermediate soil water conditions, the AT would be a fraction of the PT. The water stress response function for grass was selected from the default database in HYDRUS. The database does not distinguish between different species of grass, and transpiration is assumed to cease at soil water pressures below the assumed wilting point of -8,000 cm. However, plants in many arid and semiarid environments

(many of which were selected for the ET cover) commonly maintain transpiration at significantly lower (more negative) soil water pressures. For example, crested wheatgrass can survive in soil water conditions where the soil water pressure ranges between -20,000 and -40,000 cm (Chabot and Mooney, 1985; Brown, 1995).

The rate of potential evaporation (PE) is also assigned as part of the atmospheric input file. In HYDRUS, the PE rate is reduced to an actual evaporation (AE) rate if a specified pressure head is reached at the surface. The pressure head at which this occurs is controlled by equilibrium conditions between soil water and atmospheric water vapor. All simulations have assumed a minimum surface pressure head of -15,000 cm, which is the recommended value by the program. When the pressure head at the surface reaches -15,000 cm the program calculates a reduced, actual evaporation rate.

To evaluate the effect of these two assumptions, and potential impacts on subsurface water content and fluxes through the ET cover, two scenarios were modeled:

- a scenario with a vegetation wilting point of -30,000 cm and a minimum surface pressure head of -150,000 cm combined with 40% cover and the anticipated rooting density/depth distribution
- a scenario with a vegetation wilting point of -30,000 cm and a minimum surface pressure head of -150,000 cm combined with 30% cover and the anticipated rooting density/depth distribution.

A more negative soil water pressure head specified at the upper boundary would result in decreased soil water pressures and reduced moisture contents within the upper 1 to 2 centimeters of the cover; while a more negative soil water pressure head specified for the wilting point would result in drier conditions within the rooting zone and reduced fluxes at the bottom of the cover system. The objective of these two scenarios is to determine whether the moisture contents that are input into the radon attenuation model are conservative. Unless otherwise noted, all simulations assume the default wilting point of -8,000 cm and a minimum surface pressure head of -15,000 cm.

Biointrusion

The probability of reduced performance due to burrowing animals is evaluated here through an order-of-magnitude calculation, even though to date the site has experienced only minor problems with burrowing animals (Denison, 2009). Impacts to the cover from invading woody species was not evaluated because such plants are not expected to populate the vegetative community, as discussed in Appendix D. Based on empirical data published in the literature, and the potential species that may use the site as habitat, any burrowing activity that may occur would be limited to the upper one meter of the cover, but would not impact the remainder of the cover (1.84 m). Effects from a burrowing prairie dog are used to evaluate changes in porosity of cover material and water flux through the cover.

The average prairie dog burrow diameter is reported to be 11 cm, resulting in a cross-sectional area of one burrow equal to 95 cm^2 . The typical burrow frequency is 12 burrows per acre (Burns et al., 1989; Cheatheat, 1977). Assuming a cylindrical burrow that is 100-cm deep, the volume of void space for one burrow would equal $9,500 \text{ cm}^3$, which is equal to a total void space of $114,000 \text{ cm}^3$ on a per acre basis. As a comparison, the total void space for a 100-cm layer of soil, with no burrows, and a porosity of 0.40 would equal 1.6 billion cm^3 on a per acre basis. Based on these estimates, the void space added by burrowing animals would increase the porosity by approximately 0.007%. Therefore, it is reasonable to conclude that if burrowing animals invade the cover, the potential impacts to porosity of the cover materials would be minimal.

To evaluate potential impacts from burrows on water flux rates, the amount of precipitation on a daily basis was assumed to directly recharge the cover system through the circular holes. Using the long-term average amount of annual precipitation recorded at the Blanding weather station (1932-1988), the amount of precipitation that would recharge the cover on a per acre basis through the burrows would equal $98 \text{ cm}^3/\text{d}$ (assuming burrows are 11-cm diameter and there are 12 burrows per acre). The average model-predicted long-term infiltration rate through the cover ($1.2 \times 10^{-4} \text{ cm}/\text{d}$; see Appendix E) would equal $4,856 \text{ cm}^3/\text{d}$ of water on a per acre basis minus surface areas

exposed by burrows. As a conservative estimate, if precipitation were to directly enter all of the burrows and recharge the lower portion of the monolithic ET cover, the long-term infiltration rate could be expected to increase approximately 2% from 0.45 to 0.46 millimeters per year. Therefore, it is reasonable to conclude that if burrowing animals invade the cover the infiltration rate through the cover would not be significantly affected. Surface runoff into burrows is not expected as burrows usually are surrounded by a berm of soil.

Precipitation

The anticipated climate record for the White Mesa Mill was taken from historic data recorded at the Blanding weather station between 1932 and 1988. Development of the climate record for the site is discussed in detail within the main body of the report. To evaluate the effects of long-term accumulation of water in the water storage layer and ET cover performance, the three wettest years on record were inserted into the climate record. Inclusion of consecutive-wet years is the recommended procedure for evaluating the effects of increased precipitation on infiltration rates through an ET cover (Khire et al., 2000).

To evaluate the effect of increased precipitation on a climate-record basis two scenarios were modeled:

- an anticipated scenario using the 57-year climate record between 1932 and 1988
- an increased precipitation scenario using the 57-year climate record with the three wettest years consecutively inserted in place of three average years.

The three largest precipitation years in the climate record were 1957 (56.9 cm), 1906 (59.9 cm), and 1909 (62.2 cm). These years replaced precipitation values measured in years 17 through 19 (between 1946 and 1948), which were 29.4, 35.3, and 35.1 cm, respectively, and are close to the long-term average. The two climate scenarios are illustrated in Figure G-2. All of the simulations include the period 1978-1987 (years 47

through 56), which is a 10-year timeframe characterized by above-average annual precipitation (38.6 cm).

INFILTRATION MODEL CONFIGURATION

The proposed conceptual cover design consists of a 2.84-m (9.3-ft) thick monolithic ET cover as described in Appendix E. The hydraulic properties of the cover material, and grid spacing of the HYDRUS-1D model, are summarized in Appendix E.

Initial Conditions

Initial conditions for the infiltration model were determined separately for each scenario. The initial pressure head distribution was determined by evaluating a long-term (114-year) simulation that used the concatenated atmospheric input file as an upper boundary condition (i.e., the 57-year climate record repeated twice). The pressure head distribution for the final time step of the 114-year simulation was used as the initial condition for the transient simulations used to predict water infiltration rates through the cover. The model was then rerun using these initial conditions, and the long-term water infiltration rates were averaged during a second 114-year simulation. The methodology implemented to establish the initial conditions for the site is a commonly accepted approach for solving hydrogeologic modeling problems.

Boundary Conditions

The upper surface of the model domain was simulated with an atmospheric boundary condition, while the lower boundary of the cover system was simulated as a unit gradient. The amount of precipitation was based on the 57-year climate record 1932-1988, or the modified climate record with increased precipitation, as explained above. The winter months that included December, January, and February were assigned a transpiration rate of zero, and only evaporation was simulated in the HYDRUS model. The HYDRUS models did not include runoff and 100% of the precipitation was allowed to evaporate or

infiltrate into the top layer of the cover. Each scenario was modeled with daily precipitation and ET input using the 57-year climate record.

INFILTRATION MODEL RESULTS

Water Flux

The average infiltration rate predicted to pass through the ET cover and enter the top of the tailings cells during the 57-year climate record for all simulations is summarized in Tables G-1 and G-2. The simulations include scenarios that account for differences in the establishment of vegetation (percent cover; rooting depth and distribution), root water uptake (wilting point), evaporation at the surface (minimum surface pressure head), and amount of precipitation. Simulations for the ET cover produced a few instances in which surface ponding occurred; however, runoff was not simulated so that estimates of infiltration through the cover, via surface ponding, would be conservative. For all HYDRUS simulations the water mass balance errors did not exceed 1%. As a general rule-of-thumb, mass balance errors that do not exceed 3% are considered acceptable.

Overall, for simulations that received the same amount of precipitation, the average infiltration rate is least sensitive to the percentage of vegetation covering the surface and most sensitive to the rooting depth and root density distribution, while the wilting point and minimum surface pressure head allowed at the surface have an intermediate effect (see Figure G-3 and Table G-1). For example, assuming the anticipated rooting depth/distribution and the anticipated climate record, a change in the percent vegetative cover from 40% to 30% increased the flux rate from 0.45 millimeters per year (mm/yr) to 0.53 mm/yr. A change from the anticipated to a reduced rooting depth/distribution (for 40% vegetative cover and the anticipated climate record) increased the flux rate from 0.45 mm/yr to 2.3 mm/yr. And finally, a change from the default wilting point to the decreased wilting point (for 40% vegetative cover, anticipated rooting depth/distribution, and anticipated climate record) decreased the flux rate from 0.45 mm/yr to 0.19 mm/yr. The scenario that leads to the highest infiltration rate (2.4 mm/yr) consists of the

following assumptions: 30% vegetative cover, reduced rooting depth/distribution, anticipated climate record, and default wilting point.

Assuming all other variables are equal, the average infiltration rate increased for the simulations that modeled increased precipitation (see Figure G-4 and Table G-2). For example, assuming the anticipated rooting depth/distribution and 40% vegetative cover, the change from an anticipated to an increased precipitation record increased the flux rate from 0.45 mm/yr to 2.0 mm/yr. However, if a decreased wilting point was assumed together with the increased precipitation record (with anticipated rooting depth/distribution and 40% vegetation cover) the average flux rate increased from 0.45 mm/yr to 1.2 mm/yr. On the whole, modeling of increased precipitation resulted in a short-term large magnitude change in infiltration and an asymptotic return to the long-term average infiltration rate for each scenario modeled following the increased precipitation in years 17-19 (see Figure G-4). As a comparison, the 10-year period (years 47 through 56 included in both climate records) that received above-average precipitation resulted in a smaller magnitude change in infiltration; however, the simulations also predicted a similar asymptotic return to the long-term average infiltration rate (see Figure G-4).

The model-predicted water flux through the ET cover indicates that the available storage capacity of the cover should be sufficient to significantly minimize infiltration. The transport of water below the rooting zone and into the tailings material would occur when the storage capacity of the overlying soil materials is exceeded; for example, during multi-consecutive years or longer that receive above average amounts of precipitation.

The lower bound, anticipated, and upper bound long-term average water flux rates entering the tailings were 0.19 mm/yr, 0.45 mm/yr, and 2.4 mm/yr, respectively, which would result in approximately 38 mm (0.12 ft), 90 mm (0.3 ft), and 480 mm (1.6 ft) of water entering the tailings during the 200-year regulatory timeframe, respectively, and corresponding to an increase in saturated tailings thickness of 67 mm (0.21 ft), 160 mm (0.53 ft), and 840 mm (2.8 ft), respectively. Therefore a significant build-up of water (“bathtub effect”) within the cells is not anticipated.

Moisture Content

Moisture contents at five depths (25, 50, 100, 150, and 284 cm) within and below the rooting zone of the monolithic ET cover during the anticipated 57-year climate record for the two scenarios using a decreased wilting point of -30,000 cm and a default wilting point of -8,000 cm are plotted in Figures G-6, G-7 and G-8. All model results plotted assumed 40% vegetative cover, the anticipated rooting depth/distribution, and the anticipated climate record because these conditions would lead to reduced moisture contents compared to the other scenarios (i.e., 30% cover, reduced rooting depth/distribution, increased precipitation) which would lead to increased moisture contents. Within the rooting zone at 25-cm depth (see Figure G-5) and 50-cm depth (see Figure G-6) the average long-term moisture content at these two depths for the scenario that assumed the default wilting point was approximately 15%, while for the scenario that assumed a decreased wilting point was approximately 13%. The average long-term moisture content, at 100-cm depth, for the scenario that assumed the default wilting point was approximately 12%, while for the scenario that assumed a decreased wilting point was approximately 10%. Below the rooting zone at 150-cm and 284-cm depths (see Figure G-7), there was no significant difference in moisture contents between the two scenarios, and the average long-term volumetric moisture content for both scenarios was approximately 15%. Overall, the amount of moisture in the cover predicted by the infiltration model exceeds the amount of moisture used in the radon attenuation model.

CONCLUSIONS

The results of the sensitivity analysis demonstrate that the design and construction of a monolithic ET cover will be sufficient to minimize infiltration into the tailings and prevent the formation of a bathtub effect for a broad range of conditions used to represent the establishment of vegetation, root water uptake by vegetation, and amount of precipitation that may occur at the site, thereby meeting closed cell performance requirements specified in the Ground Water Discharge Permit (Part I.D.8.a and Part I.D.8.b). The results of the sensitivity analysis, for the broad range of conditions mentioned above, also demonstrate that the monolithic ET cover will have sufficient

long-term moisture to attenuate radon fluxes thereby achieving the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Overall, all of the simulations demonstrate that the amount of moisture predicted with the infiltration model exceeds the amount of moisture used in the radon attenuation model, which indicates that the predictions of radon emanation at the surface are conservative.

The results of the sensitivity analysis also demonstrate that establishment of vegetation is important in reducing infiltration, but that a greater emphasis should be placed on establishing a mixture of species with a broad range in rooting depths and root density distributions, rather than the percent vegetative cover to maximize root water uptake. The establishment of a diverse plant community is supported by the proposed species mix (see Appendix D).

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TABLE G-1. AVERAGE WATER FLUX ENTERING THE TAILINGS CELLS DURING A 57-YEAR PERIOD USING DIFFERENT ASSUMPTIONS REGARDING THE ESTABLISHMENT OF VEGETATION AND ROOT WATER UPTAKE.		
	Anticipated Climate Record & 40% vegetative cover	Anticipated Climate Record & 30% vegetative cover
Anticipated Rooting Depth and Root Density Distribution & Default Wilting Point	1.2 x10 ⁻⁴ cm/d 0.45 mm/yr ¹	1.5 x10 ⁻⁴ cm/d 0.53 mm/yr
Reduced Performance Rooting Depth and Root Density Distribution & Default Wilting Point	6.2 x10 ⁻⁴ cm/d 2.3 mm/yr	6.7 x10 ⁻⁴ cm/d 2.4 mm/yr
Anticipated Rooting Depth and Root Density Distribution & Decreased Wilting Point	5.3 x10 ⁻⁵ cm/d 0.19 mm/yr	6.4 x10 ⁻⁵ cm/d 0.23 mm/yr
Notes: 1. The average water flux for the anticipated case (base case) flux for comparison in the sensitivity analysis is 1.2 x10 ⁻⁴ centimeters per day (cm/d) or 0.45 millimeters per year (mm/yr).		

TABLE G-2. AVERAGE WATER FLUX ENTERING THE TAILINGS CELLS DURING A 57-YEAR PERIOD USING DIFFERENT ASSUMPTIONS REGARDING ROOT WATER UPTAKE AND AMOUNT OF PRECIPITATION.		
	Anticipated Climate Record & 40% vegetative cover	Increased Precipitation Climate Record & 40% vegetative cover
Anticipated Rooting Depth and Root Density Distribution & Default Wilting Point	1.2 x10 ⁻⁴ cm/d ¹ 0.45 mm/yr	5.5 x10 ⁻⁴ cm/d 2.0 mm/yr
Anticipated Rooting Depth and Root Density Distribution & Decreased Wilting Point	5.3 x10 ⁻⁵ cm/d 0.19 mm/yr	3.4 x10 ⁻⁴ cm/d 1.2 mm/yr
Notes:		
1. The average water flux for the anticipated case (base case) flux for comparison in the sensitivity analysis is 1.2 x10 ⁻⁴ centimeters per day (cm/d) or 0.45 millimeters per year (mm/yr).		

Figure G-1. Semilog plot of the anticipated and reduced root density distributions and maximum rooting depths.

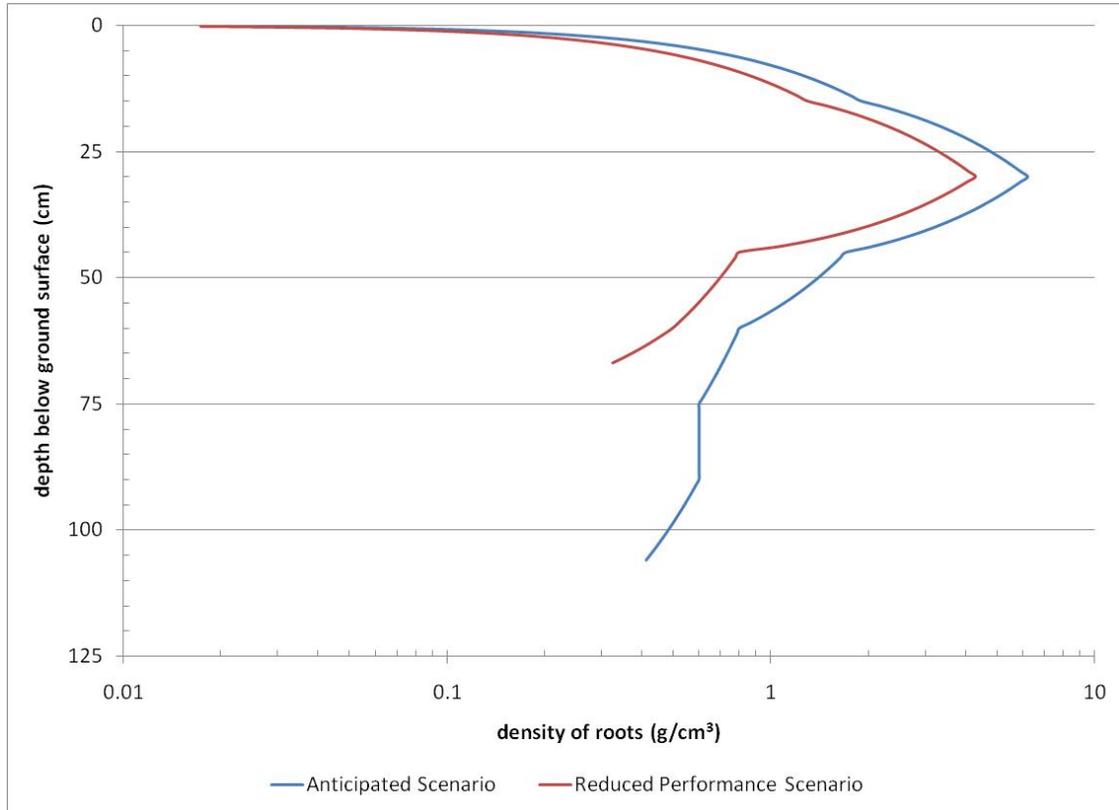


Figure G-2. Annual amount of precipitation incorporated into the 57-year anticipated and increased precipitation climate records.

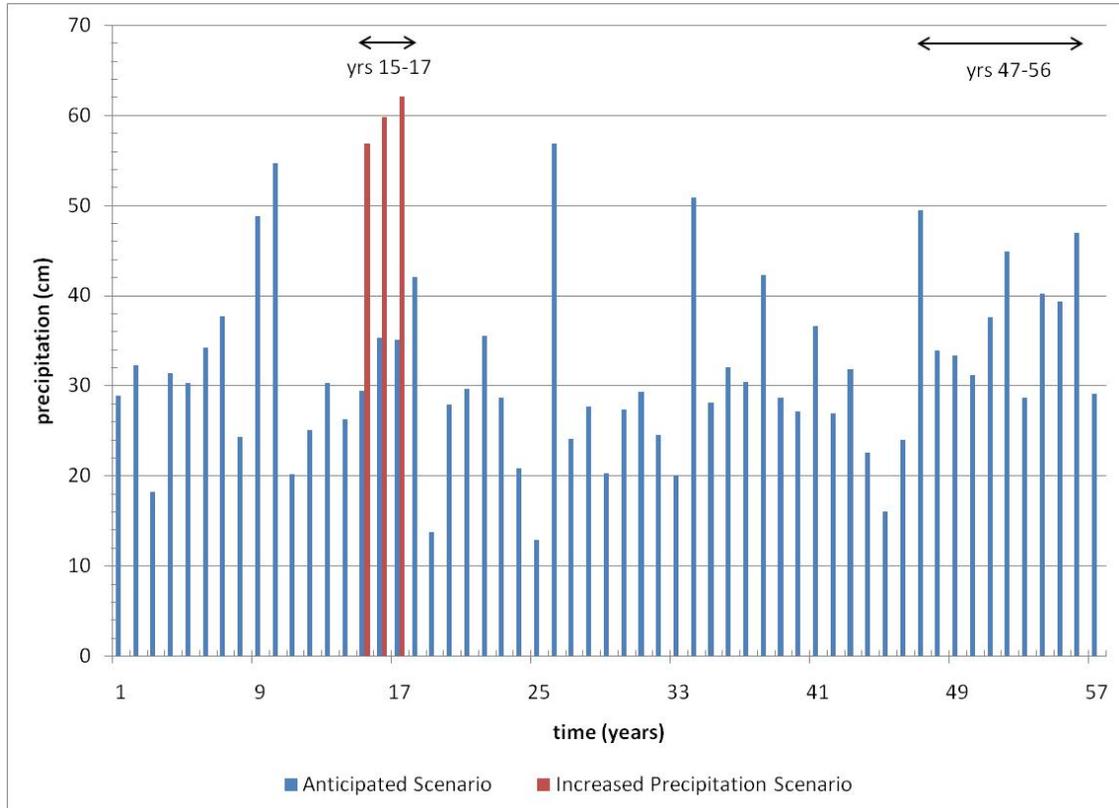


Figure G-3. Semilog plot of model-predicted rate of water flux through the tailings cell cover during the anticipated 57-year climate record for simulations that assume 30% and 40% vegetative cover combined with the anticipated scenario (AS) and reduced performance scenario (RPS) for establishment of vegetation (rooting depth/distribution).

