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Grand Junction Office
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JUN 17 2002

Moab Ground Water Subcommittee:
H. Dawson, EPA
F. Gardner, Kayenta Consulting Group, Inc.
B. Hedden, Grand Canyon Trust
R. Irwin, National Park Service
D. Kimball, National Park Service
L. Morton, UDEQ
P. Mushovic, EPA
P. Penoyer, National Park Service
T. Wright, Shepherd Miller
B. Waddel, U.S. Fish & Wildlife Service
D. Solomon, University of Utah

Subject: Transmittal of Documents Related to the Moab Project, Moab, Utah

Enclosed are the following final draft Moab Project documents for your review and comment:

> *Ground Water and Tailings Pile Characterization Activities to Support the Plan for Remediation—Work Plan*

In order to acquire data needed for the revised Plan for Remediation, installation of the piezometers will commence during the week of June 10, 2002. Therefore, please provide any comments that you have to Don Metzler via telephone at (970) 248-7612 or email at Don.Metzler@gjo.doe.gov.

> *Sensitivity Analysis of Ground Water Flow and Transport Models for the Moab Project—Letter Report*

> *Characterization of Brine Zones at the Moab Project Site (Phase 1)*

Please have any comments ready for discussion at the next Atlas Stakeholders Ground Water Subcommittee meeting presently scheduled for July 12, 2002.

Sincerely,

Audrey Berry

Audrey Berry
Public Affairs Specialist

Enclosures

cc w/enclosures:
M. Fliegel, NRC
Project File MOA 4.3 (T. Smith)

cc w/o enclosures:
J Berwick, DOE-GJO
D Metzler, DOE-GJO
T Plessinger, DOE-GJO
J Elmer, MACTEC-ERS

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GJO-2002-337-TAR
GJO-MOA 1.9

Moab Project

Groundwater and Tailings Pile Characterization Activities To Support the Plan for Remediation

Work Plan

June 2002

U.S. Department of Energy

GRAND JUNCTION OFFICE

Work Performed Under DOE Contract No. DE-AC13-96GJ87335 for the U.S. Department of Energy
Approved for public release; distribution is unlimited.

GJO-2002-337-TAR
GJO-MOA 1.9

Moab Project

Groundwater and Tailings Pile Characterization Activities to Support the Plan for Remediation

Work Plan

June 2002

Prepared for
U.S. Department of Energy
Grand Junction Office

Work Performed Under DOE Contract Number DE-AC13-96GJ87335
Task Order Number MAC02-16

Contents

Figures

End of current text

Acronyms

BLM	U.S. Bureau of Land Management
DOE	U.S. Department of Energy
EA	environmental assessment
EIS	environmental impact statement
ECL	environmental checklist
ft	feet
PFR	Plan for Remediation
RRM	residual radioactive material
SHPO	Utah State Historic Preservation Office
SOW	statement of work
TDS	total dissolved solids
WRR	work readiness review

End of current text

1.0 Introduction

The U.S. Department of Energy (DOE) is currently in the process of preparing a revision to the draft Plan for Remediation (PFR) of the tailings and groundwater contamination at the Moab site. The subsurface hydrogeology and geochemistry warrant more study in the vicinity of the Moab site and tailings area in order to bound uncertainties in refining the conceptual site model. The draft PFR identified additional characterization needs ("data gaps") required to reduce uncertainties in the targeted remediation alternatives. A sensitivity analysis (DOE 2002) of the groundwater flow and transport model used to develop the groundwater remediation strategy suggests that more information regarding the "water budget" is required to support the site conceptual model before comparative differences in the effectiveness and time frames for the cleanup alternatives can be evaluated. In addition, more information is required to better understand potential contamination in the subpile sediments so that more refined cost estimates for surface remediation can be developed and to evaluate the impacts of a potential continuing source of groundwater contamination.

DOE is planning additional site characterization to collect information to reduce uncertainties in the PFR. A description of the data collection objectives for characterizing the water budget and a potential continuing source beneath the pile is described below. Proposed monitor wells and sample locations are shown on Figures 1 and 2.