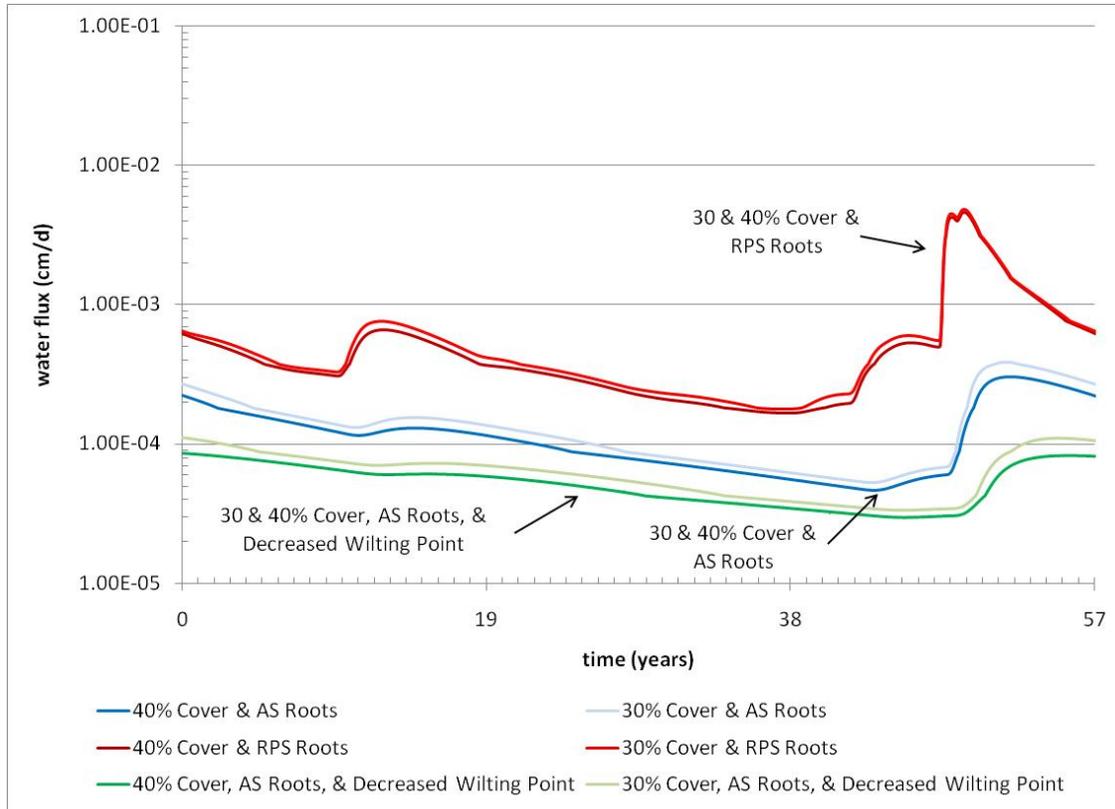


Figure G-4. Semilog plot of model-predicted rate of water flux through the tailings cell cover during 57-year climate record with increased precipitation for simulations that assume 40% vegetative cover combined with the anticipated scenario (AS) and reduced performance scenario (RPS) for establishment of vegetation (rooting depth/distribution) and decreased wilting point.

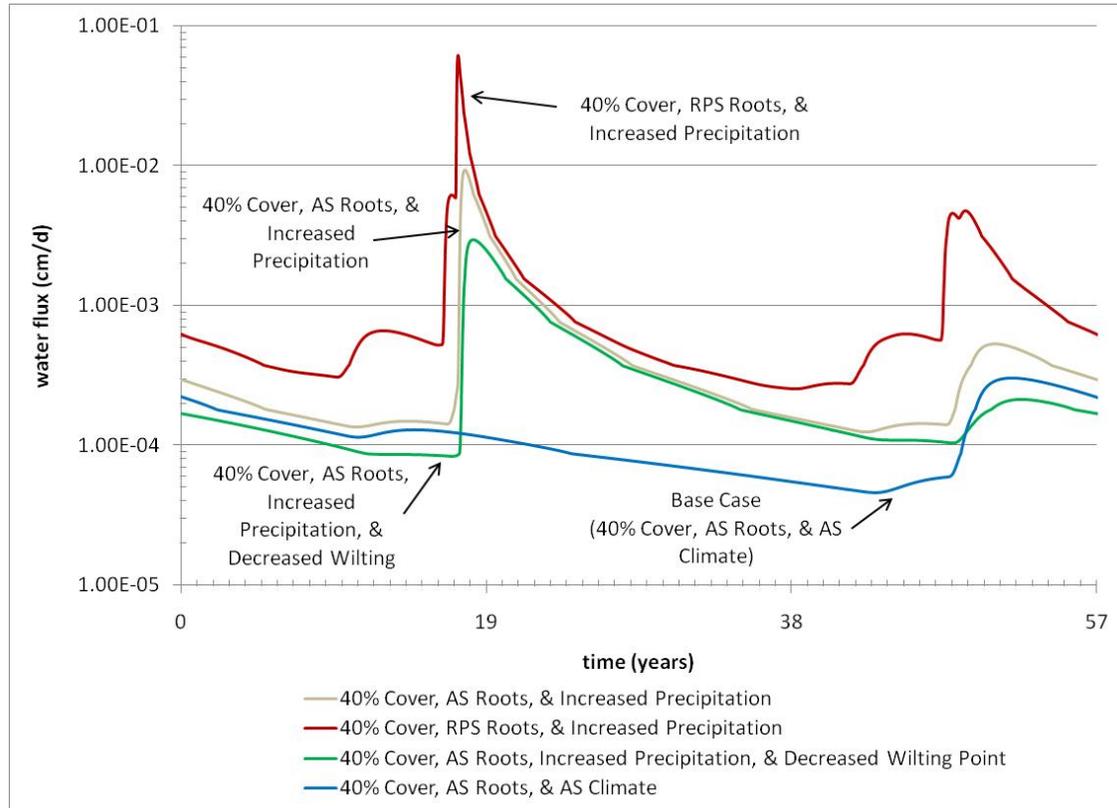


Figure G-5. Moisture contents at 25-cm depth within the rooting zone of the monolithic ET cover during the anticipated 57-year climate record for the two scenarios that use a decreased wilting point of -30,000 cm and a default wilting point of -8,000 cm.

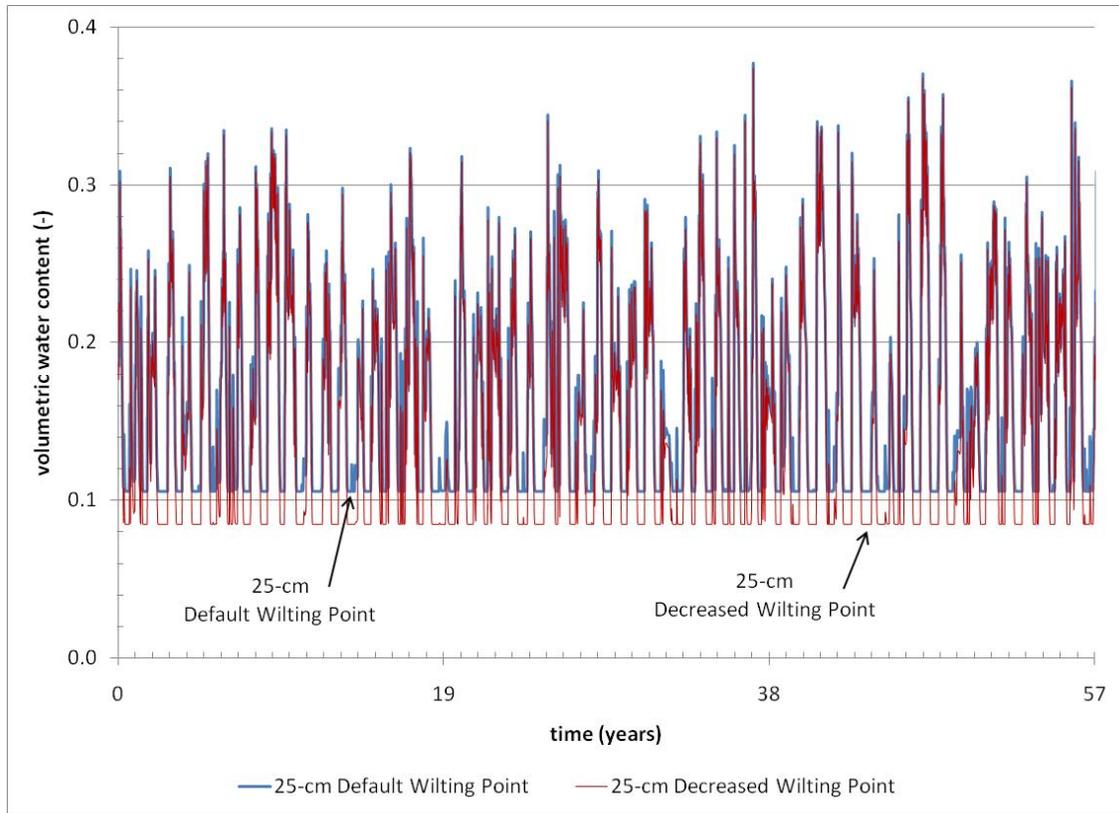


Figure G-6. Moisture contents at 50-cm (**upper figure**) and 100-cm (**lower figure**) depth within the rooting zone of the monolithic ET cover during the anticipated 57-year climate record for the two scenarios that use a decreased wilting point of -30,000 cm and a default wilting point of -8,000 cm.

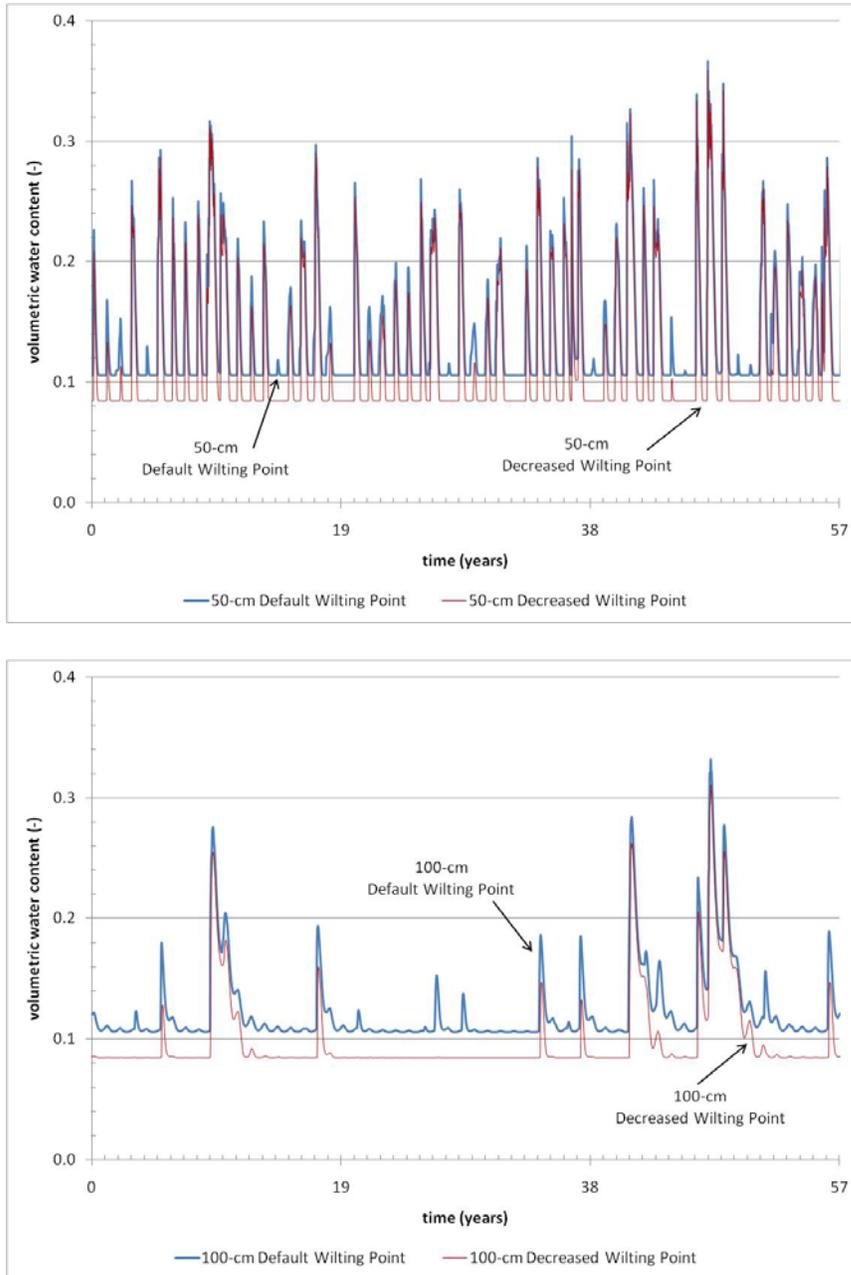
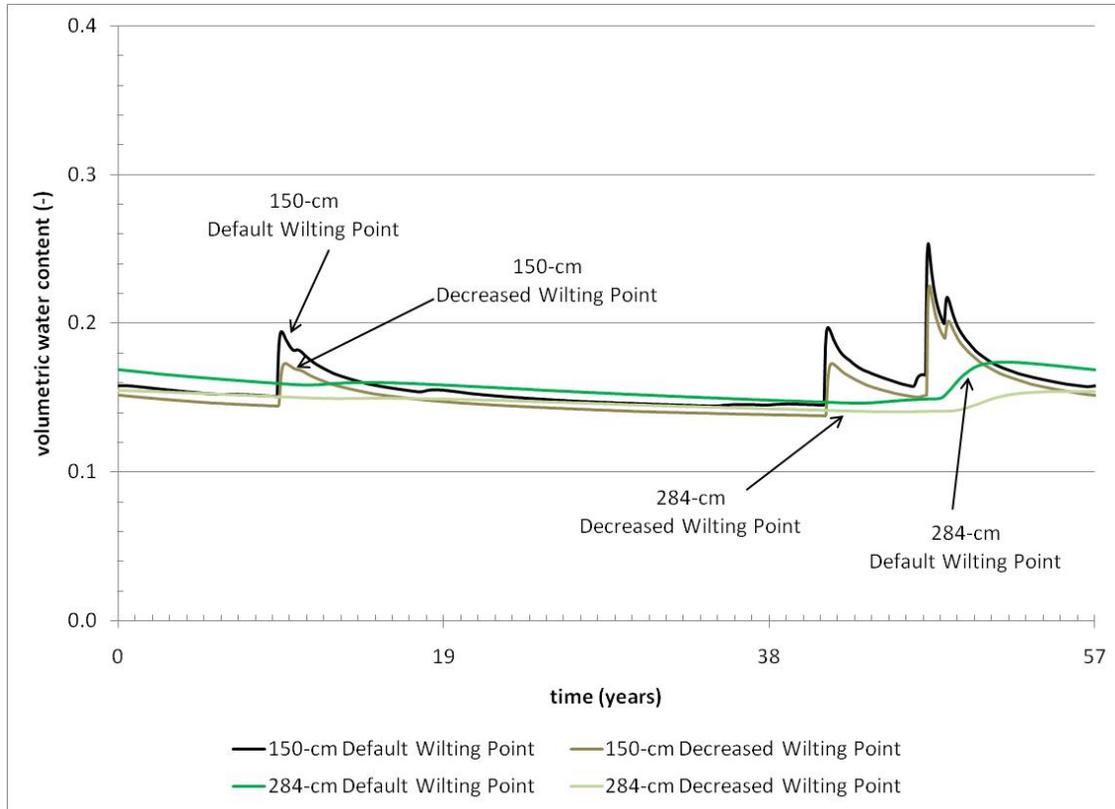


Figure G-7. Moisture contents at 150-cm and 284-cm depth below the rooting zone of the monolithic ET cover during the anticipated 57-year climate record for the two scenarios that use a decreased wilting point of -30,000 cm and a default wilting point of -8,000 cm.



APPENDIX H

**RADON EMANATION MODELING FOR THE
EVAPOTRANSPIRATION COVER**

APPENDIX H

RADON EMANATION MODELING FOR THE EVAPOTRANSPIRATION COVER

This appendix presents the results of modeling the emanation of radon-222 from the top surface of the proposed monolithic evapotranspiration (ET) cover. The material thicknesses for the different cover layers were based on the results of radon attenuation modeling to achieve the State of Utah's long-term radon emanation standard for uranium mill tailings (Utah Administrative Code, Rule 313-24). Radon modeling completed for this appendix supersedes previous radon attenuation modeling (TITAN Environmental, 1996; IUC, 2000) because of the proposed changes to the tailings cover system from a conventional rock cover design to an ET cover design.

CONCEPTUAL COVER DESIGN

Radon emanation modeling was evaluated for the proposed monolithic ET cover design. The material and layer thicknesses presented below were based on the radon modeling results discussed in this appendix. The thickness of the upper platform fill layer (random fill compacted to 95 percent of Standard Proctor dry density) was optimized in order to minimize radon fluxes at the surface.

The 2.84-m (9.3-ft) thick cover would consist from top to bottom of:

- 15 cm (0.5 ft) of a gravel-amended topsoil admixture to promote revegetation and provide for protection against erosion and frost damage
- 107 cm (3.5 ft) of random fill soil placed at 85% of standard Proctor dry density to serve as a water storage, biointrusion, and radon attenuation layer
- 162 cm (5.3 ft) of random fill soil comprised of 2.8 feet random fill compacted to 95% of standard Proctor dry density over 2.5 feet of random fill placed at 80% of

standard Proctor dry density, to serve as grading (platform fill) and radon attenuation layers.

RADON MODEL CONFIGURATION

The thickness of the reclamation cover necessary to limit radon emanation from the disposal areas was analyzed using the U.S. Nuclear Regulatory Commission (NRC) RADON model (NRC, 1989). The model utilizes the one-dimensional radon diffusion equation, which uses the physical and radiological characteristics of the tailings and overlying materials to calculate the rate of radon emanation from the tailings through the cover. The model was used to calculate the cover thickness required to limit the radon emanation rate through the top of the cover to 20 picocuries per square meter per second (pCi/m²/s), following the guidance presented in NRC publications NUREG/CR-3533 (NRC, 1984) and Regulatory Guide 3.64 (NRC, 1989). This maximum rate of emanation is an average over the entire surface of the disposal area.

Input Values

Stockpiles of soil will be used to construct the monolithic ET cover. Geotechnical properties and input data of the soil (also referred to as random/platform fill) and tailings were based on available site-specific data summarized from previously submitted reports.

Thickness of Tailings. The tailings thickness currently deposited in Cells 2 & 3 is approximately 30 ft (914 cm), while the anticipated tailings thickness deposited in Cells 4A & 4B will be approximately 42 ft (1,280 cm). However, as documented in NRC Regulatory Guide 3.64, a tailings thickness greater than 100 to 200 cm is effectively equivalent to an infinitely thick radon source. Therefore, a thickness of 500 cm may be used in RADON to represent an equivalent infinitely thick tailings source of radon.

Radium Activity Concentration. The radium-226 activity concentration value for the tailings in the impoundments was based on laboratory data reported by Rogers & Associates (1988); their original laboratory report is reproduced here as part of

Attachment H-1. The radium activity of the random fill (used to construct the frost barrier, water storage, and platform fill/grading layers for the proposed cover) was assumed to be zero. The assumption of zero radium activity for the cover soil was based on guidance in NRC Regulatory Guide 3.64, which states that radium activity in the cover soils may be neglected for cover design purposes provided the cover soils are obtained from background materials that are not associated with ore formations or other radium-enriched materials. The radium activity values used in the model are summarized in Table H-1.

Radon Emanation Coefficient. The emanation coefficients were based on laboratory data (see Attachment H-1 for Rogers & Associates 1988). Because site-specific laboratory data were available, the NRC's default value of 0.35 is not appropriate. The radon emanation coefficient values used in the model are summarized in Table H-2.

Specific Gravity, Density, and Porosity. Specific gravity of the tailings was estimated to be 2.75, corresponding to a solid particle density of 172 pounds per cubic foot (pcf) (2.75 grams/cm³), while the dry bulk density of the tailings was estimated to be 74.3 pcf (1.19 grams/cm³), which is 70 percent of standard Proctor dry density. Specific gravity and maximum dry bulk density were average values determined by laboratory tests (see Attachment E-1 in Appendix E for Chen and Associates, 1987; see Attachment H-1 in this Appendix for Western Colorado Testing, 1999b). Porosity was calculated based on the average specific gravity and dry bulk density based on the following equation:

$$n = 1 - \left(\frac{\rho_b}{\rho_s} \right)$$

where

n = porosity (-)

ρ_b = dry bulk density of soil or tailings (pcf or grams/cm³)

ρ_s = density of solids of soil or tailings (pcf or grams/cm³)

A minimum of 3 feet of random fill has already been placed above Cell 2 on top of the tailings. It is assumed that the random fill was placed and compacted to 80 percent standard Proctor compaction by construction traffic. The upper 0.5 feet of this fill will be compacted by additional passes of compactors to reach 95 percent of standard Proctor compaction. Subsequent layers of random fill placed above the 0.5-foot zone will also be compacted to 95 percent until the necessary thickness of this layer is achieved. Porosity was calculated based on average specific gravity and dry bulk density values determined by laboratory tests (see Attachment E-1 for Chen and Associates, 1978, 1979, 1987; Western Colorado Testing, 1999a; Geosyntec, 2006). The uppermost 3.5 feet of random fill (used to construct the water storage layer) will be placed at 85 percent of standard Proctor in order to optimize water storage and rooting characteristics for plant growth. The top 0.5-foot of erosion protection was assumed to consist of a soil-gravel admixture (e.g., rock mulch) placed by mixing approximately 25 percent gravel into the top layer of stockpiled topsoil and random fill. Dry bulk density and porosity values for the soil and tailings materials used as input to the RADON model are summarized in the Table H-3.

Long-term Moisture Content. Long-term moisture content value was assumed to be 6 percent for the tailings. This is a conservative assumption, per NRC Regulatory Guide 3.64, which represents the lower bound for moisture in western soils.

Long-term moisture content for the soil cover corresponding to approximately 15 atmospheres of soil water tension, was estimated using the Rawls and Brakenseik (1982) equation as presented in NRC Regulatory Guide 3.64 as follows:

$$\theta = 0.026 + 0.005z + 0.0158y$$

where

θ = volumetric water content (-)

z = percent clay in cover soil (%)

y = percent organic matter in cover soil (%).

Volumetric water content is related to gravimetric water content, w , by the following equation:

$$w = \frac{\theta \cdot \rho_w}{\rho_b}$$

where

w = gravimetric water content (-)

θ = volumetric water content (-)

ρ_w = density of water (pcf or grams/cm³)

ρ_b = dry bulk density of soil or tailings (pcf or grams/cm³).

The percent clay in the random fill was taken from average values measured in laboratory tests (see Attachment E-1 for Chen and Associates, 1978, 1979, 1987; Western Colorado Testing, 1999a; Geosyntec, 2006). For sieve analyses in which hydrometer tests were not conducted, the percent clay (particles finer than 2 μm) was assumed to be 35% of the portion finer than the No. 200 sieve (0.74 mm), which corresponded to the average clay fraction from tests in which hydrometer analyses were performed. Organic matter was considered negligible and assumed to equal zero. Long-term moisture parameters are summarized in Table H-4.

Diffusion Coefficient. The radon diffusion coefficients used in the RADON model can either be calculated within the model (based on an empirical relationship dependent upon porosity and the degree of saturation) or input directly in the model using values measured from laboratory testing. Although laboratory test data were available for the tailings and the cover material (see Attachment H-1 for Rogers & Associates 1988), tests were performed at porosities and water contents different than those estimated to represent long-term conditions. Therefore, the empirical relationship in RADON was used to estimate values for use in the model; input values are summarized in Table H-5.

PROTECTION FROM BIOINTRUSION AND FROST PENETRATION

Biointrusion

Potential impacts to the radon flux at the surface due to biointrusion can be estimated using weighted average principals by incorporating the bare source flux from the uncovered tailings into the radon flux through the cover. The bare source flux, or the flux from the tailings without a cover, from the RADON modeling was approximately 689 pCi/m²/s. The flux from the top of the cover was 20 pCi/m²/s. Root holes (from dead shrubs) were estimated to have a diameter of 10 mm (0.4 in) and a frequency of one hole every 10 feet, or 400 root holes per acre of cover. Animal burrow holes were estimated to have a diameter of 11 cm (4.3 in) and a frequency of 12 holes per acre of cover. Based on the hole diameters and frequencies, and conservatively assuming that the holes extend through the cover to the tailings, the cross-sectional area of open hole area to allow radon emanation at the bare source flux rate was 0.15 m² (1.57 ft²) per acre. The resulting flux would be 20.02 pCi/m²/s, or an insignificant increase in average radon flux of 0.1% over the cover surface. Therefore, it is reasonable to conclude that the radon flux at the surface would not be affected by root holes and animal burrows.

Frost Penetration

Previously, TITAN Environmental (1996) completed a freeze/thaw evaluation based on site-specific conditions which indicated that the anticipated maximum depth of frost penetration was 6.8 inches (0.6 ft). Therefore, the entire soil-gravel admixture layer and upper few centimeters of the underlying soil layer will provide adequate protection against frost penetration.

RADON MODEL RESULTS

The material thicknesses supported by the radon modeling, and the long-term model-predicted radon fluxes at the surface for the monolithic ET cover, are summarized in Table H-6. The output file for the RADON model is included as part of Attachment H-2.

CONCLUSIONS

Radon emanation modeling was evaluated for the monolithic ET cover constructed entirely of sandy clay soil. The results of modeling with RADON indicate this design attenuates radon to 20 pCi/m²/s or less, which is the stated regulatory criterion (Utah Administrative Code, Rule 313-24). The actual radon emanation rate is likely to be lower because the actual moisture content in the cover is likely to be greater than the values used in the radon emanation modeling.

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Western Colorado Testing, Inc. (1999a), Additional Clarifications to the White Mesa Mill Reclamation Plan, Report prepared for International Uranium (USA) Corporation and submitted to the U.S. Nuclear Regulatory Commission 15 April 1999.

Western Colorado Testing, Inc. (1999b), Report of soil sample testing of tailings collected from Cell 2 and Cell 3, Prepared for International Uranium (USA) Corporation 4 May 1999.

Table H-1. Radium activity concentrations used as input to the RADON model.

Material	Radium Activity Concentration (pCi/g)
Tailings	981
Random Fill	0
Erosion Protection	0

Note: Units are in picocuries per gram (pCi/g)

Table H-2. Radon emanation coefficients used as input to the RADON model.

Material	Radon Emanation Coefficient (-)
Tailings	0.19
Random Fill	0.19
Erosion Protection	0.19

Table H-3. Density and porosity characteristics of soil layers and tailings used as input to the RADON model.

Material	Specific Gravity (-)	Maximum Dry Bulk Density (pcf)	Degree of Compaction (%)	Placed Dry Bulk Density (pcf)	Porosity (-)
Tailings	2.75	106.1	70% SP	74.3	0.57
Random Fill (low compaction used to construct lower grading layer, already in place for Cell 2)	2.67	116.7	80% SP	93.4	0.44
Random Fill (high compaction used to construct upper grading layer)	2.67	116.7	95% SP	110.9	0.33
Random Fill (low compaction used to construct water storage layer)	2.67	116.7	85% SP	99.2	0.40
Erosion Protection	2.67	---	---	124.2*	0.25

SP = standard Proctor compaction

MP = modified Proctor compaction

pcf = pounds per cubic foot

* Estimated by applying 25% gravel correction factor

Table H-4. Long term moisture characteristics used as input to the RADON model.

Material	Percent Clay (%)	Volumetric Water Content (%)	Placed Dry Bulk Density (pcf)	Gravimetric Water Content (%)
Tailings	---	---	74.3	6.0
Random Fill (low compaction used to construct lower grading layer, already in place for Cell 2)	20	12.6	93.4	8.4
Random Fill (high compaction used to construct upper grading layer)	20	12.6	110.9	7.1
Random Fill (low compaction used to construct water storage layer)	20	12.6	99.2	7.9
Erosion Protection	16	10.6	124.2	5.3

Table H-5. Radon diffusion coefficients calculated using empirical relationships.

Material	Saturation (%)	Diffusion Coefficient (cm ² /s)
Tailings	12.5	0.0499
Random Fill (low compaction used to construct lower grading layer, already in place for Cell 2)	28.7	0.0275
Random Fill (high compaction used to construct upper grading layer)	37.8	0.0177
Random Fill (low compaction used to construct water storage layer)	31.1	0.0244
Erosion Protection	41.5	0.0141

Table H-6. Summary of RADON model results including material thicknesses (in feet) and radon emanation at the cover surface for the proposed monolithic ET cover design.

Material Layers	Thickness & Radon Exit Flux
Erosion Protection	0.5
Random Fill (low compaction used to construct water storage layer)	3.5
Random Fill* (high compaction used to construct upper grading layer)	2.8
Random Fill (low compaction used to construct lower grading layer, already in place for Cell 2)	2.5
Total Cover Thickness	9.3
Radon Exit Flux (pCi/m ² /s)	20.0

*The thickness of the upper platform fill layer (random fill compacted to 95% of Standard Proctor dry density) was optimized in order to minimize radon fluxes.

APPENDIX I

TAILINGS HYDRAULIC CONDUCTIVITY EVALUATION

APPENDIX I

TAILINGS HYDRAULIC CONDUCTIVITY EVALUATION

The purpose of this appendix is to compare grain size distribution data of uranium tailings at the White Mesa Mill to uranium tailings at the Canon City Mill to determine whether measurements of hydraulic conductivity at Canon City can be considered as a representative surrogate for White Mesa. The saturated hydraulic conductivity of the tailings assumed for White Mesa was based on measured values reported for the Cotter Corporation's Canon City Mill tailings impoundment.

GRAIN SIZE ANALYSES

The White Mesa tailings are generally silty sand but heterogeneous due to the placement process. Based on grain-size analyses performed on the tailings, sand-sized particles are dominant with the remainder being silt- and clay-sized particles. The average grain size distribution for White Mesa, based on 13 samples, consists of 57% sand, 26% silt, and 7% clay (see Table I-1). For sieve analyses in which hydrometer tests were not conducted, the percent clay (particles finer than 2 μm) was assumed to be 17% of the portion finer than the No. 200 sieve (0.74 mm), which corresponded to the average clay fraction from tests in which hydrometer analyses were performed.

The Canon City Mill tailings impoundment is operated by Cotter Corporation and is located near Canon City, Colorado. The tailings are generally silty sand but heterogeneous due to the placement process. Based on grain-size analyses performed on the tailings, sand-sized particles are dominant with the remainder being silt- and clay-sized particles. The average grain size distribution, based on five samples, consists of 61% sand, 33% silt, and 6% clay (see Table I-2) (MFG Inc., 2005). During hydrometer testing, two of the seven samples experienced flocculation and were not included in the averaging.

The mill tailings at Canon City are considered to be representative of the mill tailings at White Mesa because the average grain size distribution and approximate D_5 values between the two sites are similar:

- Canon City: 61% sand, 33% silt, and 6% clay with a D_5 of $\sim 2 \mu\text{m}$
- White Mesa: 57% sand, 26% silt, and 7% clay with a D_5 of $\sim 2 \mu\text{m}$.

Gradation curves are not available for the Canon City tailings; however, the similarity in average grain size distribution (% sand, silt, clay) and D_5 values between the two sites is expected to produce tailings materials that would behave in a similar hydrogeologic manner.

SATURATED HYDRAULIC CONDUCTIVITY TESTING

The saturated hydraulic conductivity of the White Mesa tailings were estimated based on the results from a multiple well aquifer test completed at the Canon City impoundment (MFG Inc., 2005) because site-specific measurements were lacking for White Mesa. The average hydraulic conductivity of the tailings at Canon City ranged from 2.1 ft/day (7.4×10^{-4} cm/sec) to 8.5 ft/day (3.0×10^{-3} cm/sec) with an average value of 4.8 ft/day (1.7×10^{-3} cm/sec) (MFG Inc., 2005). A hydraulic conductivity of 4.8 ft/day was assumed for the White Mesa mill tailings cell dewatering model.

CONCLUSIONS

The saturated hydraulic conductivity of the tailings assumed for White Mesa was based on measured values reported for the Cotter Corporation's Canon City Mill tailings impoundment. The mill tailings at Canon City are considered to be representative of the mill tailings at White Mesa because the average grain-size distributions between the two sites are similar.

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TABLE I-1. GRAIN SIZE DISTRIBUTION OF WHITE MESA MILL TAILINGS.			
Reference	Sand (%)	Silt (%)	Clay (%)
CSMRI, 1978	56	37	8
CSMRI, 1978	53	39	8
CSMRI, 1978	57	36	7
CSMRI, 1978	57	35	7
CSMRI, 1978	57	35	7
CSMRI, 1978	58	35	7
Chen & Associates, 1987	54	38	8
WCT, 1999	76	19	5
WCT, 1999	17	70	13
WCT, 1999	67	23	10
WCT, 1999	68	29	4
WCT, 1999	39	60	1
WCT, 1999	77	17	6
AVERAGE	57	36	7
Notes:			
1. CSMRI = Colorado School of Mines Research Institute. Data taken from samples labeled as DSM Screen Undersize.			
2. WCT = Western Colorado Testing.			

TABLE I-2. GRAIN SIZE DISTRIBUTION OF CANON CITY MILL TAILINGS.			
Reference	Sand (%)	Silt (%)	Clay (%)
MFG Inc., 2005	1	-	Floc
MFG Inc., 2005	86	10	4
MFG Inc., 2005	2	-	Floc
MFG Inc., 2005	80	15	5
MFG Inc., 2005	88	7	5
MFG Inc., 2005	33	59	8
MFG Inc., 2005	17	73	10
AVERAGE	61	33	6
Notes:			
1. Floc = Flocculation occurred during hydrometer testing. Samples were not included in the averaging.			
2. Clay cutoff varied between 3 to 6 micrometers because hydrometer tests were terminated before 2 micrometer settling time had been reached.			

APPENDIX J

TAILINGS CELL DEWATERING MODELING

APPENDIX J

TAILINGS CELL DEWATERING MODELING

This appendix describes the dewatering modeling performed with MODFLOW to estimate the time required to dewater the tailings in Cells 2 & 3 and estimate the residual saturated thickness of tailings. The model-predicted water levels (saturated thickness of tailings) are used in the Giroud-Bonaparte Equation to calculate potential flux rates through the liner into the underlying bedrock vadose zone, as described in Appendix L. A tailings cell dewatering model was not constructed for Cells 4A & 4B because analytical solutions presented by Geosyntec Consultants (2007) were deemed adequate given the uniform distribution of the drain system in those cells.

Tailings Cells 2 & 3 Slimes Drains

To dewater the tailings in Cells 2 & 3, slimes drain networks consisting of perforated PVC pipe are located across the base of the cells which drain to an extraction sump on the southern side of each cell. The drains cover an approximately 400-foot by 600-foot area in the southern part of the cells. The design for the slimes drains is the same for both cells (D'Appolonia Consulting Engineers, 1982). The drain pipes are situated in nine alignments spaced 50 feet apart running in an approximately east-west direction. Each drain is 600 feet long, extending 300 feet in each direction from the central collection pipe that drains to the sump. The drain pipes are covered by an envelope of sand over the drains, rather than a continuous layer across the bottom of the tailing cells ("burrito drains"). Water gravity drains to the sump, whence it is pumped to Cell 1.

METHODOLOGY

Model Code

The computer code MODFLOW was used in this modeling effort with the Department of Defense Groundwater Modeling System (GMS) pre- and post-processor. MODFLOW is

a modular three-dimensional finite-difference flow model developed by the United States Geological Survey (McDonald and Harbaugh, 1988; Harbaugh et al., 2000) to calculate hydraulic-head distribution and determine flow within a simulated aquifer. This model was selected because it can adequately represent and simulate the hydrogeologic conditions necessary and it is well-documented, frequently used, and a versatile program that is widely accepted by the scientific and regulatory communities (Anderson and Woessner, 1992).

Model Domain, Layering, and Grid

The domain for the tailings cell model was approximately 3,500 by 1,200 feet, representing Cells 2 & 3 (see Figure J-1). The finite-difference grid consisted of a constant spacing of 10 feet. The model included two layers to represent the tailings and slimes drains. The bottom layer was 1 foot thick so that the drains could be simulated explicitly (hydraulic conductivity was variable to represent tailings between the drains). The top layer had a variable thickness that represented the tailings. The water level in the top layer was allowed to vary spatially and temporally. The bottom elevations were set based on information presented in the tailings cell construction report (D'Appolonia Consulting Engineers, 1982).

Boundary Conditions

Boundary conditions define hydraulic constraints at the boundaries of the model domain. There are three general types of boundary conditions:

1. Specified head or Dirichlet (e.g., constant head)
2. Specified flux or Neumann (e.g., constant flow, areal recharge, extraction wells, no flow)
3. Head-dependent flux or Cauchy (e.g., drains, evapotranspiration)

No-flow boundaries are a special case of the specified flux boundary in which the flow is set to zero.

For the tailings cell model, no-flow boundaries were assumed to surround the domain. A net flux rate from the cell was assumed across the entire domain. This assumed flux rate represents the combination of potential fluxes from the cell through the liner and potential infiltration into the cell through the cover. The net flux rate was calculated using the average infiltration rate through the cover predicted by the HYDRUS-1D tailings cover model and the potential flux rate through the bottom of Cells 2 & 3 (see Appendix L). The resulting average net flux rate for Cells 2 & 3 was 6.9×10^{-4} cm/day (2.27×10^{-5} ft/day). This assumed net flux rate was applied uniformly across the domain and was simulated with MODFLOW as a negative recharge rate.

The slimes drains were simulated with the Drain package in MODFLOW. Drains are head-dependent boundary conditions in which flow varies based on the difference in hydraulic head in the aquifer and the drain: as head in the aquifer declines (tailings in this case), so does the dewatering rate. Groundwater flow to this array is gravity driven and dependent on the head difference between the surrounding material and the perforated pipe. Operation of the slimes drain extraction pump is only necessary to extract the groundwater driven into this array to maintain a head difference. Essentially, this system acts as a field drain array. The MODFLOW Drain package was developed specifically to simulate this sort of gravity driven, head dependent drain system. A thorough quantitative explanation of the MODFLOW Drain package is presented in *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1* (McDonald and Harbaugh, 1988).

Drain cells were set along nine alignments spaced 50 feet apart. Each drain was 600 feet long. Drains were set in the model as shown on Figure J-1.

Hydraulic Properties

The saturated hydraulic conductivity of the tailings assumed for White Mesa was based on measured values reported for the aquifer testing performed in uranium mill tailings at Cotter Corporation's Canon City Mill tailings impoundment (MFG, Inc., 2005). See Appendix I for details concerning the comparison of tailings grain size for the White Mesa Mill to those of the Canon City Mill. The average hydraulic conductivity of the tailings ranged from 2.1 ft/day (7.4×10^{-4} cm/sec) to 8.5 ft/day (3.0×10^{-3} cm/sec) with an average value of 4.8 ft/day (1.7×10^{-3} cm/sec). A hydraulic conductivity of 4.8 ft/day was assumed for the tailings (in both model layers). A hydraulic conductivity of 25 ft/day was assumed for the sand adjacent to the slimes drain in the bottom layer of the model. This was used only in layer 1 in the cells that represent drains. Hydraulic conductivity values representative of tailings were assumed across the remainder of the bottom layer.

Calibration

The calibration process involves iterating values for model parameters in sequential model simulations to produce estimated values that better match field-measured data. The initial-parameter values were adjusted through calibration until the model produced results that adequately simulated the known data. The tailings cell model was calibrated by varying the drain conductance term until the flow rates approximately matched the 2007 dewatering rates (average rate of 12.5 gpm) and average water levels of 20 feet above the liner.

RESULTS

The MODFLOW dewatering model predicts that the tailings would drain down nonlinearly through time reaching an average saturated thickness of 3.5 feet (1.07 m) after 10 years of dewatering (see Figure J-2). The model also predicts that dewatering rates would decline to approximately 2 gallons per minute (gpm) after 10 years of pumping. This reduction in pumping rates is caused by the reduction in saturated

thickness of tailings. Dewatering rates are also controlled by the saturated hydraulic conductivity of the tailings. If the actual hydraulic conductivity of the tailings is higher than the value assumed in the model, dewatering rates could be higher and water levels could be lowered more rapidly. Conversely, if the actual hydraulic conductivity of the tailings is lower than the value assumed in the model, dewatering rates could be lower and water levels could require more time to dewater. Mass balance errors for the MODFLOW model were less than 1%.

A dewatering model was not constructed for Cells 4A & 4B because dewatering rates were estimated by Geosyntec Consultants (2007). Water levels in Cell 4A were estimated to decline to less than 1 foot after approximately six years of dewatering. Cells 4A & 4B is estimated to be dewatered significantly faster than Cells 2 & 3 due to the more extensive slimes drain network. The dewatering system in Cell 4B is assumed to be designed similarly to Cell 4A, thus dewatering rates were assumed to be similar.