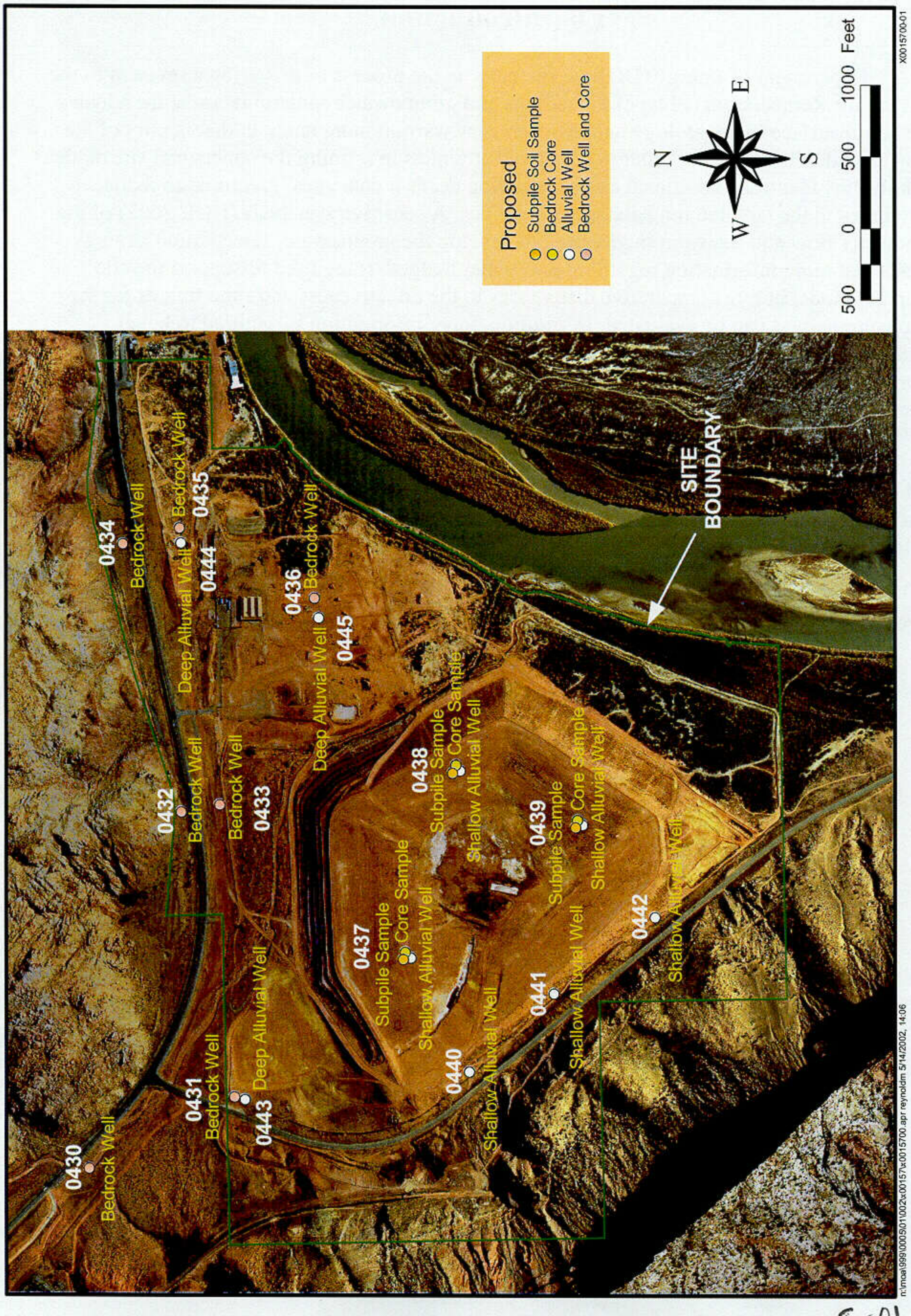

Figure 1. Proposed Sample and Well Locations

C-01

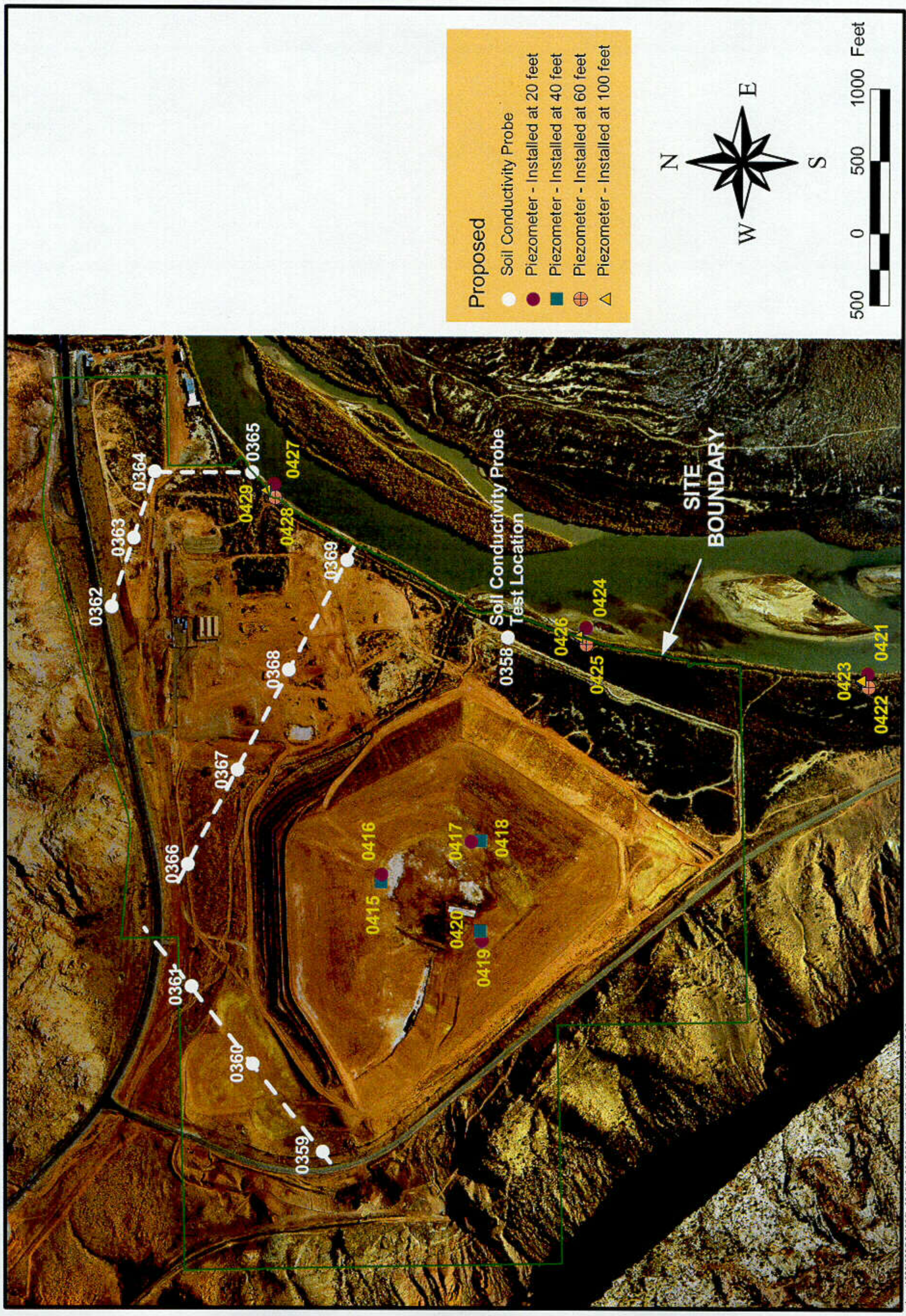

Figure 2. Proposed Piezometer Installations and Soil Conductivity Measurement Location

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2.0 Water Budget Characterization

2.1 Background

The most current conceptual model for the site assumes a significant amount of the total groundwater recharge to the alluvial system originates as upward flow from the Glen Canyon bedrock formation (SMI 2001). However, examination of the very limited amount of site characterization data that is currently available suggests otherwise. For example, two bedrock borings (TH–27 and AMM–1) located at the northwest and northeast corners of the site boundary, respectively, encountered Moenkopi Formation which is an effective aquitard. In another example, apparent downward hydraulic gradients are observed at the SMI–PW–03 location where nested alluvial wells are established near the center of the site where most of the upward flow from the Glen Canyon is postulated.

Specific conductance measurements from water samples collected from the bottom of a deep alluvial well installed near the center of the site (SMI–PW–03) suggests the presence of an interface between fresh water and an underlying brine unit. The presence of a brine unit would preclude upward flow of fresh water from the bedrock formation. DOE wants to determine where the fresh water at the site originates from and estimate the flux.