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Figure J-1. MODFLOW tailings cell model domain, grid, and boundary conditions

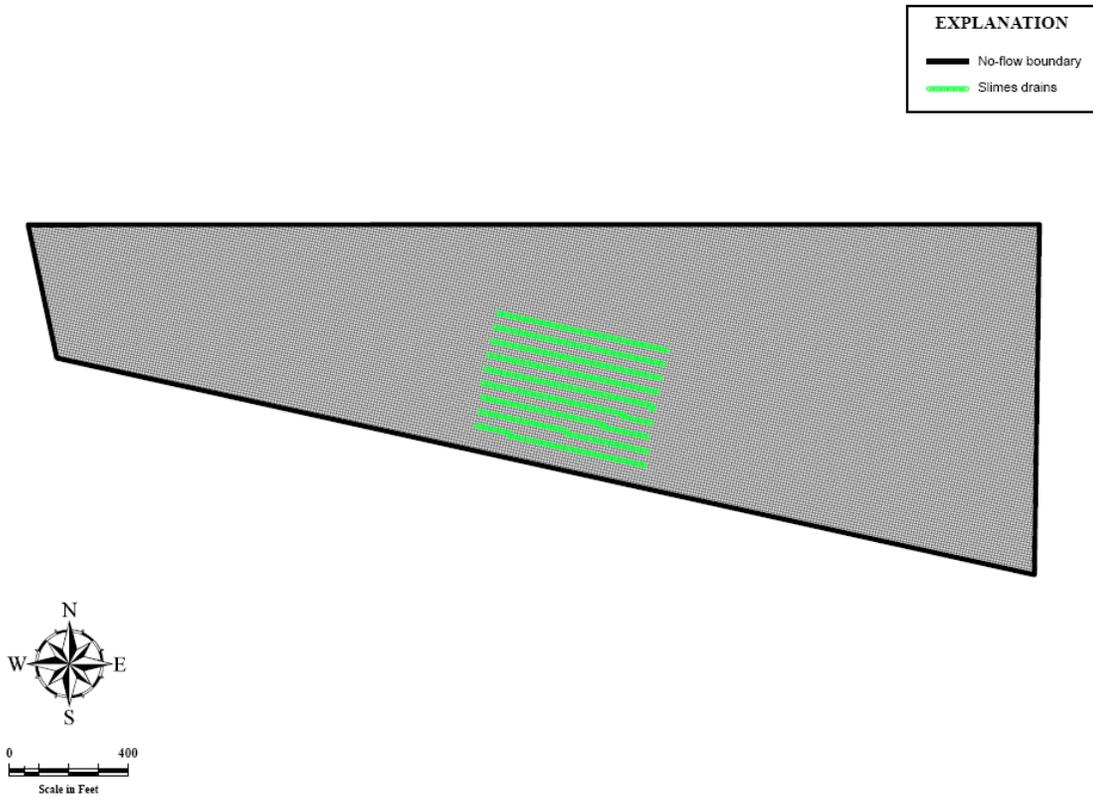
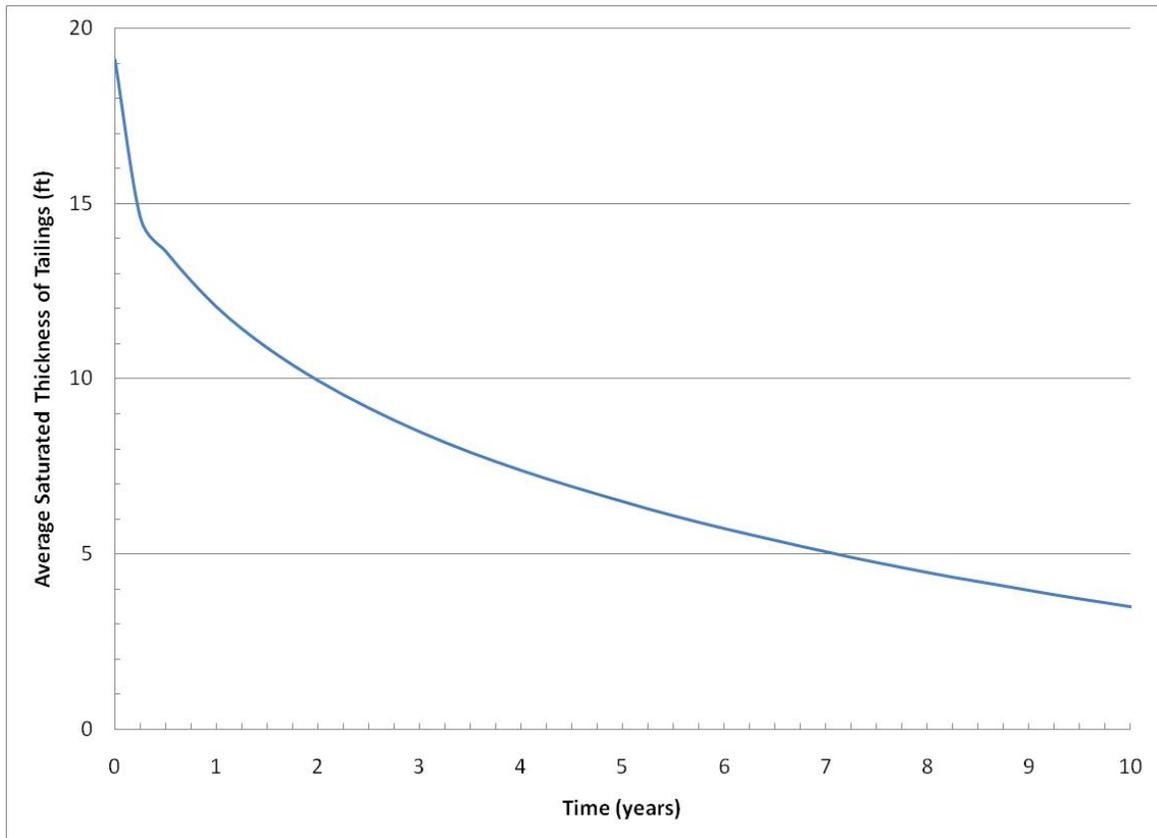


Figure J-2. Model-predicted average saturated thickness of tailings in Cells 2 & 3 with dewatering pumping.



APPENDIX K

**STATISTICAL EVALUATION OF TAILINGS PORE WATER
CHEMISTRY AND IDENTIFICATION OF SOURCE TERM
CONCENTRATIONS**

APPENDIX K

STATISTICAL EVALUATION OF TAILINGS PORE WATER CHEMISTRY AND IDENTIFICATION OF SOURCE TERM CONCENTRATIONS

The purpose of this appendix is to present the source term solution chemistry for the tailings pore water. The source term chemistry is used as input to the predictive vadose zone geochemical and solute transport models. Descriptive statistics of the source term chemistry are also presented.

BACKGROUND

Tailings pore water in the slimes drains (i.e., immediately above the tailing cell liners) is considered to be more representative of solutions that would remain in the tailings cells during operations and at closure given that these solutions would have had sufficient time to equilibrate with the tailings. Furthermore, water extracted from the slimes drains, as opposed to samples grabbed from surface ponds, is not affected as much by evaporation/evapoconcentration and addition/recirculation of mill process water; evaporation and recirculation of mill process water would tend to create a variable source term solution chemistry that is dissimilar to and not representative of the pore water in the tailings.

As described below, the solution chemistry of the tailings pore water, as represented by samples collected from the Cell 2 slimes drain, was assumed to be identical for all of the cells, given the similarities in ores and process solutions used over time. Cell 3 slimes drain data were not included in the statistical analysis because the analytical results contained an irregularity: the total dissolved solids (TDS) concentration was identical to the sulfate concentration, which is chemically impossible. Furthermore, only one sample has been collected from the Cell 3 slimes drain which limits the evaluation of potential trends. In other words, this one sample appears to be in error or could represent an outlier, rather than being representative. Cell 4A was not included in the statistical analysis because the facility was only constructed recently (as of Fall 2008) and contains

a minimal amount of tailings. Cell 4B was not included because the facility is currently being permitted (as of Spring 2010).

RESULTS

The analytical results of samples collected from the slimes drain for Cell 2 are tabulated in Table K-1. Statistical analyses of the data, including number of data points, minimum and maximum values, median, arithmetic average (mean), arithmetic standard deviation, geometric mean, and geometric standard deviation are tabulated in Table K-2. Overall, the data suggest that the solution chemistry of the tailings pore water is fairly consistent from year to year.

Four constituents consistently had concentrations detected at the reporting limit: fluoride, mercury, silver, and tin. Therefore, these analytes were excluded from further discussion and inclusion as part of the source term chemistry. For each analyte, the arithmetic mean was greater than the geometric mean, while the mean and median were in general agreement. The mean plus one-half standard deviation, which corresponds to approximately 38% of the observations if the data are distributed normally, was less than the maximum. However, the mean plus one standard deviation, which corresponds to approximately 68% of the observations, generally exceeded the maximum. Therefore such a metric (mean plus one standard deviation) should not be used as part of a sensitivity analysis to yield an end member (e.g., higher concentration) source term chemistry. In addition, the maximum value generally should not be used because this metric corresponds to a statistically insignificant percentage of the dataset, and its use would lead to unrealistic predictions; however, in response to a request by the Utah Division of Radiation Control, the maximum value was selected as the upper bound. To determine a range of source term chemistries for the modeled solutes, the maximum value was selected as an upper bound, the arithmetic average (mean) was selected as the base case, and the mean minus one-half standard deviation was selected as the lower bound.

University of Utah Data

In July 2007, the University of Utah collected samples from the Cell 2 slimes drain (Hurst and Solomon, 2008). Denison sampled the Cell 2 slimes drain in September 2007. The values reported by the University of Utah for July 2007 samples are compared to the September 2007 data reported by Denison below:

- Nitrate + Nitrite as N: 5.19 mg/L (University of Utah) and 30.9 mg/L (Denison)
- Manganese: 139 mg/L (University of Utah) and 117 mg/L (Denison)
- Selenium: <4 mg/L (University of Utah) and 0.422 mg/L (Denison)
- Sulfate: 666,000 mg/L (University of Utah) and 60,600 mg/L (Denison)
- Uranium: 23.7 mg/L (University of Utah) and 23 mg/L (Denison).

Nitrate values reported by the University of Utah were lower than values reported by Denison. Manganese and uranium values reported by the University of Utah agreed closely with results reported by Denison. The selenium values could not be compared because the detection limit reported by the University of Utah was far greater than the selenium concentration reported by Denison. The sulfate concentration reported by the University of Utah differed significantly from historical sulfate data reported by Denison and is considered to be anomalous.

The University of Utah data were not included in the statistical analysis because their dataset was limited to five analytes and a more comprehensive suite of analytes was available for data collected two months later by Denison. Furthermore, because the University of Utah analysis did not include all major ions, a charge balance could not be performed to check the data.

CONCLUSIONS

The arithmetic average (mean) will be used as the base case to set the initial conditions. As part of the sensitivity analysis, the modeled solutes will assume the maximum value for an upper bound and the mean minus one-half standard deviation for the lower bound.

REFERENCES

Hurst, T.G, and D.K. Solomon (2008), Summary of Work Completed, Data Results, Interpretations, and Recommendations for the July 2007 Sampling Event at the Denison Mines, USA, White Mesa Uranium Mill, near Blanding, Utah. Report prepared for the Utah Division of Radiation Control, May 2008, pp. 62.

TABLE K-1. Analytical results of samples collected from the Cell 2 slimes drain. All units are in mg/L except for pH which is in standard units.

Analyte	Cell 2 Slimes Drain Collected by UMETCO June 1991	Cell 2 Slimes Drain Collected by Denison September 2007	Cell 2 Slimes Drain Collected by Denison October 2008	Cell 2 Slimes Drain Collected by Denison August 2009
MAJOR IONS	-	-	-	-
Calcium	390	572	528	508
Chloride	2,573	3,700	3,860	2,750
Fluoride	2.0	3.3	0.05 ⁵	0.05 ⁵
Magnesium	2,540	4,100	4,030	3,750
Nitrogen, Ammonia as N	2,240	4,020	3,620	3,240
Nitrogen, Nitrate+Nitrite as N	100 ²	30.9	20.3	38
Potassium	291	636	560	689
Sodium	2,626	4,050	4,600	4,410
Sulfate	44,586	60,600	74,000	72,200
PHYSICAL PROPERTIES	-	-	-	-
pH	- ³	3.18	3.24	3.11
Total Dissolved Solids (TDS)	67,060	84,300	74,800	84,600
METALS – DISSOLVED ¹	-	-	-	-
Arsenic	0.5 ⁴	26.9	19.3	14.2
Beryllium	0.15	0.298	0.245	0.271
Cadmium	1.2	5.50	5.84	5.51
Chromium	1.2	2.75	2.45	2.23
Cobalt	15	46.5	43.8	38.7
Copper	185	106	154	170
Iron	2,420	2,770	3,310	3,230
Lead	0.5 ⁴	0.566	0.528	0.403
Manganese	178	117	130	160
Mercury	0.00025 ⁶	0.00025 ⁶	0.00025 ⁶	0.00025 ⁶
Molybdenum	0.5 ⁴	4.08	3.19	2.24
Nickel	12	123	122	108
Selenium	0.005	0.422	0.647	0.726
Silver	0.9	0.005	0.005 ⁷	0.005 ⁷
Thallium	1.2	0.361	0.703	0.368
Tin	0.05 ⁸	0.05 ⁸	0.05 ⁸	0.05 ⁸
Uranium	15	23	29.2	29.9
Vanadium	268	409	463	536
Zinc	53	767	750	582

Notes. (1) June 1991 metals concentrations correspond to total rather than dissolved. (2) June 1991 Nitrate+Nitrite as N not analyzed but original value Nitrate as N was <200 mg/L. (3) June 1991 pH not included because original value was not reported. (4) June 1991 Arsenic, Lead, and Molybdenum assumed to equal 0.5 because original values were <1 mg/L. (5) Fluoride from 2008 through 2009 assumed to equal one-half reporting limit or 0.05 mg/L. (6) Mercury assumed to equal one-half lowest reporting limit or 0.00025 mg/L because no detects were reported. (7) Silver from 2007 through 2009 assumed to equal one-half lowest reporting limit or 0.005 mg/L. (8) Tin assumed to equal one-half lowest reporting limit or 0.05 mg/L because no detects were reported.

TABLE K-2. Statistical analysis of Cell 2 slimes drain data. All units are in mg/L except for pH which is in standard units.									
Analyte	Number of Samples	Minimum	Maximum	Arithmetic Mean	Standard Deviation	Geometric Mean	Geometric Standard Deviation	Median	Mean Minus 0.5 Standard Deviation
MAJOR IONS	-	-	-	-	-	-	-	-	-
Calcium	4	390	572	500	78	495	1.18	518	461
Chloride	4	2,573	3,860	3,221	653	3,171	1.23	3,225	2,894
Fluoride	4	0.05	3.3	1.4	1.6	0.36	9.81	1.0	0.55
Magnesium	4	2,540	4,100	3,605	726	3,542	1.25	3,890	3,242
Nitrogen, Ammonia as N	4	2,240	4,020	3,280	763	3,206	1.29	3,430	2,899
Nitrogen, Nitrate+Nitrite as N	4	20.3	100	47.3	35.9	39.3	1.96	34.5	29.4
Potassium	4	291	689	544	177	517	1.48	598	456
Sodium	4	2,626	4,600	3,922	893	3,833	1.29	4,230	3,475
Sulfate	4	44,586	74,000	62,847	13,545	61,640	1.26	66,400	56,074
PHYSICAL PROPERTIES	-	-	-	-	-	-	-	-	-
pH	3	3.11	3.24	3.18	0.07	3.18	1.02	3.18	3.14
Total Dissolved Solids (TDS)	3	67,060	84,300	75,387	8,635	75,058	1.12	74,800	71,069
METALS - DISSOLVED	-	-	-	-	-	-	-	-	-
Arsenic	4	0.5	26.9	15.2	11.1	7.8	6.36	16.8	9.7
Beryllium	4	0.15	0.298	0.241	0.064	0.233	1.36	0.258	0.209
Cadmium	4	1.2	5.84	4.51	2.21	3.82	2.16	5.51	3.41
Chromium	4	1.2	2.75	2.16	0.67	2.06	1.45	2.34	1.82
Cobalt	4	15	46.5	36.0	14.4	33.0	1.70	41.3	28.8
Copper	4	106	185	154	34	151	1.28	162	137
Iron	4	2,420	3,310	2,933	416	2,910	1.16	3,000	2,724
Lead	4	0.403	0.566	0.499	0.070	0.495	1.16	0.514	0.464
Manganese	4	117	178	146	28	144	1.21	145	132
Mercury	4	0.00025	0.00025	0.00025	0	0.00025	1.00	0.00025	0.00025
Molybdenum	4	0.5	4.08	2.50	1.53	1.95	2.56	2.72	1.74
Nickel	4	12	123	91	53	66	3.13	115	64.6
Selenium	4	0.005	0.726	0.450	0.323	0.177	10.92	0.535	0.288
Silver	4	0.005	0.9	0.23	0.45	0.018	13.42	0.005	0.005
Thallium	4	0.361	1.2	0.658	0.395	0.579	1.78	0.536	0.460
Tin	4	0.05	0.05	0.05	0	0.05	1.00	0.05	0.05
Uranium	4	15	29.9	24.3	6.9	23.4	1.38	26.1	20.8
Vanadium	4	268	536	419	113	406	1.35	436	362
Zinc	4	53	767	538	334	365	3.64	666	371

APPENDIX L

EVALUATION OF POTENTIAL WATER FLOW THROUGH THE TAILINGS CELL LINERS

APPENDIX L

EVALUATION OF POTENTIAL WATER FLOW THROUGH THE TAILINGS CELL LINERS

The purpose of this appendix is to document the assumptions and methods used to calculate potential water flux rates through the liners installed beneath the tailings cells at the White Mesa Site. In principle, a geomembrane liner consists of an impermeable material that should preclude all leakage. However, the occurrence of a limited number of installation defects is generally anticipated and is assumed in the assessment of environmental impacts and sizing of leachate removal systems. Calculated flow rates through the liners are compared to data published by the U.S. Environmental Protection Agency (EPA) and data reported for Cell 4A during the first year of operations. There is evidence to suggest that there has been no leakage of tailings pore water through the liner systems at White Mesa.

Conservative assumptions were used in the calculations described below. In this document, the term conservative will generally apply to assumptions that are considered more protective of the environment, or in this context, will result in greater fluxes (e.g., more potential defects). Nevertheless, these conservative estimates of potential water flux rates through the liners will be used as an upper boundary condition (time-dependent flux) for the contaminant transport model used to predict flow and solute transport through the vadose zone to the perched aquifer during the operational, dewatering, and post-closure steady-state timeframes.

TAILINGS LINER SYSTEMS

Details of the tailings liner systems design and construction are necessary to calculate potential water flux rates that may migrate into the vadose zone beneath the cells. Details of the liner systems for Cells 2 & 3 are provided in D'Appolonia Consulting Engineers (1982), for Cell 4A in Geosyntec Consultants (2006), and for Cell 4B in Geosyntec

Consultants (2007b). The tailings liner systems are schematically illustrated in Figure L-1. Leak detection systems were installed beneath the liners and are monitored weekly.

The tailings liner systems for Cells 2 & 3 are identical and consist of a slimes drain collection system overlying a single liner. The design consists from top to bottom of:

- slimes drain system (cell bottom only)
- liner protective blanket
- 30-mil (0.03-inch) poly vinyl chloride (PVC) flexible membrane liner (FML)
- compacted bedding material
- prepared subgrade with limited leak detection system (i.e., a single pipe at the toe of the southern dike).

The tailings liner system for Cell 4A is double lined, and consists of a slimes drain collection system overlying a primary liner, leak detection system, and composite secondary liner. A composite liner is defined as a geomembrane liner underlain by a low-permeability soil (e.g., naturally compacted soil or geosynthetic clay layer). The design for Cell 4B is currently under review but preliminary drawings indicate an identical design to Cell 4A with minor deviations. The design consists from top to bottom of:

- slimes drain system (cell bottom only)
- 60-mil (0.06-inch) high-density polyethylene (HDPE) geomembrane (primary liner)
- geonet drainage layer (leak detection system)

- 60-mil (0.06-inch) high-density polyethylene (HDPE) geomembrane (secondary liner)
- geosynthetic clay liner (GCL)
- prepared subgrade.

ASSUMED SIZE OF DEFECTS

Based on forensic analysis of installed landfill liner systems, most defects occur during installation, and may result from discontinuous seaming and/or accidental puncturing of the geomembrane during construction activities (Giroud and Bonaparte, 1989). To estimate potential flux rates through the liners at White Mesa for use in the vadose zone flow and transport model, defect sizes were assumed based on recommendations provided in Giroud and Bonaparte (1989). The authors recommend that a circular defect with a diameter of 2 mm (area of $3.14 \times 10^{-6} \text{ m}^2$) should be used for evaluating performance of the liner, while a circular defect with a diameter of 10 mm (area of $7.85 \times 10^{-5} \text{ m}^2$) should be used for sizing leachate removal components and computing maximum design flows. The smaller diameter defects (small holes) may result from discontinuous seaming, while the larger diameter defects (large holes) may result from accidental puncturing of the geomembrane. Generally, large holes in a geomembrane are included in an analysis to size components of the lining system, and such defects are generally identified and sealed during routine quality assurance monitoring. Furthermore, especially in the context of fine-grained tailings, defects that arise may essentially become sealed by fine-grained slimes during tailings deposition and consolidation. Additionally, because of the elevated solute concentrations in the tailings solutions, potential defects may also become sealed by mineral phases that could precipitate from solution (e.g., gypsum or iron hydroxides). Therefore, for the purposes of modeling, defects are assumed that would give rise to a potential flux through the liner, while the actual flux through the liner could be insignificant.

ASSUMED FREQUENCY OF DEFECTS

To estimate potential flux rates through the liners at White Mesa for use in the vadose zone flow and transport model, the assumed number of defects was based on recommendations provided in Giroud and Bonaparte (1989) and Schroeder et al. (1994), the latter publication being the user's guide manual for the EPA's HELP model. General recommendations follow that one small hole defect is anticipated per acre, while the number of large hole defects will depend on the quality of the installation. An excellent installation quality for the liner may have up to one large hole defect per acre, while good installation quality for the liner may have between one to four large hole defects per acre. The liner beneath Cells 2 & 3 is comprised of PVC which has a lower puncture resistance than the HDPE liner beneath Cells 4A & 4B. Therefore, the number of potential large hole defects beneath Cells 2 & 3 is expected to be greater than the number of potential large hole defects beneath Cells 4A & 4B. Furthermore, Cells 4A & 4B were installed more recently (late 2000s versus early 1980s) and as such the liner installation quality is expected to be better as compared to Cells 2 & 3. The liner installation quality for Cells 2 & 3 and Cells 4A & 4B are assumed to be good and excellent, respectively (these qualitative ratings are required as part of the calculations).

As part of the sensitivity analysis, a range in potential water flux rates through the liners as a function of different assumptions regarding the number of defects is presented below. For Cells 2 & 3, the following scenarios were evaluated:

- base case: 1 small hole and 1 large hole defect per acre
- upper bound: 1 small hole and 3 large hole defects per acre
- lower bound: 1 small hole defect per acre.

For Cells 4A & 4B, only one scenario was calculated:

- base case: 1 small-hole defect per acre.

The inclusion of only one scenario for Cells 4A & 4B is considered to be representative because these cells contain a leak detection system installed between the upper primary and lower secondary liner, have more puncture resistant liners, and the liner installation quality is considered to be excellent. Furthermore, the head on the secondary liner is expected to be very small, as explained below.

EQUATION TO DETERMINE POTENTIAL WATER FLOW THROUGH DEFECTS

The flow of water through a circular defect assuming imperfect contact between the geomembrane and underlying soil liner can be evaluated using the following equation Giroud (1997):

$$Q = \beta \left[1 + 0.1 \left(\frac{h_w}{L_s} \right)^{0.95} \right] a^{0.1} h_w^{0.9} K_s^{0.74}$$

where:

- Q = leakage rate per defect [m³/sec]
- β = coefficient of contact between the geomembrane and the underlying soil liner [dimensionless]
- h_w = head above geomembrane [m]
- L_s = low-permeability soil liner thickness [m]
- a = area of defect [m²]
- K_s = saturated hydraulic conductivity of the soil liner [m/sec].

Giroud's (1997) equation is a semi-empirical equation that must be used with the identified units. The accuracy of Giroud's equation was evaluated using numerical simulations completed by Foose et al. (2001). Overall, leakage rates predicted with Giroud's equation were substantially higher and therefore more conservative than those predicted based on hydraulic theory, especially for facilities constructed with a composite

liner (a geomembrane overlying a GCL or compacted soil liner). Therefore, Giroud's equation is anticipated to over-predict flow rates through the liners for all of the cells. Furthermore, Giroud's equation assumes that the material above the liner readily transmits all available water, which may not be accurate for consolidated fine-grained tailings that may essentially seal any holes. In reality, the tailings may limit the transmission of water, thus actual flow rates for a given hole size would be less than the calculated potential flow rates through the liners. The equations and tests were based on landfills, which contain materials that have much higher permeability than tailings slimes.

INPUT VARIABLES USED TO ESTIMATE POTENTIAL WATER FLOW THROUGH DEFECTS

The total leakage rate per unit area is calculated by summation as a function of the head above the geomembrane and the total number of defects. The calculated volumetric flux rates were then divided by the cell area to estimate a flux rate, which was used as the boundary condition for the bedrock vadose zone flow and transport models.

For Cells 2 & 3, contact between the geomembrane and the underlying soil bedding is assumed to be good, thus the coefficient of contact (dimensionless empirical coefficient) is assumed to be 0.21 in the calculations (Khatami et al., 1989). Good contact assumes that the liner was laid on a well-prepared, smooth soil surface with good wrinkle control. The thickness of the soil bedding, 0.15 m, is based on as-constructed records (D'Appolonia Consulting Engineers, 1982). The saturated hydraulic conductivity for the compacted bedding material was assumed to be 2.0×10^{-7} cm/sec. For simplicity, the footprint for each cell (Cells 2 & 3) was assumed to equal 70 acres (283,290 m²). The head on the liner during the operational and dewatering phases is explained below.

For Cells 4A & 4B, the coefficient of contact between the secondary geomembrane and the underlying GCL was also assumed to equal 0.21 for use in the calculations. The thickness of the GCL, 0.005 m, was based on material specifications. The saturated hydraulic conductivity of the GCL was taken as the maximum value reported in

manufacturer's specifications (5.0×10^{-9} cm/sec). For simplicity, the footprint for each cell (Cell 4A & 4B) was assumed equal to 40 acres (161,880 m²). The head on the secondary liner during the operational and dewatering phases is explained below.

HEAD ON LINERS DURING OPERATIONS AND DEWATERING

The head above the single liner beneath Cells 2 & 3 was used as input to calculate the potential rate of fluid migration through the liners into the underlying vadose zone. For Cells 2 & 3, operational data and predictions with the MODFLOW dewatering model were used to estimate the saturated thickness of the tailings through time (see Appendix J for details regarding the dewatering model). Cell 2 went into service in 1980 and filling was completed in 1999, at which time the interim cover was placed, which is equivalent to a 19-year operational timeframe. Cell 3 went into service in 1983 and completion of filling and placement of the interim cover is scheduled for 2010, which is equivalent to a 27-year operational timeframe. For simplicity, the average operational period for Cells 2 & 3 (23 years) was used in the flux calculations. For modeling purposes, the head on the liner was assumed to increase linearly for 13 years from zero to fully saturated conditions, and then assumed to remain fully saturated for an additional 10 years for a total operational period of 23 years, at which point active dewatering was assumed to be initiated. The MODFLOW dewatering model predicted that the tailings would draindown nonlinearly through time reaching an average saturated thickness of 1.07 m (3.5 ft) after 10 years (i.e., total operational phase plus dewatering phase equal to 33 years). The maximum saturated tailings thickness during operations was varied as part of the sensitivity analysis to determine a range of potential liner flux rates for the scenario that considered the base case number of defects (1 small hole and 1 large hole defect per acre). For Cells 2 & 3, the following scenarios were evaluated:

- base case: the average saturated thickness across the entirety of the cell (when cell is entirely full), 5.82 m (19.1 ft), was used as the maximum head during operations

- upper bound: the maximum saturated thickness (which only occurs near the sumps when cell is entirely full), 8.23 m (27 ft), was used as the maximum head during operations
- lower bound: the average value minus the difference between the upper bound and base case saturated thicknesses, 3.41 m (11.2 ft), was used as the maximum head during operations.

For Cells 4A & 4B, the head on the secondary liner during operations and dewatering is a function of the amount of water that may migrate through the primary liner and remain in the leak detection system. The head above the secondary liner beneath Cells 4A & 4B was used as input to predict the potential rate of fluid migration into the underlying vadose zone. Cell 4A went into service in 2008 and is projected to be filled with tailings by 2014, which is equivalent to a 6-year operational timeframe. Cell 4B is scheduled to go into service in 2011 and is assumed to be filled with tailings by 2017, also a 6-year operational timeframe. As a result, a 6-year operational period was assumed in the calculations for both Cells 4A & 4B. Potential flow through the primary liner during the operational phase was evaluated by Geosyntec Consultants (2006, 2007b). A dewatering model was not constructed for Cells 4A & 4B because dewatering rates were estimated by Geosyntec Consultants (2007a). Water levels in the tailings for Cell 4A were estimated to decline to less than 0.3 m (1 ft) after approximately six years of dewatering. Cell 4A is estimated to be dewatered significantly faster than Cells 2 & 3 due to the significantly more extensive slimes drain network. The dewatering system in Cell 4B is assumed to be designed similarly to Cell 4A, thus dewatering rates were assumed to be similar and the dewatering period was assumed to be approximately six years. The maximum head on the secondary liner during operations is assumed to equal 0.004 m (0.01 ft) for Cells 4A & 4B. Significantly reduced head on the secondary liner during operations for Cells 4A & 4B, as compared to Cells 2 & 3, is due to a more extensive slimes drain collection system, the upper primary liner, and pumping of the leak detection system, thus reducing the head on the secondary liner. The maximum head on the secondary liner was assumed to remain constant throughout the operational and

dewatering periods (total of 12 years). The actual head on the secondary liner during the majority of the operational and dewatering periods is expected to be less than 0.004 m.

POTENTIAL FLUX THROUGH LINERS DURING OPERATIONS, DEWATERING, AND POST-CLOSURE STEADY STATE

Cells 2 & 3 Flux Rate Sensitivity Analysis for Different Saturated Thicknesses

The head on the liner (saturated thickness of tailings) for Cells 2 & 3 during the operational phase, dewatering phase, and post-closure steady state assuming three different values of maximum saturated thicknesses during operations (as described above) are plotted in Figure L-2. The calculated flux of water through the single liner beneath Cells 2 & 3 as a function of the assumed saturated thicknesses during operations, dewatering, and post-closure steady state for the base case number of defects (one small hole and one large hole per acre) is plotted in Figure L-3.

For the base case liner head and base case number of defects, the calculated potential flux rate for the maximum head during the operational phase is approximately 8.3 mm/yr. For the upper bound liner head and base case number of defects, the calculated potential flux rate for the maximum head during the operational phase is approximately 15 mm/yr. And for the lower bound liner head and base case number of defects the calculated potential flux rate for the maximum head during the operational phase is approximately 3.6 mm/yr.

During dewatering the calculated potential fluxes decrease from the maximum values reported above to approximately 0.7 mm/yr at closure (after 10 years of active dewatering) for all three liner head scenarios assuming the base case number of defects. As a simplification, excluding early stages of dewatering, the heads were assumed to be equal for all three liner head scenarios. Therefore, the potential flux rates for all three scenarios were the same because the post-closure steady state head was predicted to be the same after dewatering, and the number of assumed defects did not change. The flux

rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state.

Cells 2 & 3 Flux Rate Sensitivity Analysis for Different Liner Defect Frequencies

The calculated flux of water through the single liner beneath Cells 2 & 3 as a function of the range of assumed number of defects for the base case liner head during operations, dewatering, and post-closure steady state is plotted in Figure L-4.

For the base case number of defects and base case liner head, the calculated potential flux rate for the maximum head during the operational phase is approximately 8.3 mm/yr. For the upper bound number of defects and base case liner head, the calculated potential flux rate for the maximum head during the operational phase is approximately 18 mm/yr. And for the lower bound number of defects and base case liner head the calculated potential flux rate for the maximum head during the operational phase is approximately 3.5 mm/yr.

During dewatering, for the base case line head, the calculated potential flux decreases from the maximum values reported above to approximately 0.7 mm/yr at closure (after 10 years of active dewatering) for the base case number of defects, 1.5 mm/yr for the upper bound number of defects, and 0.3 mm/yr for the lower bound number of defects. During post-closure steady state the flux rates for all three scenarios were slightly different because the number of assumed defects differed. The flux rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state.

Cells 4A & 4B Flux Rate

The calculated flux of water through the secondary liner beneath Cells 4A & 4B for the maximum head within the leak detection system during the operational and dewatering periods is approximately 8×10^{-5} mm/yr. The flux rates predicted at the end of dewatering are assumed to equal the rate during post-closure steady state because the increase in water levels is anticipated to be minor (see Appendix E).

DISCUSSION

The EPA (1992) reported measured leakage rates (water pumped from primary leak detection systems located beneath composite liners) for landfill facilities. The leakage rates varied according to the level of construction quality assurance (CQA). Liners installed with excellent CQA had measured leak detection system flow rates that ranged from <5 to 50 gallons per acre per day (gpad) (<1.7 to 17 mm/yr), while facilities that had no rigorous CQA had measured leak detection system flow rates that generally were in excess of 50 gpad (17 mm/yr).

The calculated potential flow rates through the liners beneath Cells 2 & 3 for the maximum head during the operational phase ranged between 3.5 to 18 mm/yr for the six sensitivity scenarios presented above. The calculated potential flow rates through the liners at the end of dewatering and during post-closure steady state, which is more typical for the conditions evaluated by the EPA, ranged between 0.3 to 1.5 mm/yr for the six sensitivity scenarios presented above. The calculated values at the end of dewatering are slightly lower than flux rates from landfill facilities reported in the literature. The potential difference is assumed to be offset by the difference in hydraulic properties; leakage rates computed for a tailings facility are expected to be less than the measured leakage rates for landfills because tailings are likely to have a limited capacity to transmit all available water and the fine-grained nature of the tailings, coupled with the chemical nature of the pore water (e.g., precipitation of gypsum), is anticipated to essentially seal some of the defects.

The measured flow rates within the leak detection system beneath Cell 4A during the first year of operations (253,955 gallons pumped) for head conditions near capacity averaged approximately 20 gpad (6.8 mm/yr). The data collected from Cell 4A are not directly comparable to the EPA data because Cell 4A only has a single liner above the leak detection system, and the head is near capacity at ~10 meters; the presence of an underlying compacted soil layer or GCL would significantly reduce these rates. The measured flow rates through the primary liner of Cell 4A are significantly less than the value calculated by Geosyntec (2006) by a factor of ~30, which confirms that the

calculations used to predict flow through the composite liner (secondary liner and underlying GCL) for Cells 4A & 4B are conservative.

CONCLUSIONS

The potential liner flux rates calculated herein are assumed to be overestimates because of the conservative nature of the assumptions used. There is strong evidence to suggest that no significant leakage has occurred through the liner systems beneath Cells 2 & 3 over the past 30 years. Evidence that Cells 2 & 3 are not leaking includes:

- No significant leakage indicated by the leak detection systems
- No leakage indicated by the perched aquifer water table surface
- No observations of contamination (e.g., acid leaching, dissolution of carbonates, gypsum precipitation, staining) were recorded during drilling of monitoring wells installed adjacent to the cells during spring 2005
- Total uranium was detected at background levels in bedrock core samples collected while drilling monitoring wells adjacent to the cells (see Appendix A)
- No contaminants detected in groundwater at levels above natural background concentrations (INTERA, 2007a; 2007b; 2008), which is corroborated by the finding that the groundwater age beneath the tailings cells is dominated by water that is at least 50 years old (Hurst and Solomon, 2008)
- No contaminants detected in groundwater as evaluated through stable isotopes (Hurst and Solomon, 2008).

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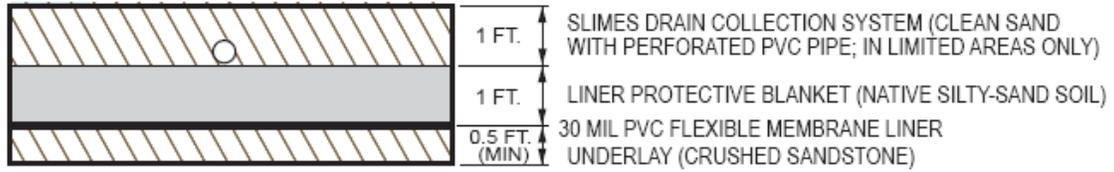
INTERA, Inc., 2008. Revised Addendum Background Groundwater Quality Report: New Wells For Denison Mines (USA) Corp.'s White Mesa Mill Site, San Juan County, Utah. Prepared for Denison Mines (USA) Corp. on 30 April 2008.

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Figure L-1. Cross section of tailings liner systems beneath Cells 2 & 3 and Cells 4A & 4B (not to scale).

Cells 2 and 3



Cells 4A and 4B

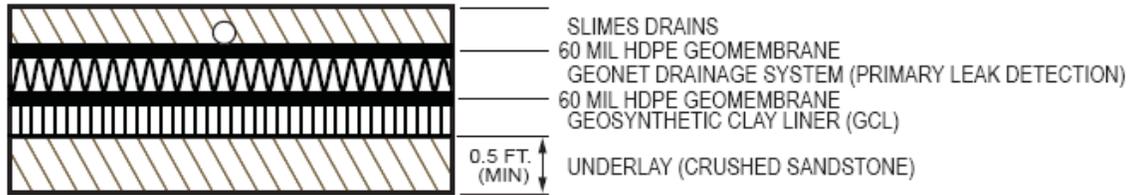


Figure L-2. Water levels assumed in the tailings (head on the liner) during the operational period (assumed to be 23 years), dewatering period (assumed to be 10 years), and post-closure steady state for Cells 2 & 3 for each of the three saturated thickness scenarios.

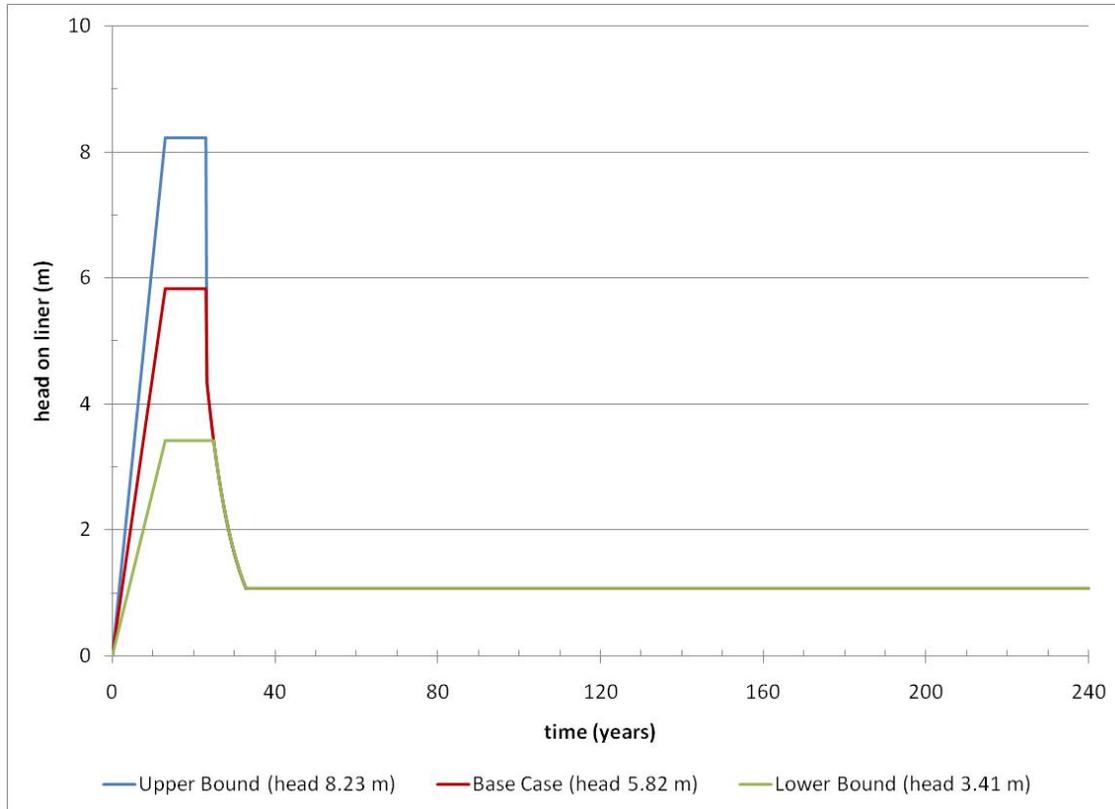


Figure L-3. Calculated potential flux of water through the single liner beneath Cells 2 & 3 for the base case number of defects (one small hole and one large hole per acre) as a function of three different assumed saturated thicknesses (plotted in Figure L-2) during the operational phase, dewatering phase, and post-closure steady state.