Another reason for characterizing the fresh water and brine interface is because it may be possible that manipulating groundwater gradients by either a passive remediation (i.e. phyreatophytes) or by an active pumping well field may induce upward flow of brine from the lower hydrostratigraphic unit, thus potentially adversely affecting the upper fresh water zone. Furthermore, the presence of even moderate amounts of brine in the upper fresh water zone could classify the groundwater as limited use and would qualify the groundwater for supplemental standards based on concentrations of total dissolved solids (TDS) in excess of 10,000 milligrams per liter [40 CFR 192.11(e)(1)].

Limited characterization data also exists for other boundaries at the site where lateral recharge to the alluvial groundwater may be occurring such as along Moab Wash and the contacts between the alluvium and bedrock in subcrop.

2.2 Scope of Work

The primary data sets to characterize the water budget consists of obtaining the following information:

- Core samples to identify the geologic bedrock formation sub cropping at the site (430-439).
- Monitor wells completed in the alluvium and bedrock formation to evaluated vertical flow gradients at the site (431 and 433, 436 and 445, 435 and 444), to better estimate lateral recharge to the alluvium near the northern (432 and 433, 434 and 435) and western (440-442) boundaries of the site, and to define the elevation and saturated thickness of the alluvial water beneath the tailings pile (437, 438, and 439).
- Piezometers installed at various depths along the river to evaluate vertical flow gradients and to determine the hydrologic interactions between the river and the alluvial aquifer (421-429).

- Electrical soil conductivity logs collected by direct-push methods to map the vertical and horizontal extent of the brine zone (358-369).

A casing-advanced drilling method (Sonic) will be used to obtain the core samples and to drill the boreholes for the monitor well installations. The drilling statement of work (SOW) provided in Appendix A presents the details. The Sonic method used to drill through the tailings pile consists of setting a casing at the base of the tailings and then applying a bentonite seal at the contact or filling the inner casing with grout before advancing the borehole below the tailings layer. This method will ensure that downward leakage of tailings pore fluids and materials are prevented during and after the drilling operation.

A direct-push method will be used to collect electrical soil conductivity measurements. Auger drilling will be used to install the piezometers in the alluvial sediments along the river. The SOW for the piezometer installations and soil conductivity measurements is provided in Appendix B.

Standard operating procedures for collecting samples and performing field tests for these activities are listed in Appendix C.

3.0 Source Term Characterization

3.1 Background

Groundwater beneath the tailings pile has been limited to a single sampling event at 3 locations. Analytical results for some constituents at these temporary locations suggest that minimal groundwater contamination is present in the alluvial aquifer beneath the pile and that the relative concentrations for the more mobile constituents are much lower than groundwater contamination near the river. This suggests that the vertical and horizontal extent of groundwater contamination beneath the Moab pile may not be adequately characterized. Uncertainties in the extent and nature of contamination could lead to underestimating the volume of groundwater that may require cleanup, the effectiveness of the treatment technology selected, and the time period required for natural flushing.

Approximately 30 to 40 feet (ft) of unsaturated subpile sediments may be present beneath a hardened, low permeability base underlying the tailings (borings AR–4D, –4, and –7) (SRK 2000). However, the extent of any potential subpile contamination has not been evaluated. Contamination in the subpile sediments may limit the effectiveness of either an active remediation or a natural flushing strategy, since the contamination would act as a continuing source. At other Uranium Mill Tailings Remedial Action Project Title I sites DOE's experience suggests that natural flushing is more likely to be successful in a shorter period of time if the continuing source is removed. Thus, the actual groundwater cleanup time assumed for the cap-in-place option in this plan would be underestimated. Similarly, the assumed amount of subpile soils excavated (2 ft) for the off-site disposal option would be underestimated.

3.2 Scope of Work

The primary data sets to characterize a potential subpile source term consists of obtaining the following information:

- Sediment samples collected at multiple depths from the hardened base layer (silt?), the unsaturated zone, and from the upper saturated zone beneath the tailings pile (437-439). Analyze sediment samples for leachability, distribution coefficient (K_d) determinations, and/or total digestions and water samples for constituents of concern.
- Piezometers installed at different depths in saturated portions of the tailings to evaluate vertical flow gradients (415-420).