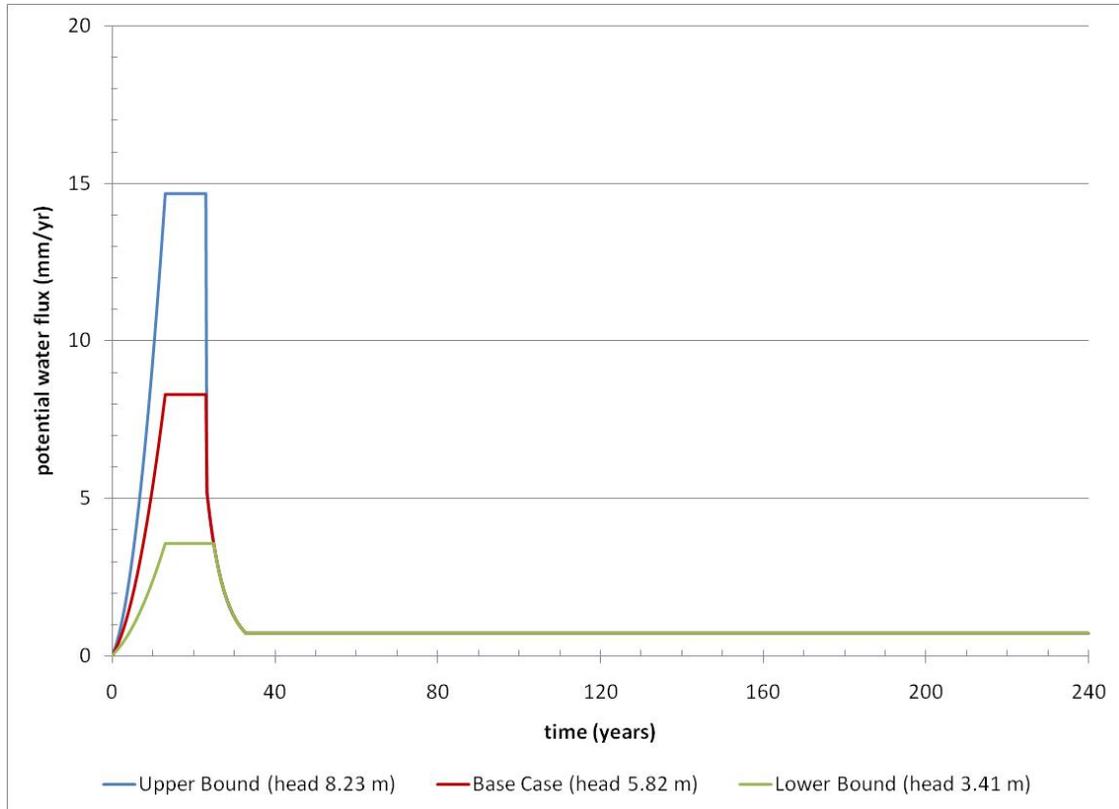
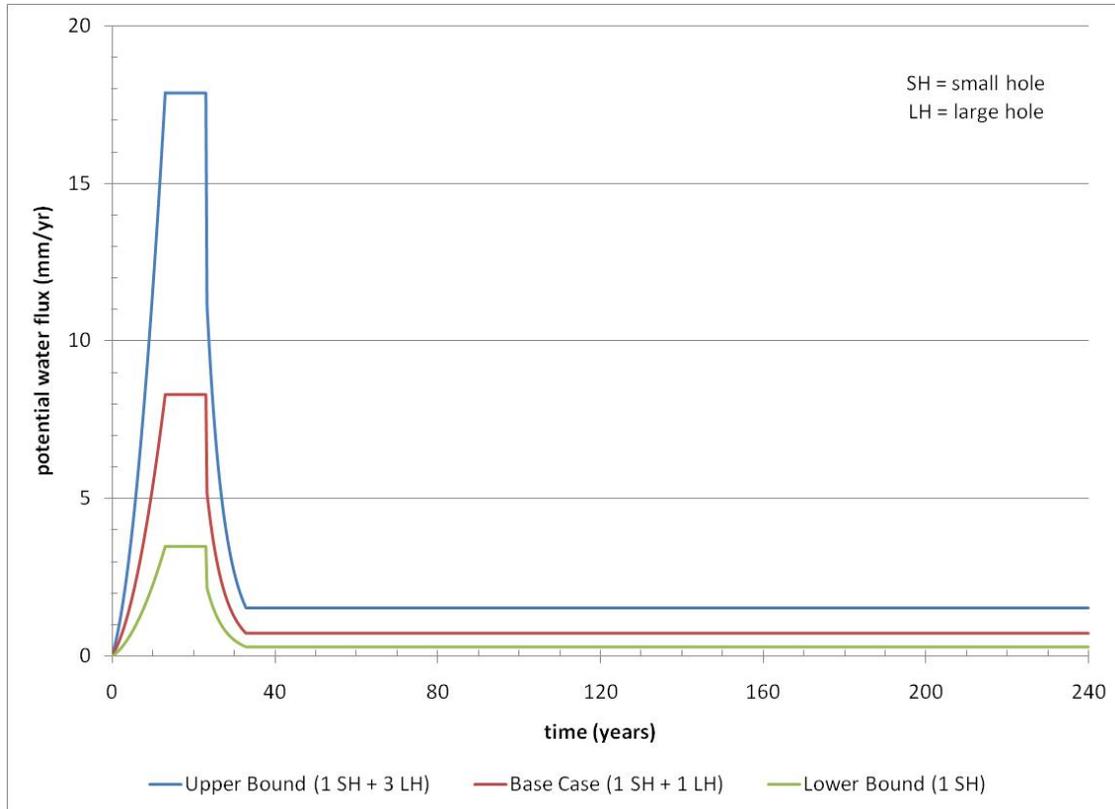


Figure L-4. Calculated potential flux of water through the single liner beneath Cells 2 & 3 for the base case saturated thickness (maximum head during operations equal to 5.82 m) as a function of three different assumed defect frequencies during the operational phase, dewatering phase, and post-closure steady state.



APPENDIX M

**GEOCHEMICAL MODEL AND REACTIVE TRANSPORT
MODELING OF FLOW AND TRANSPORT THROUGH THE
BEDROCK VADOSE ZONE**

APPENDIX M

GEOCHEMICAL MODEL AND REACTIVE TRANSPORT MODELING OF FLOW AND TRANSPORT THROUGH THE BEDROCK VADOSE ZONE

This appendix describes the geochemical and reactive transport model used to predict the potential transport of conservative and nonconservative solutes through the bedrock vadose zone beneath the White Mesa Mill tailings cells. Neutralization of the infiltrating acidic tailings porewater, speciation of solutes, sorption of solutes, and mineral precipitation/dissolution reactions within the bedrock vadose zone were predicted with HP1.

The conceptual model describing the potential transport of contaminants through the bedrock vadose zone is described in Section 2.0 of this report. Details of the implementation of the conceptual model into the numerical model as well as parameter values, boundary conditions, and initial conditions used in the modeling are described in this appendix. A description of the sensitivity analysis and results for the bedrock zone contaminant transport modeling is also included as part of this appendix.

BACKGROUND

Reactive Transport Modeling

Chemical reactions between dissolved constituents and minerals present within the vadose zone often dictate spatial and temporal variations in contaminant-plume transport and mobility. Historically, solute transport processes have been modeled using a simplified attenuation-based contaminant transport modeling approach, in which a distribution coefficient (K_d) is calculated and substituted into the advection-dispersion equation which predicts contaminant fate and transport (e.g., Bethke and Brady, 2000; Brady and Bethke, 2000; Zhu et al., 2001). However, attenuation-based contaminant transport models are generally insufficient to describe the complex geochemical reactions that may occur at mine sites in which acidic solutions containing elevated concentrations of metals and sulfate may migrate through an unsaturated zone toward a perched aquifer.

Recent computer and programming advances allow more accurate simulations of reactive transport processes in the unsaturated zone (e.g., Jacques et al., 2006). In mining and post-mining environments, neutralization of infiltrating acidic waters coupled with other geochemical reactions (speciation, sorption, mineral dissolution, mineral precipitation) control the transport of nonconservative solutes and represent an ideal application of reactive transport modeling. Therefore, a reactive transport model (e.g., HP1), which incorporates linkages between flow and reactive transport processes, is preferred and used in this report over an attenuation-based transport model.

Adsorption of Metals

The sorption of uranium, and other trace elements, onto mineral surfaces is strongly dependent on the solution pH, initial solute concentration, and mass of adsorbent. Generally, the amount of sorption increases for decreasing initial concentrations and increasing mass of adsorbent (Payne, 1999). The variability of sorption as a function of pH is controlled by the surface charge that develops on the mineral surface. Generally, cationic metals show maximum sorption at circumneutral pH ranges with decreasing sorption as the pH changes from neutral to either acidic or basic values. Therefore, a reactive transport model (e.g., HP1) that accounts for changes in acidity, solution pH, and solute concentrations during water-rock interactions as solutes are transported through the unsaturated zone is preferred and used in this report over an attenuation-based transport model which does not account for these changes.

Reactive transport modeling with HP1 for use in predicting surface complexation reactions (adsorption/desorption) is preferred instead of laboratory-based K_d tests (using vadose zone samples exposed to multiple tailings leachate samples with a range of contaminant concentrations), because:

- HP1 simulations consider the complexity of the tailings solutions, aquifer matrix chemistry, and potential water-rock reactions that may occur along a flow path in the subsurface beneath the site.
- Empirical determinations of K_d 's were originally developed to quantify the sorption of organic compounds and alkali/alkaline earth cations whose speciation and sorption is nearly insensitive to changes in solution chemistry.

- Empirical determinations of K_d 's are not an adequate metric for determining the sorption of uranium and other trace elements because these species are strongly controlled by the chemical reactions and expected solution chemistry.
- The quantification of potential reactions (required for attenuation-based models) that may occur beneath the facility, during the course of a laboratory experiment, are very difficult to reproduce, especially taking into account the inherent variability in the geochemical reactions that may occur during transport through the vadose zone. Specific examples include:
 - Range in uranium concentration and other trace elements
 - Range in neutralization potential
 - Range in the mass and number of sorbing phases
 - Range in alkalinity of (partially) neutralized tailings solutions
 - Range in water to rock proportions.

METHODOLOGY

HP1

Reactive transport processes within the bedrock vadose zone, including speciation of aqueous complexes within the porewater, sorption of aqueous complexes onto mineral surfaces, dissolution of calcite (acid neutralization), and precipitation of gypsum and amorphous mineral phases, were predicted using HP1 (Jacques and Simunek, 2005). HP1 is a reactive transport code that combines the infiltration, unsaturated flow, and multicomponent contaminant transport modeling capabilities of HYDRUS-1D (Simunek et al., 2009) with the equilibrium geochemical model PHREEQC (Parkhurst and Appelo, 1999). HYDRUS-1D was used to support the results for flow and transport of a conservative solute (chloride) predicted by HP1.

The HP1 model was developed by the Belgian Nuclear Research Center in collaboration with the U.S. Salinity Laboratory and Department of Environmental Sciences at the University of California at Riverside. The HP1 code retains all of the features documented in HYDRUS (as described in Section 3.0 of this report) but incorporates additional modules capable of simulating a broad range of low-temperature geochemical

reactions in water, soil, and groundwater systems. HP1 can simulate multicomponent reactive transport, including geochemical interactions with minerals, gases, exchangers, and sorption surfaces, using thermodynamic equilibrium, kinetics, or mixed equilibrium-kinetic reactions.

Aqueous Complexation Reactions

The distribution of elements among aqueous species (e.g., uranium as $\text{UO}_2(\text{OH})^+$, $\text{UO}_2(\text{SO}_4)_2^{-2}$, etc.) and ionic states (e.g., uranium in its +4 oxidation state as the uranous ion (U^{+4}) or uranium in its +6 oxidation state as the uranyl ion [UO_2^{+2}]), has a significant effect on solution chemistry and contaminant-transport mobility. Generally, dissolved trace elements in porewater under oxidized conditions will have increased mobility as compared to reduced conditions. Decreased mobility associated with reduced conditions often results because minerals with lower solubility tend to precipitate from solution, sequestering many trace elements including uranium from the dissolved to the solid phase. Oxidizing geochemical conditions within the vadose zone were assumed.

The speciation of elements and formation of aqueous complexes is governed by mass-action equations and aqueous-complex formation (stability) constants, and is based on thermodynamic constraints. Geochemical reactions and formation constants are contained within the thermodynamic database. For this report, the thermodynamic database compiled by the U.S. Geological Survey (wateq4f.dat) was updated to be consistent with uranium thermodynamic data provided by the Nuclear Energy Agency (Guillaumont et al., 2003) and the U.S. Department of Energy (Bernhard et al., 2000).

Surface Complexation Reactions

Surface complexation modeling with HP1 was used to predict the adsorption of trace elements using the large body of published literature that has evaluated the sorption of uranium and other trace elements onto the surfaces of HFO (hydrous ferric oxide) (Dzombak and Morel, 1990). The diffuse layer (sorption) database developed by Dzombak and Morel (1990) has also been incorporated by the U.S. EPA into their geochemical model MINTEQA2 (Allison et al., 1991), by the U.S. Geological Survey

into their geochemical model PHREEQC (Parkhurst and Appelo, 1999), and into HP1 (Jacques and Simunek, 2005), indicating a general acceptance by the regulatory and scientific communities.

The Dzombak and Morel (1990) diffuse layer database has been modified slightly to adjust the sorption coefficients for uranium because the original values tended to overpredict the amount of adsorption under low-pH conditions and underpredict the amount of adsorption under high-pH conditions (Mahoney et al., 2009). The agreement (R^2 of ~ 0.9) between the final model-selected parameters to extensive literature data (Mahoney et al., 2009), show a consistency that supports the general application of this revised model in describing uranium adsorption onto HFO.

The surface complexation modeling approach incorporated into this report is functionally similar to the methodology developed by the U.S. Geological Survey for the U.S. Nuclear Regulatory Commission, as presented in NUREG/CR-6820 (Davis and Curtis, 2003). As discussed in NUREG/CR-6820, the use of a surface complexation model that incorporates linkages between surface and aqueous species is preferable to models that rely on a constant partition coefficient (i.e., single K_d) or empirical approaches (i.e., adsorption isotherms from batch tests).

Surface complexation modeling for the Naturita UMTRA Site suggests that additional mineral phases (e.g., hematite, montmorillonite/smectite, and quartz) would adsorb uranium (Davis and Curtis, 2003). Furthermore, adsorption of uranium onto the surfaces of aluminum and manganese hydroxides is also expected to occur (e.g., Langmuir, 1997). All of these mineral phases, in addition to HFO, are expected to be present within the bedrock vadose zone (either as part of the original mineralogy or due to precipitation of minerals along a flow path during transport), and available to participate in surface complexation reactions. To remain conservative, these additional mineral phases that would sorb uranium and other metals were not included in the model. Sorption is only allowed to occur onto the surface of a single mineral phase (HFO), and the amount of sorption is limited to the calculated sorbent site densities (i.e., finite number of sorption sites). As an additional conservative assumption, uranium adsorption was allowed to

compete with other metals, which would decrease the total amount of uranium that could adsorb.

Mineral Precipitation/Dissolution Reactions

In addition to sorption, the precipitation/dissolution of minerals during the potential transport of contaminants through the bedrock vadose zone will control the attenuation and mobility of nonconservative solutes such as sulfate, aluminum, and iron. The extent of acid neutralization was based on the measured mass of calcite (acid neutralizing potential or ANP) of the bedrock vadose zone, while surface complexation reactions (adsorption) were based on the measured mass of HFO of the bedrock vadose zone (see Appendix C for a statistical analysis of site-specific geochemical data collected from the bedrock core samples). Mineral dissolution (calcite) and precipitation (sulfate minerals and amorphous phases) were based on equilibrium constraints and were mass limited. The precipitation of aluminum and iron hydroxide phases also introduces additional mineral acidity (H^+ ions), which would consume calcite in addition to the acidic waters potentially transported through the liners. Coprecipitation reactions were not accounted for during the geochemical modeling as a simplification and to maintain conservative assumptions. Coprecipitation of uranium (Abdelouas et al., 1998) and metals onto the surfaces of precipitating phases was ignored, which could also serve as a sink for metals and reduce transport mobility.

FLOW AND REACTIVE (CONTAMINANT) TRANSPORT MODEL OF THE BEDROCK VADOSE ZONE

Reactive transport models were developed for the bedrock vadose zone beneath Cells 2 & 3. Reactive transport models in HP1 were not constructed for Cell 1 (contingency cell identified for the potential disposal of decommissioning and deconstruction debris), and Cells 4A & 4B because the model did not predict chloride to exceed 10 mg/L at the bottom of the bedrock vadose zone, which is the minimum groundwater compliance limit (GWCL) for monitoring wells located immediately downgradient from the tailings cells (see Section 4.0 of this report). Considering that chloride is a conservative tracer, and that transport is not affected by sorption or mineral precipitation reactions, coupled with

the fact that the model predictions demonstrate nearly zero impact, additional model predictions of solute transport for nonconservative contaminants (sulfate, uranium, other trace elements) was considered unnecessary for Cell 1 and Cells 4A & 4B.

Domain

The bedrock vadose zone model extended from the base of the tailings cell liner systems through the Dakota Sandstone and Burro Canyon Formation to the perched water table surface (see Figure 3-1). The vadose zone thickness was calculated by taking the difference between the bottom elevation of the cell and the distance to the water table for individual monitoring wells. The minimum vadose zone thickness beneath Cells 2 & 3 and Cell 4A was approximately 12.8 m (42 ft) and 12.2 m (40 ft), respectively (based on 2007 water level data). As a comparison, the average vadose zone thickness beneath Cell 2, Cell 3, and Cell 4A are 19.2 m (63 ft), 20.1 m (66 ft), and 17.1 m (56 ft). As a conservative assumption the minimum vadose zone thickness of 12.8 meters (42 feet) was assumed for all of the simulations of potential solute transport beneath the cells (see Appendix C for a discussion of vadose zone thicknesses and a summary table of vadose zone thickness beneath the tailings cells).

Finite Element Node Spacing

The finite-element nodes were discretized in the vertical direction to simulate layers in the bedrock vadose zone. The bedrock vadose zone model had a uniform node spacing of 5 cm. In order to reduce numerical errors due to spatial discretization, grid spacing was based on recommendations provided by Jacques et al. (2006).

Boundary Conditions

Variable specified mass flux rates (flux multiplied by the concentration) were applied to the upper boundary of the bedrock vadose zone.

Potential water flux rates through the liner systems for Cells 2 & 3 were calculated using the Giroud-Bonaparte Equation as described in Appendix L. The predicted saturated

thickness of the tailings during the operational phase, during active dewatering, and during post-closure steady state was used to calculate the potential flux rate through the liner for use as an upper boundary condition in the flow and contaminant transport model of the bedrock vadose zone. Groundwater flow modeling with MODFLOW of Cells 2 & 3 was performed to estimate tailings-dewatering rates through time and average water levels (saturated thickness) that will remain in the tailings after dewatering (described in Appendix J). In addition to the maximum saturated thickness of the tailings during operations, the number of potential liner defects and their impacts on potential water flux through the liners were evaluated as part of the sensitivity analysis (see Appendix L for details).

The lower boundary of the domain was assumed to be fully saturated (i.e., water table conditions with a constant pressure head equal to 0 cm [atmospheric pressure]), representing the water-table surface of the perched aquifer. A zero concentration gradient was specified at the lower boundary for solute transport. Because of the one-dimensional nature of the model, the sides of the domain are implicitly assumed to be zero-flux boundaries.

Input Parameters

Water Flow. Hydraulic properties required for the vadose zone flow model include vertical saturated hydraulic conductivity, residual soil water content, saturated soil water content, and the soil water retention empirical curve-fitting parameters. The saturated and unsaturated hydraulic properties were measured in core samples collected from the Dakota Sandstone and Burro Canyon Formation (see Appendix B for original laboratory report). Bedrock core sample collection methodologies, presentation of soil water retention and unsaturated hydraulic conductivity curves, and selection of hydrologic units are discussed in Appendix C. Hydraulic properties used in the model are presented in Section 3.0 and Table 3-1 of this report.

The vadose zone model assumed a single set of hydraulic properties consistent with the test results reported for the Dakota Sandstone. This assumption is considered appropriate because the saturated and unsaturated hydraulic properties of the samples are quite

similar to one another (see Appendix C). Assignment of a single set of hydrogeologic properties should not significantly affect the model results given the similarity in unsaturated hydraulic properties [$\theta(h)$] and [$K(h)$] for all samples (i.e., there were only small differences in soil water retention curves or unsaturated hydraulic conductivity curves for the materials tested). The hydraulic properties (and dry bulk density) from MW-23 (55.5-56.0 ft) were used as input to the model because the hydraulic functions are intermediate as compared to the other samples. Unsaturated hydraulic conductivity of the vadose zone was not included in the sensitivity analysis because the unsaturated hydraulic conductivities vary to match flux rates under a unit hydraulic gradient.

Contaminants Modeled. The contaminants modeled included pH, major cations and anions necessary to achieve charge balance (aluminum, calcium, carbonate, chloride, magnesium, potassium, sodium, and sulfate), and selected trace elements (arsenic, cadmium, copper, iron, nickel, uranium, vanadium, and zinc). Trace elements included in the model were based on their elevated concentrations in the tailings slimes drains as compared to the GWCLs. Aluminum was included and used to obtain charge balance. These solutes are the most dependable indicators of site water quality and of potential cell failure due to their predominance (uranium and sulfate) and predominance/mobility (chloride). In particular, chloride will migrate unretarded and would be expected to be detected before all other site contaminants. Uranium was included because it is one of the primary contaminants of concern.

Source Term Concentrations. The average solute concentrations measured in the tailings slimes drains were used as input to represent the source term solution chemistry of the tailings pore water (see Appendix K for a discussion of source term chemistries). The average concentration of chloride, sulfate, and uranium were 3,221 milligrams per liter (mg/L), 62,847 mg/L, and 24.3 mg/L, respectively. No source degradation, treatment, or dilution was assumed, that is, concentrations were held constant through time. As part of the sensitivity analysis, the initial solute concentrations were varied and ranged between the maximum reported values for the upper bound and the mean minus one-half standard deviation for the lower bound. The source term concentrations for the three scenarios are summarized in Table M-1.

Geochemistry. Geochemical properties of the vadose zone included the mass of ANP and mass of HFO present in the bedrock vadose zone. The amount of ANP and HFO were based on measured values obtained from core samples. The sampling methodology, testing procedures, results, and statistical analysis of the data, in addition to a discussion regarding the selection of hydrogeochemical units, are summarized in Appendix C, while the original laboratory data are contained in Appendix A. To simplify the conceptual model, the geometric mean of the entire population was selected as the base case value for both ANP and HFO.