A casing-advanced drilling method (Sonic) will be used to obtain samples from and beneath the tailings and to drill the boreholes for the monitor well installations. The drilling statement of work (SOW) provided in Appendix A presents the details. The Sonic method used to drill through the tailings pile consists of setting a casing at the base of the tailings and then applying a bentonite seal at the contact or filling the inner casing with grout before advancing the borehole below the tailings layer. This method will ensure that downward leakage of tailings pore fluids and materials are prevented during and after the drilling operation.

A direct-push method will be used to install the piezometers in the tailings. The SOW for the piezometer installations is provided in Appendix B.

Standard operating procedures for collecting samples and performing field tests for these activities are listed in Appendix C.

4.0 Health and Safety

The site-specific Health and Safety Plan (DOE 2001) has been prepared for the Moab Project in accordance with the requirements of 29 CFR 1910.120. All fieldwork will be performed according to the site-specific health and safety requirements developed for this task (DOE 2001) and the MACTEC–ERS operational health and safety regulations as outlined in the *Drilling Health and Safety Requirements*, MAC–2012, Revision 3, October 2000.

End of current text

5.0 Regulatory Compliance

The following regulatory drivers were determined to be applicable to the scope of work addressed in this work plan.

National Environmental Policy Act—With the exception of one off-site well (430) located on BLM lands, the proposed activities are addressed in the Environmental Checklist (ECL) (GJP 01–02) recommending categorical exclusion, which was approved by the DOE on November 8, 2001. Location 430, north of the site, (T25S, R21E, Section 28, NW4 NE4) is being assessed for impacts under a U.S. Bureau of Land Management (BLM) Environmental Assessment (EA). DOE will then consider adopting the BLM EA as sufficient for meeting DOE National Environmental Policy Act regulations. Work will not commence at location 430 until DOE has determined the adequacy and the BLM NEPA documentation.

National Historic Preservation Act—There is no evidence, including the EIS, that investigations and surveys were ever conducted within the site boundaries. At the time the site was disturbed (1950s) the land was in private ownership and not subject to the National Historic Preservation Act, which was enacted at a later date. The majority of the site surface is sufficiently disturbed, so further investigation at this time appears unnecessary. In addition, a letter dated September 19, 1994 from the Utah Division of State History (Appendix H, EIS), which concurs with proposed on-site disturbances and reclamation. However, a literature search will be conducted for the entire site to determine if any areas within the site boundary have ever been surveyed or investigated. Results will be confirmed by the archeological subcontractor with the Utah State Historic Preservation Office (SHPO).

For activities outside the site boundary (e.g. well location 430) an archeologist licensed in the State of Utah was subcontracted to investigate the need for further archeological clearances. Results will be reported to the appropriate land management agency (e.g. BLM) and clearances received from the SHPO. Mitigation, including avoidance if necessary, will be complied with.

Threatened/Endangered Species—DOE has conducted informal consultation routinely with the U.S. Fish and Wildlife Service and was authorized to proceed with work in areas that would not adversely affect potentially suitable southwest willow flycatcher habitat. The proposed activities will not adversely affect Threatened and Endangered species or their habitat.

State of Utah Well Installation Regulations—Permanent piezometers installed in the tailings pile and electrical conductivity probing using a direct-push method will not require notice or permitting with the State of Utah. Any temporary or permanent well less than 30 ft will not require notice or permitting with the State of Utah. Monitor wells installed greater than 30-ft in depth will require notice and permitting with the State of Utah. Environmental Services has applied for the permits.

Waste Management—Drill cuttings and well development water within the site boundary can be disbursed around the drill locations. It is assumed that soils within the site boundary are contaminated and will be remediated at a later date. Soils outside the site boundary could be contaminated; therefore, cuttings and development waters in suspect areas will be managed in accordance with the Management Plan for Field-Generated Investigation Derived Waste (DOE 2000). If, for any reason, locations outside the millsite boundary are suspected of being contaminated and special circumstances exist that the management plan does not address the project manager will contact Environmental Services to determine site-specific management requirements. If cuttings, development waters, or other waste requires management (i.e. drumming, transportation, storage, disposal), including relocation of drummed residual radioactive material (RRM) to the millsite, Environmental Services will be contacted to coordinate storage and disposal with the project manager.

Land Ownership and Relations—Some of the proposed activities are located on private land to the south of the site. Access will be obtained and the landowner notified of potential environmental concerns, including archeological and threatened or endangered species.

6.0 Logistics and Schedule

A work readiness review (WRR) will be conducted by MACTEC–ERS at the Grand Junction Office before the team mobilizes for field sampling and mapping activities. The purpose of the WRR is to ensure that all personnel, facilities, systems, and processes are ready before the start of the fieldwork and to minimize the possibility of delays and problems due to incomplete planning and preparations.

Examples of specific topics that will be addressed include health and safety, training requirements, personnel resources, site access, equipment and supplies, and work tasks. A checklist specific to the field task will define the WRR scope.

A general schedule for each activity is summarized below.

Date	Activity
June 17–29, 2002	Direct-push piezometer installations and electrical conductivity measurements.
July 8 through August 16, 2002	Bedrock coring, monitor well installations, subpile soil sampling.
August 5 through September 20, 2002	Develop and sample new monitor wells. Physical survey of well locations and elevations. Laboratory analysis of subpile soil and groundwater samples.
August 9 through November 8, 2002	Input to PFR (analyze data, prepare maps, calculation sets, update site conceptual model, revise and edit text).

End of current text

7.0 Deliverables

The primary deliverable is input to the revised PFR. To support the revision several preliminary data/calculation sets will be developed, such as (1) well completion logs, (2) piezometer installations, (3) electrical conductivity measurements, (4) packer tests, (5) subpile soil analysis, and (6) an updated site conceptual model. After the revised PFR is submitted on November 8, 2002 a characterization report will be prepared that synthesizes all the field activities to support the development of a final compliance strategy.

End of current text

8.0 References

Shepard Miller, Inc. (SMI), 2001. *Site Hydrogeologic and Geochemical Characterization and Alternatives Assessment for the Moab Mill Tailings Site, Moab, Utah*, April.

SRK, 2000. *Dewatering Options for Placement of Cover—Moab Tailings Impoundment*, prepared for the Moab Mill Reclamation Trust c/o PricewaterhouseCoopers LLP, Houston, Texas, June.

U.S. Department of Energy (DOE), 2001. *Moab Health and Safety Plan*, GJO–MOA1.3, prepared for the U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado.

———, 2000. *Drilling Health and Safety Requirements*, MAC–2012, Revision, prepared for the U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado.

———, 2002. *Sensitivity Analysis of Groundwater Flow and Transport Models for the Moab Project Site–Letter Report*, MAC–MOA 19.1.2, prepared for the U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado, May.

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Appendix A

Drilling Statement of Work
Moab, Utah

EXHIBIT X

Moab Project

Drilling Statement of Work

Moab, Utah

May 2002

Prepared by
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract Number DE–AC13–96GJ87335
Task Order Number MAC02–16