The amount of ANP present in the bedrock vadose zone was reported as grams of calcite (CaCO_3) per kilogram of rock and was converted to moles of calcite per unit volume of bedrock for input into HP1. As part of the sensitivity analysis, the amount of ANP was varied with the geometric mean plus one geometric standard deviation for the upper bound and the geometric mean minus one geometric standard deviation for the lower bound. The upper bound, base case, and lower bound ANP values were 0.18, 0.11, and 0.04 moles of calcite per unit volume of bedrock. ANP data are considered to be representative because the test only measures rapidly-reacting carbonate minerals.

The amount of HFO present in the bedrock vadose zone was converted to grams of HFO per unit volume of bedrock for input into HP1. The mass of HFO per unit volume of bedrock was 1.8. The total number of sorption sites was based on converting the above concentration to a molar mass (assuming a molecular weight of 89 grams per mole) and multiplying by site density recommendations provided by Dzombak and Morel (1990) (0.2 moles weak sites/mole of iron and 0.005 moles strong sites per mole of iron). The number of weak and strong sites input into HP1 was 4.0×10^{-3} moles and 9.9×10^{-5} moles, respectively. As suggested by Dzombak and Morel (1990) the surface area of HFO was input at 600 square meters per gram (m^2/g). The amount of HFO did not vary significantly within the bedrock vadose zone and was not included in the sensitivity analysis (see Appendix C). HFO is the only solid phase that serves as a potential sorption site of uranium and other trace elements, which is a conservative assumption because other phases (e.g., hematite, quartz, clays, etc.) also participate in surface complexation reactions.

The partial pressure of oxygen was fixed in the model assuming a dissolved oxygen concentration in vadose zone porewater equal to 2 mg/L. The partial pressure of carbon dioxide was fixed in the model assuming $10^{-2.0}$ atmospheres of pressure, but was varied as part of the sensitivity analysis to $10^{-1.0}$ atmospheres of pressure used for an upper bound and $10^{-3.0}$ atmospheres of pressure used for the lower bound. Redox conditions were controlled by the oxygen couple. The following minerals or amorphous phases were allowed to participate or dissolve, depending on their saturation indices: gypsum, calcite (ANP), amorphous aluminum hydroxide (HAO), and amorphous iron hydroxide (HFO). The mass of HFO allowed to participate in surface complexation reactions was fixed according to measured values in bedrock (geometric mean), and as a conservative assumption, the HFO that precipitated from solution did not add to the available sorption sites.

Diffusion. Tortuosity, and its effect on molecular diffusion, was explicitly modeled by incorporation of a tortuosity factor for the liquid phase (Simunek et al., 2009). Given the extremely low advective velocity, mechanical dispersion was assumed to be negligible relative to molecular diffusion (see Section 2.0). Diffusion coefficients for all modeled solutes were assumed to be equal to 1.75 square centimeters per day (cm^2/day) which is the diffusion coefficient of chloride.

Degradation and Production. No degradation or production of chloride, sulfate, uranium, or other trace elements was assumed. Radioactive decay of uranium is considered to be relatively minor due to the slow processes involved (e.g., the half-life for natural uranium, which is predominantly U-238, is 4.4×10^9 years). Although uranium and other trace elements can be removed from solution through microbial processes, to yield more conservative model predictions, these microbial processes were not simulated.

Initial Conditions

Water Flow. Initial soil water pressure heads within the bedrock vadose zone were estimated by applying a constant flux boundary using ~1% of average annual amount of

precipitation. For all HP1 simulations, initial conditions were prescribed as pressure heads (as opposed to water content) to facilitate model convergence.

Geochemistry. Solution concentrations in the bedrock vadose zone were estimated by assuming equilibrium of calcite with the HFO. Only calcium and carbonate were included as aqueous species. While there are naturally-occurring concentrations of chloride, sulfate, uranium, and other trace elements in the vadose zone initially, the modeling assumed no initial values for simplicity.

Duration of Simulations and Time Steps

Simulations were run to evaluate potential solute transport during the operational phase, dewatering phase, and post-closure steady-state timeframes equal to a total duration simulation of 240 years. The operational and dewatering phases (see Appendix L for details) were followed by 200 years following closure as required by the Permit.

The minimum and maximum time-steps were 1.04×10^{-2} day (900 seconds) and 180 days for the HP1 model. The maximum number of iterations per time step was 40. In HP1, solution efficiency is maximized by incorporating adaptive time-step adjustments based on criteria described in Simunek et al. (2009). In order to reduce numerical errors due to temporal discretization, time-step and stability criteria were based on recommendations provided by Jacques et al. (2006).

Sensitivity Analysis

A sensitivity analysis was performed to quantify the model-prediction uncertainty due to estimating model input parameters. Three values were selected for each input parameter, corresponding to a lower bound, base case, and upper bound. Input variables incorporated into the sensitivity analysis for reactive transport included source term solution chemistry of the tailings pore water (see Appendix K for details), number of potential liner defects (see Appendix L for details), acid neutralization potential of the bedrock (ANP) vadose zone (see Appendix C for details), and partial pressure of carbon dioxide gas within the bedrock vadose. Results between simulations using different input

assumptions are compared to evaluate the effect of parameter uncertainty on predictions of contaminant transport through the bedrock vadose zone. Based on the results for chloride transport discussed in Section 4.0 of this report, the maximum tailings saturated thickness was excluded from the sensitivity analysis assessing nonconservative solute transport. The input variables including ANP and partial pressure of carbon dioxide gas within the bedrock vadose zone were not included for conservative transport of chloride because these parameters would only affect the transport of nonconservative solutes. Because the number of potential liner defects was explicitly simulated in the bedrock vadose zone model, variability in this parameter was incorporated in the sensitivity analysis by varying the potential flux rates through the liner.

RESULTS

For the transport of conservative and nonconservative solutes, model-predicted chloride (conservative) and sulfate (nonconservative) concentrations at the bottom of the vadose zone (entering the perched aquifer) are presented. In contrast, uranium concentrations approximately equal to the minimum GWCL are presented at the vadose zone depth at which they were predicted to occur. Variations in bedrock vadose zone porewater pH and the depth at which complete calcite dissolution was predicted to occur are also presented. Sensitivity analysis results are compared to evaluate the effect of parameter uncertainty on predictions of contaminant transport through the bedrock vadose zone. Based on the results for conservative transport of chloride (i.e., limited transport distance) within the bedrock vadose zone beneath Cells 4A & 4B and Cell 1, the sensitivity analysis was only evaluated for Cells 2 & 3. For all HYDRUS-1D and HP1 simulations the water and mass balance errors did not exceed 1%. As a general rule-of-thumb, mass balance errors that do not exceed 3% are considered acceptable.

Chloride Concentrations. The model-predicted chloride concentrations at the bottom of the bedrock vadose zone beneath Cells 2 & 3 after 240 years of transport was summarized in Section 4.0 and Table 4-1 of this report. Chloride transport predicted with HP1 did not differ from simulations predicted with HYDRUS-1D.

The model-predicted chloride concentration at the bottom of the vadose zone beneath Cells 2 & 3 for the base case scenario after 240 years of transport is 0.0096 mg/L. The upper bound model-predicted chloride concentration at the bottom of the vadose zone is 18 mg/L, which is slightly greater than the minimum GWCL of 10 mg/L. However, considering the extremely low transport rates (0.5 mm/yr), mixing of vadose zone pore water with groundwater in the perched aquifer system would dilute this concentration below the minimum GWCL. The lower bound model-predicted chloride concentration at the bottom of the vadose zone is essentially zero (9.1×10^{-6} mg/L). Assuming all other variables are equal, the model-predicted chloride concentrations are least sensitive to the source term chemistry and most sensitive to the number of potential liner defects (which affects the potential liner flux rate), while the maximum tailing saturated thickness during operations has an intermediate effect (see Table 4-1, response variable statistic column).

Dissolution of Calcite and pH of Porewater. The bedrock vadose zone depth at which complete dissolution of calcite was predicted by the model to occur after 240 years of transport is summarized in Table M-2. The bedrock vadose zone depth for complete calcite dissolution varied between 0.6 and 2.0 meters; and assuming all other variables are equal, the results are least sensitive to the partial pressure of carbon dioxide gas and most sensitive to the mass of ANP within the bedrock followed closely by the number of potential liner defects (which affects the potential liner flux rate) (see Table M-2, response variable statistic column). For the base case scenario, complete dissolution of calcite was predicted to occur at 0.95 meters depth. Complete dissolution of calcite was correlated with the model-predicted pH of vadose zone porewater (see Figure M-1). Once complete consumption of calcite occurred within the shallow vadose zone for any given simulation, variations in subsurface pH of vadose zone porewater were correlated with equilibrium with HFO (~pH <3.3) followed by HAO (~pH < 5) (see Figure M-2). The precipitation of gypsum does not affect variations in porewater pH within the bedrock vadose zone.

Precipitation of Gypsum and Sulfate Concentrations. The model-predicted sulfate concentration at the bottom of the vadose zone beneath Cells 2 & 3 after 240 years of

transport was summarized in Section 4.0 and Table 4-2 of this report. Table 4-2 is reproduced here as Table M-3.

The model-predicted sulfate concentration at the bottom of the vadose zone beneath Cells 2 & 3 for the base case scenario after 240 years of transport is 0.014 mg/L. The upper bound model-predicted sulfate concentration at the bottom of the vadose zone was 45 mg/L, which is less than the minimum GWCL of 532 mg/L. The lower bound model-predicted sulfate concentration at the bottom of the vadose zone was essentially zero (1.0×10^{-5} mg/L). Assuming all other variables are equal, the model-predicted sulfate concentrations at the bottom of the bedrock vadose zone are least sensitive to the ANP of the bedrock vadose zone and most sensitive to the number of potential liner defects (which affects the potential liner flux rate), while the source term chemistry and partial pressure of carbon dioxide gas within the bedrock vadose zone have an intermediate effect (see Table M-3, response variable statistic column). The distribution of sulfate within the bedrock vadose zone is primarily controlled by the amount of gypsum that may precipitate from solution, while below this zone the diffusive transport of sulfate controls solute concentrations predicted to occur within the bedrock vadose zone (see Figure M-3).

Uranium Concentrations. The model-predicted bedrock vadose zone depth at which the uranium concentration approximately equals the minimum GWCL (0.0049 mg/L) after 240 years of transport beneath Cells 2 & 3 was summarized in Section 4.0 and Table 4-3 of this report. Table 4-3 is reproduced here as Table M-4.

The base case model-predicted depth at which uranium approximately equaled the minimum GWCL was 2.30 meters (7.5 feet) below the liner system; a minimum of 10.5 meters (34 feet) above the perched water table. The upper bound model-predicted depth at which uranium approximately equaled the minimum GWCL was 3.9 meters. The lower bound model-predicted depth at which uranium approximately equaled the minimum GWCL was 1.3 meters. None of the sensitivity runs predicted that uranium, or other trace elements (arsenic, cadmium, copper, nickel, vanadium, and zinc), would reach the perched aquifer in the 240 year period simulated. Assuming all other variables are

equal, the model-predicted uranium transport depths are least sensitive to the source term chemistry and most sensitive to the number of potential liner defects (which affects the potential liner flux rate), while the ANP and partial pressure of carbon dioxide gas within the bedrock vadose zone have an intermediate effect (see Table M-4, response variable statistic column). Profile concentrations through time of dissolved uranium within the bedrock vadose zone are plotted in Figure M-4 for the base case scenario. The distribution of uranium is primarily controlled by sorption onto the surfaces of HFO within the bedrock vadose zone, and to a lesser extent the pH of the vadose zone porewater.

Concentrations of Other Trace Elements. The sorption of uranium was competitive because additional trace elements were modeled. Solutes included in the model were based on their elevated concentrations in the tailings pore water as compared to the GWCLs. Transport of the following trace elements was modeled: arsenic, cadmium, copper, nickel, vanadium, and zinc. Similar to uranium, these solutes were predicted to migrate a limited distance below the liner (e.g., a few meters) in the 240 year period simulated.

CONCLUSIONS

Results of the sensitivity analysis for modeling reactive transport of nonconservative solutes demonstrates that concentrations of sulfate, uranium, and other trace elements predicted by the model to potentially enter the perched aquifer will not exceed the minimum GWCL's. Model predictions are based on assumptions that are primarily considered to be conservative.

The transport of uranium and other trace elements are predicted to migrate a limited distance (a few meters) beneath the liners. The distribution of uranium, and other trace elements, is primarily controlled by sorption onto the surfaces of HFO within the bedrock vadose zone, and to a lesser extent the pH of the vadose zone porewater. Sufficient calcite is present within the bedrock vadose zone to limit the potential transport of acidic tailings solutions in vadose zone porewater beneath the tailings cells.

The distribution of sulfate is controlled by the precipitation of gypsum within the bedrock vadose zone. A significant amount of gypsum, amorphous aluminum hydroxide, and amorphous iron hydroxide was predicted to precipitate within the shallow bedrock vadose zone, which would be expected to modify liquid phase saturation and effective porosities, resulting in decreased water flux rates. It is likely that a layer of mineral precipitates would act to perch water that could potentially migrate through the liners, further reducing contaminant transport mobilities and transport distances.

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TABLE M-1. SOURCE TERM CONCENTRATIONS OF TAILINGS SLIMES DRAINS USED AS INPUT TO THE CONTAMINANT TRANSPORT MODELS. ALL UNITS ARE IN MG/L EXCEPT FOR PH.			
Analyte	Lower Bound (Mean Minus 0.5 Standard Deviation)	Base Case (Arithmetic Mean)	Upper Bound (Maximum)
MAJOR IONS	-	-	-
Calcium	461	500	572
Chloride	2,894	3,221	3,860
Magnesium	3,242	3,605	4,100
Potassium	456	544	689
Sodium	3,475	3,922	4,600
Sulfate	56,074	62,847	74,000
PHYSICAL PROPERTIES	-	-	-
pH	3.2	3.2	3.2
Dissolved Oxygen	2.0	2.0	2.0
METALS - DISSOLVED	-	-	-
Aluminum	3,000	3,000	3,000
Arsenic	9.7	15.2	26.9
Cadmium	3.41	4.51	5.84
Cobalt	28.8	36.0	46.5
Copper	137	154	185
Iron	2,724	2,933	3,310
Nickel	64.6	91	123
Uranium	20.8	24.3	29.9
Vanadium	362	419	536
Zinc	371	538	767

Notes: A description of the source term concentrations are described in Appendix K. Aluminum was included and used to obtain charge balance. The partial pressure of oxygen was fixed in the model assuming a dissolved oxygen concentration in vadose zone porewater equal to 2 mg/L.

TABLE M-2. MODEL-PREDICTED BEDROCK VADOSE ZONE DEPTH AT WHICH ALL CALCITE (ANP) IS CONSUMED AFTER 240 YEARS OF TRANSPORT.

Model Run	Solute Source Term Concentration	Partial Pressure of Carbon Dioxide Gas	Number of Potential Liner Defects	Mass of ANP	Response Variable Evaluated	Response Variable Statistic
					Bedrock Vadose Zone Depth (meters)	Change in Depth (meters)
1	Base Case	Base Case	Base Case	Base Case	0.95	0
2	Upper Bound	Base Case	Base Case	Base Case	1.10	0.15
3	Lower Bound	Base Case	Base Case	Base Case	0.85	-0.10
4	Base Case	Upper Bound	Base Case	Base Case	0.95	0
5	Base Case	Lower Bound	Base Case	Base Case	0.95	0
6	Base Case	Base Case	Upper Bound	Base Case	1.95	1.00
7	Base Case	Base Case	Lower Bound	Base Case	0.40	-0.55
8	Base Case	Base Case	Base Case	Upper Bound	0.60	-0.35
9	Base Case	Base Case	Base Case	Lower Bound	2.00	1.05

Note: A description of parameter values used as input to the sensitivity analysis is summarized in the text of this appendix.

TABLE M-3. MODEL-PREDICTED SULFATE CONCENTRATIONS AT THE BOTTOM OF THE BEDROCK VADOSE ZONE AFTER 240 YEARS OF TRANSPORT.

Model Run	Solute Source Term Concentration	Partial Pressure of Carbon Dioxide Gas	Number of Potential Liner Defects	Mass of ANP	Response Variable Evaluated	Response Variable Statistic
					Sulfate Concentration (mg/L)	Change in Concentration (mg/L)
1	Base Case	Base Case	Base Case	Base Case	0.014	0
2	Upper Bound	Base Case	Base Case	Base Case	0.017	0.0030
3	Lower Bound	Base Case	Base Case	Base Case	0.012	-0.0020
4	Base Case	Upper Bound	Base Case	Base Case	0.034	0.020
5	Base Case	Lower Bound	Base Case	Base Case	0.0085	-0.0055
6	Base Case	Base Case	Upper Bound	Base Case	45	45
7	Base Case	Base Case	Lower Bound	Base Case	0.000010	-0.014
8	Base Case	Base Case	Base Case	Upper Bound	0.014	0
9	Base Case	Base Case	Base Case	Lower Bound	0.015	0.0010

Note: A description of parameter values used as input to the sensitivity analysis is summarized in the text of this appendix.

TABLE M-4. MODEL-PREDICTED BEDROCK VADOSE ZONE DEPTH AT WHICH URANIUM CONCENTRATIONS APPROXIMATELY EQUALS THE MINIMUM GWCL AFTER 240 YEARS OF TRANSPORT.

Model Run	Solute Source Term Concentration	Partial Pressure of Carbon Dioxide Gas	Number of Potential Liner Defects	Mass of ANP	Response Variable Evaluated	Response Variable Statistic
					Bedrock Vadose Zone Depth (meters)	Change in Depth (meters)
1	Base Case	Base Case	Base Case	Base Case	2.30	0
2	Upper Bound	Base Case	Base Case	Base Case	2.50	0.20
3	Lower Bound	Base Case	Base Case	Base Case	2.15	-0.15
4	Base Case	Upper Bound	Base Case	Base Case	3.90	1.60
5	Base Case	Lower Bound	Base Case	Base Case	2.15	-0.15
6	Base Case	Base Case	Upper Bound	Base Case	3.70	1.40
7	Base Case	Base Case	Lower Bound	Base Case	1.30	-1.00
8	Base Case	Base Case	Base Case	Upper Bound	2.20	-0.10
9	Base Case	Base Case	Base Case	Lower Bound	1.55	-0.75

Note: A description of parameter values used as input to the sensitivity analysis is summarized in the text of this appendix.
 GWCL = groundwater compliance limit.

Figure M-1. Profile plots of model-predicted pH of vadose zone porewater through time between 0 and 2.5 meters depth for the base case scenario (upper figure) and scenario with the highest depth of complete calcite consumption (lower figure), which corresponded to the simulation that assumed the lower bound mass of calcite.

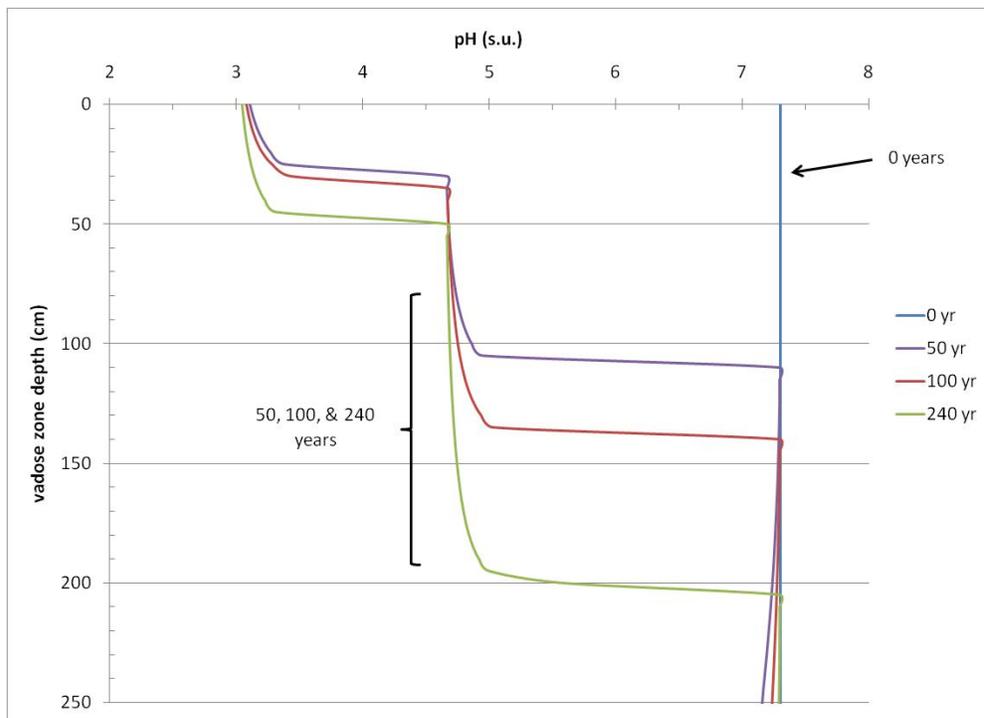
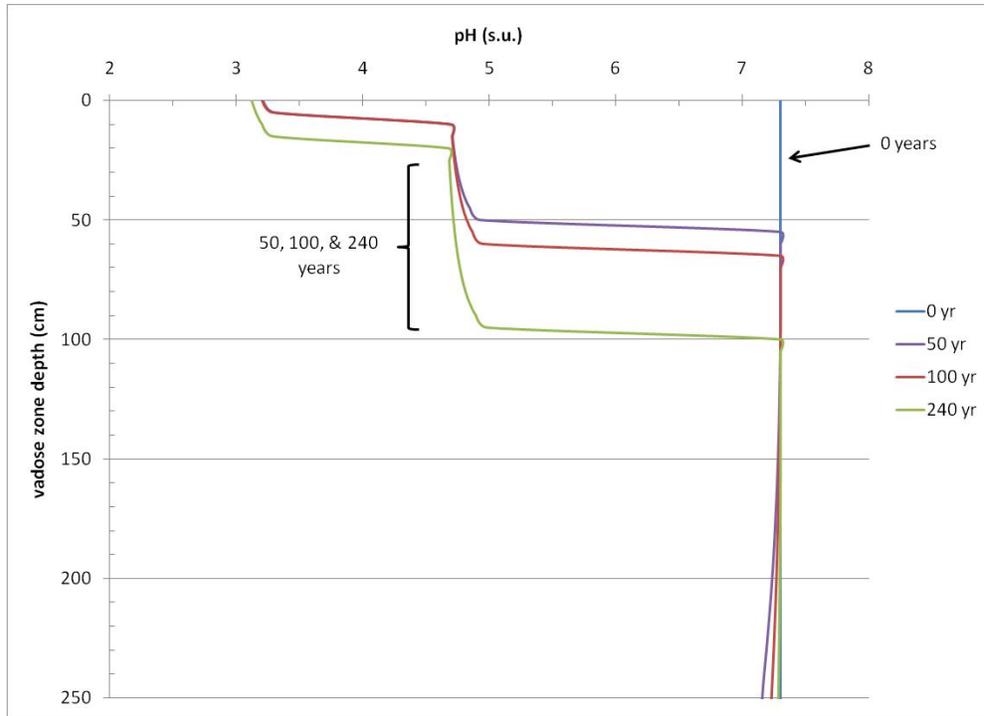


Figure M-2. Profile plots of the model-predicted amount of mineral phases dissolved (calcite) and precipitated (amorphous hydrous ferric oxide [HFO] and amorphous hydrous aluminum oxide [HAO]) within the vadose zone porewater after 240 years of transport between 0 and 2.5 meters depth for the base case scenario (upper figure) and scenario with the highest depth of complete calcite consumption (lower figure), which corresponded to the simulation that assumed the lower bound mass of calcite.

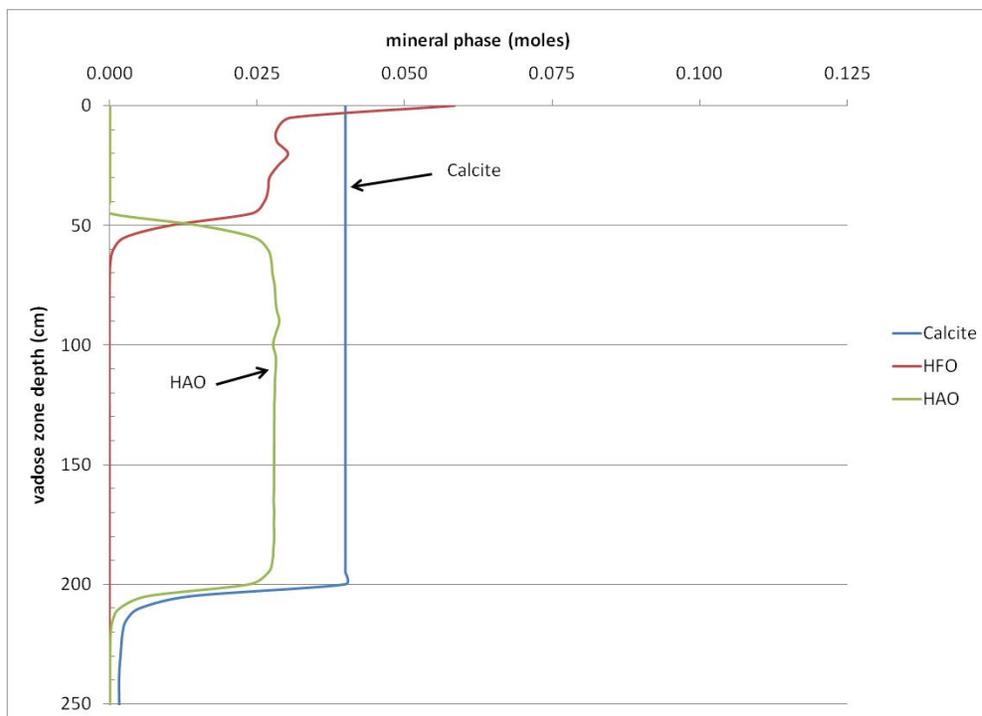
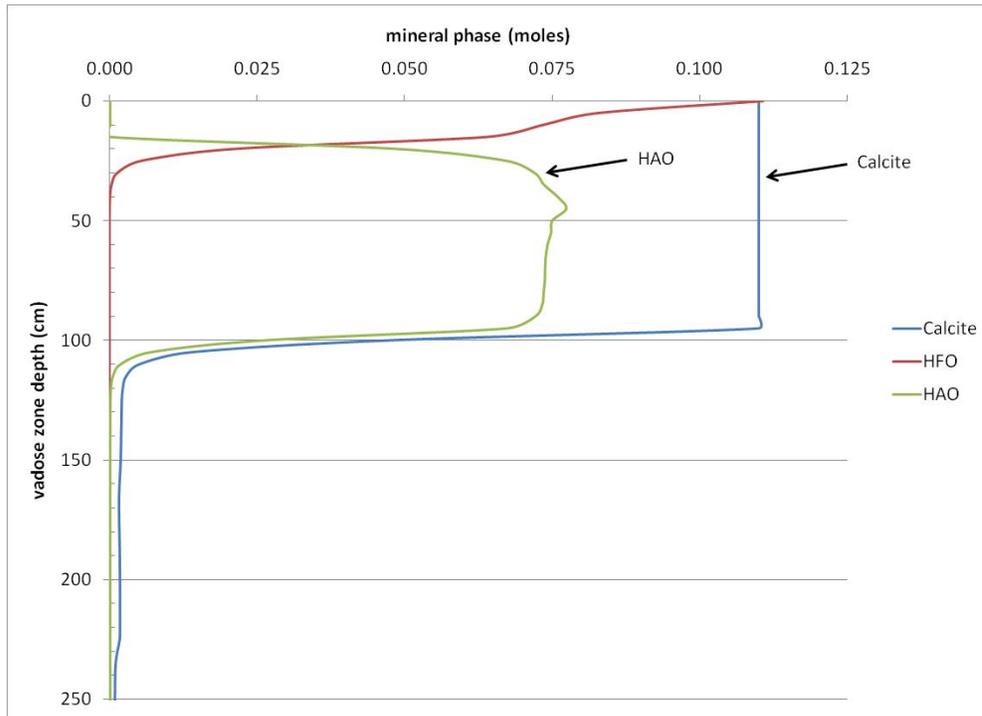


Figure M-3. Profile plots of the model-predicted concentration of sulfate in vadose zone porewater (upper figure) and the amount of gypsum precipitated (lower figure) within the vadose zone porewater after 240 years of transport between 0 and 8.0 meters depth for the base case scenario.

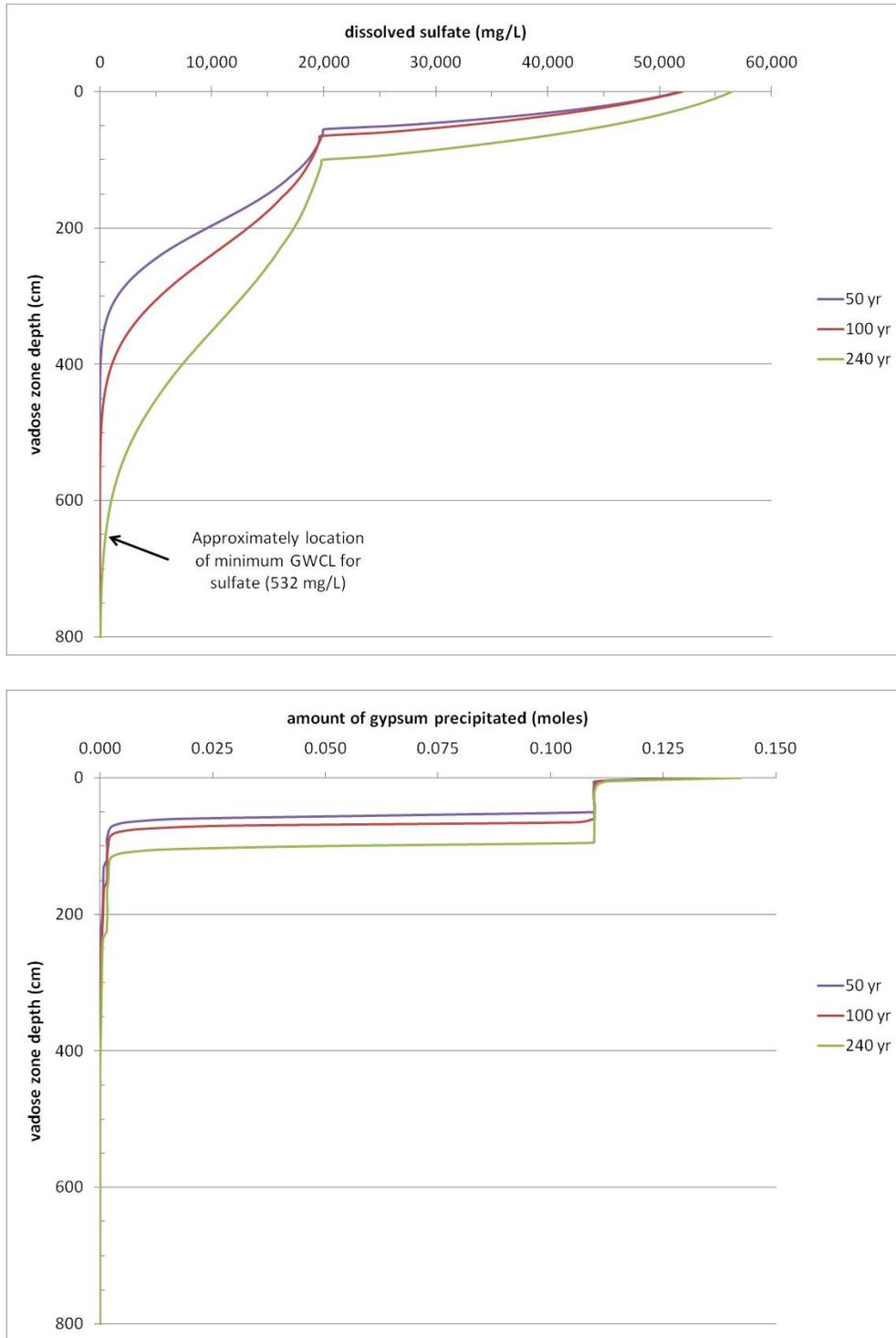
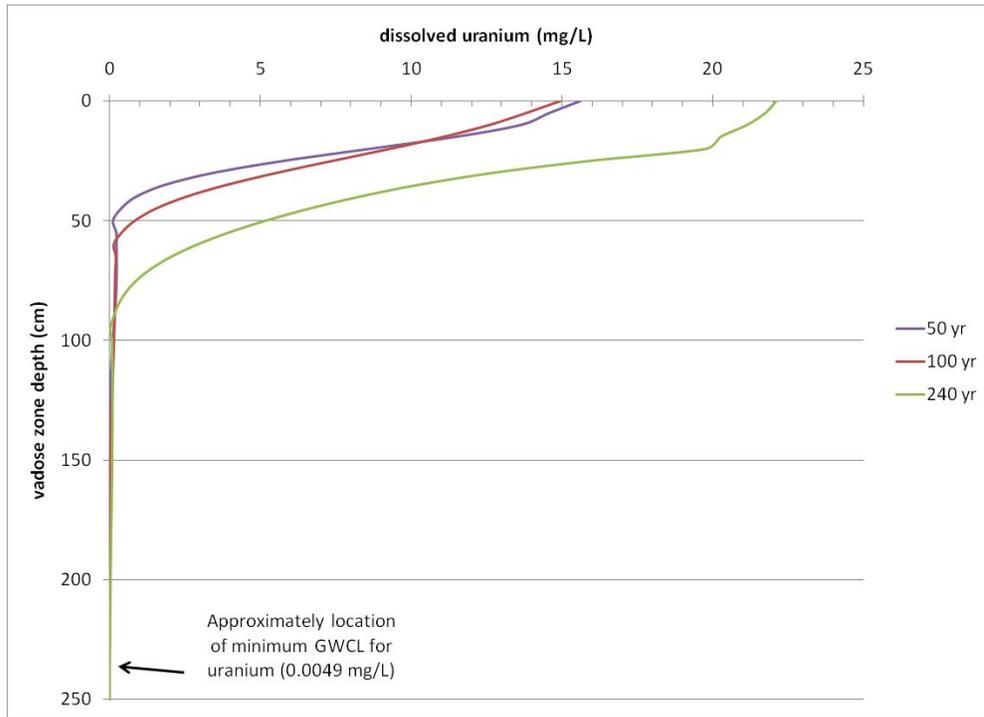


Figure M-4. Profile plots of the model-predicted concentration of uranium in vadose zone porewater through time between 0 and 2.5 meters depth for the base case scenario.



APPENDIX N

**PREDICTIVE SIMULATION INPUT AND OUTPUT FILES
IN ELECTRONIC FORMAT ONLY (ON CD)**

Table describing tailings cell cover infiltration model and bedrock vadose zone contaminant transport model input files submitted with revised Infiltration and Contaminant Transport Modeling (ICTM) Report, March 2010.

HYDRUS-1D & HP1 Code Version	Model	Folder	Root File Name (all files have a ".h1d" extension)	Brief Description
4.13	Cover system	Cover/Design	Model_1	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, anticipated root density/distribution, and 40% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Design	Model_2	Infiltration model of cover system for ET cover with compacted clay layer. Anticipated climate record, anticipated root density/distribution, and 40% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Design	Model_3	Infiltration model of cover system for ET cover with gravel layer. Anticipated climate record, anticipated root density/distribution, and 40% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Design	Model_4	Infiltration model of cover system for rock-armor cover. Anticipated climate record. Only evaporation simulated. Transpiration not simulated. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_AC-P_AC-root_30%	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, anticipated root depth/distribution, and 30% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_AC-P_AC-root_30%_WiltP	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, anticipated root depth/distribution, and 30% vegetative cover with decreased wilting point and HcritA. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_AC-P_AC-root_40%_WiltP	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, anticipated root depth/distribution, and 40% vegetative cover with decreased wilting point and HcritA. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_AC-P_RP-root_30%	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, reduced performance root depth/distribution, and 30% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_AC-P_RP-root_40%	Infiltration model of cover system for monolithic ET cover. Anticipated climate record, reduced performance root depth/distribution, and 40% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_INC-P_AC-root_40%	Infiltration model of cover system for monolithic ET cover. Increased precipitation, anticipated root depth/distribution, and 40% vegetative cover. Total time 114 years.
4.13	Cover system	Cover/Veg&Precip	Model_1_INC-P_AC-root_40%_WiltP	Infiltration model of cover system for monolithic ET cover. Increased precipitation, anticipated root depth/distribution, and 40% vegetative cover with decreased wilting point and HcritA. Total time 114 years.
4.13	Cover system	Cover/StormIntensity/ARI-100yr	Ponding_Daily_ARI-100yr	Infiltration model of cover system for monolithic ET cover. Daily P and PET input for 10 days. Anticipated root depth/distribution and 40% vegetative cover. One 100-yr ARI 1-hr long storm event simulated.
4.13	Cover system	Cover/StormIntensity/ARI-100yr	Ponding_Daily_ARI-100yr_30d	Infiltration model of cover system for monolithic ET cover. Daily P and PET input for 30 days. Anticipated root depth/distribution and 40% vegetative cover. One 100-yr ARI 1-hr long storm event simulated.
4.13	Cover system	Cover/StormIntensity/ARI-100yr	Ponding_Hourly_ARI-100yr	Infiltration model of cover system for monolithic ET cover. Hourly P and PET input for 10 days. Anticipated root depth/distribution and 40% vegetative cover. One 100-yr ARI 1-hr long storm event simulated.
4.13	Cover system	Cover/StormIntensity/Monsoon	Ponding_Daily_Sum1987	Infiltration model of cover system for monolithic ET cover. Daily P and PET input for 1987 monsoon season (92 days). Anticipated root depth/distribution and 40% vegetative cover.
4.13	Cover system	Cover/StormIntensity/Monsoon	Ponding_Hourly_Sum1987	Infiltration model of cover system for monolithic ET cover. Hourly P and PET input for 1987 monsoon season (92 days). Anticipated root depth/distribution and 40% vegetative cover.
4.13	Vadose Zone	Cell_1/Transport/Base Case	VZ-200yr_BC-Cl_No-liner_BC-Cover	Cell 1 transport model for chloride movement through bedrock vadose zone. Upper boundary based on base case long-term average flux through monolithic ET cover and base case chloride concentration.
4.13	Vadose Zone	Cells_4A&4B/Transport/Base Case	VZ-212yr_BC-Cl	Cells 4A & 4B transport model for chloride movement through bedrock vadose zone. Upper boundary based on base case potential flux rate through liner and base case chloride concentration.
4.13	Vadose Zone	Cells_2&3/Transport/Base Case	VZ-240yr_BC-Cl_5.82m_BC-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Base case chloride concentration, base case number of potential liner defects, and base case tailings saturated thickness.
4.13	Vadose Zone	Cells_2&3/Transport/Cl_sens	VZ-240yr_LB-Cl_5.82m_BC-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Lower bound chloride concentration, base case number of potential liner defects, and base case tailings saturated thickness.

4.13	Vadose Zone	Cells_2&3/Transport/Cl_sens	VZ-240yr_UB-Cl_5.82m_BC-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Upper bound chloride concentration, base case number of potential liner defects, and base case tailings saturated thickness.
4.13	Vadose Zone	Cells_2&3/Transport/LinerDefect_sens	VZ-240yr_BC-Cl_5.82m_LB-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Base case chloride concentration, lower bound number of potential liner defects, and base case tailings saturated thickness.
4.13	Vadose Zone	Cells_2&3/Transport/LinerDefect_sens	VZ-240yr_BC-Cl_5.82m_UB-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Base case chloride concentration, upper bound number of potential liner defects, and base case tailings saturated thickness.
4.13	Vadose Zone	Cells_2&3/Transport/LinerHead_sens	VZ-240yr_BC-Cl_3.41m_BC-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Base case chloride concentration, base case number of potential liner defects, and lower bound tailings saturated thickness.
4.13	Vadose Zone	Cells_2&3/Transport/LinerDefect_sens	VZ-240yr_BC-Cl_8.23m_BC-def	Cells 2 & 3 transport model for chloride movement through bedrock vadose zone. Base case chloride concentration, base case number of potential liner defects, and upper bound tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/BaseCase	VZ-240yr_BC-sol_C-2.0_BC-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, base case pressure CO2-gas, base case ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/ANP_sens	VZ-240yr_BC-sol_C-2.0_LB-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, base case pressure CO2-gas, lower bound ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/ANP_sens	VZ-240yr_BC-sol_C-2.0_UB-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, base case pressure CO2-gas, upper bound ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/CO2_sens	VZ-240yr_BC-sol_C-3.0_BC-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, lower bound pressure CO2-gas, base case ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/CO2_sens	VZ-240yr_BC-sol_C-1.0_BC-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, upper bound pressure CO2-gas, base case ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/Conc_sens	VZ-240yr_LB-sol_C-2.0_BC-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Lower bound solute concentrations, base case pressure CO2-gas, base case ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/Conc_sens	VZ-240yr_UB-sol_C-2.0_BC-ANP_5.82m_BC-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Upper bound solute concentrations, base case pressure CO2-gas, base case ANP, base case number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/LinerDefect_sens	VZ-240yr_BC-sol_C-2.0_BC-ANP_5.82m_LB-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, base case pressure CO2-gas, base case ANP, lower bound number of potential liner defects, and base case tailings saturated thickness.
4.13 (2.1.002 HP1)	Vadose Zone	Cells_2&3/HP1/LinerDefect_sens	VZ-240yr_BC-sol_C-2.0_BC-ANP_5.82m_UB-def	Cells 2 & 3 reactive transport model for solute transport through bedrock vadose zone. Base case solute concentrations, base case pressure CO2-gas, base case ANP, upper bound number of potential liner defects, and base case tailings saturated thickness.
AC = anticipated case				
ARI = average recurrence interval				
BC = base case				
CO2 = carbon dioxide				
ET = evapotranspiration				
LB = lower bound				
P = precipitation				
PET = potential evapotranspiration				
RP = reduced performance				
UB = upper bound				