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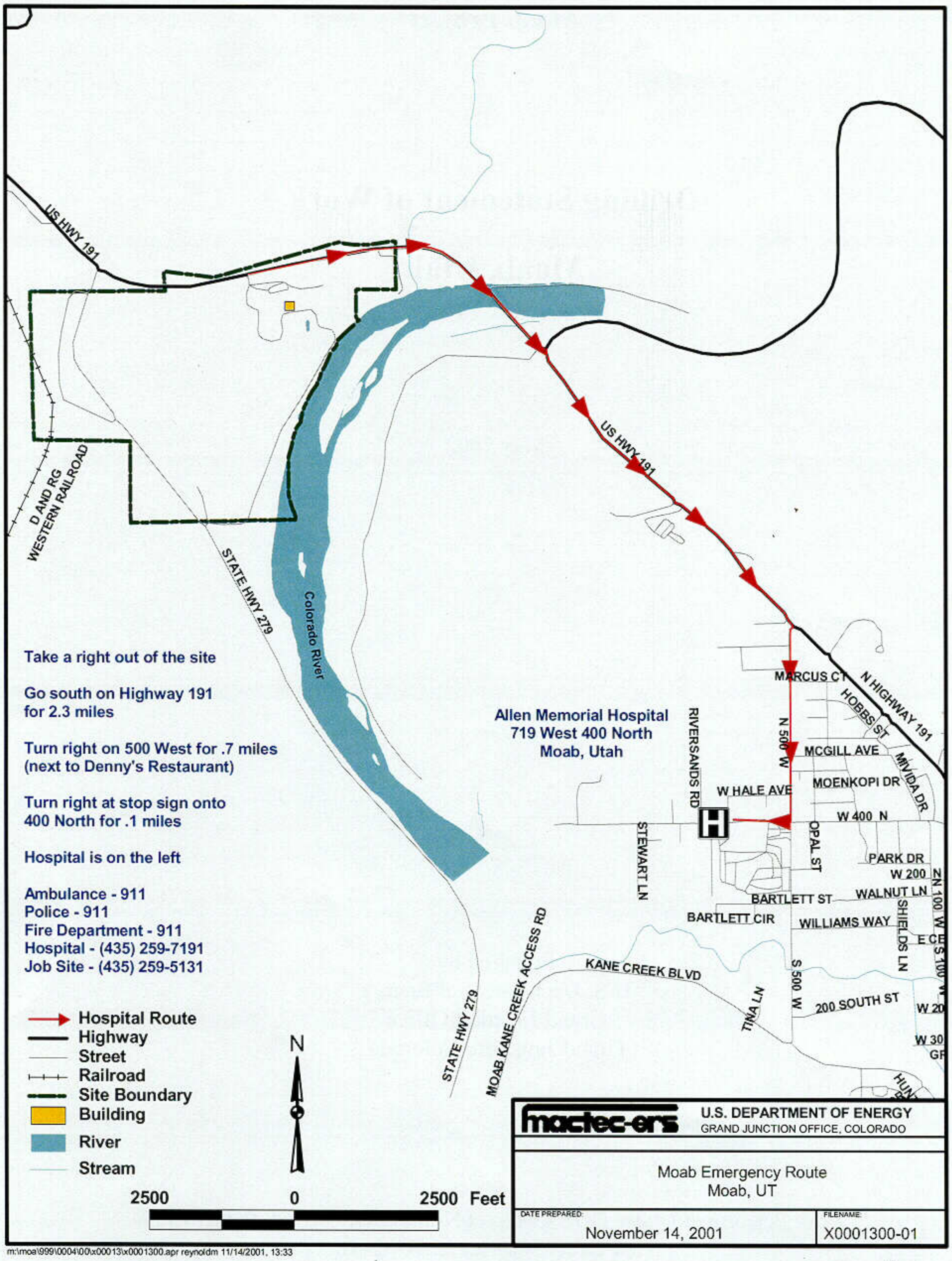

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Location and Hospital Route Map

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Tables

1.0 Introduction

1.1 Site Location and Background

The Moab Project Site (Moab site) is located at a former uranium-ore processing facility approximately 3 miles northwest of the city of Moab in Grand County, Utah (Figure 1–1). The plant was constructed in 1956 by the Uranium Reduction Company, which operated the mill until 1962 when the assets were sold to the Atlas Minerals Corporation (Atlas). Operations continued under Atlas until 1984. When the processing operations ceased in 1984, the mill had accumulated an estimated 10.5 million tons of uranium mill tailings in an unlined impoundment in the floodplain of the Colorado River. The tailings pile covers approximately 130 acres, is about 0.5 mile in diameter, averages about 94 feet in height above the surface of the Colorado River terrace, and is located about 750 feet west of the Colorado River. Atlas placed an interim cover over the tailings pile as part of decommissioning activities on going between 1988 and 1995. In October 2001, the title of the property and responsibility for remediation of the tailing pile and contaminated groundwater beneath the site were transferred to the U.S. Department of Energy (DOE).

DOE is currently in the process of preparing a plan to remediate the surface and groundwater contamination at the Moab site. The subsurface hydrogeology and geochemistry are complex in the vicinity of the Moab site and tailings area, which leads to uncertainties in defining the conceptual site model. Additional characterization data is needed to better define the water balance, assess the potential for a continuing source of contamination in the subpile sediments, and to perform a risk assessment for the site. This drilling statement of work outlines selected data collection activities and procedures for additional groundwater and tailings pile characterization required to support the plan for remediation.

1.2 Site Conditions

The Moab uranium millsite site is located three miles northwest of Moab adjacent to an outside meander of the Colorado River at the northwest end of Moab Valley (Figure 1-1). The ephemeral Moab Wash crosses the property just northeast of the tailings pile. The Moab site overlies Quaternary deposits derived mainly from the Colorado River, Moab and Courthouse Washes, and from cliffs located west of the site. The deposits include alluvium, talus, and eolian sediments. The "shallow alluvium" consists of sandy sediments (lenticular deposits of fine-grained, well-graded sands and silts with some gravels and clays, ranging in thickness from 8 to 30 feet. The "deeper alluvium" consists of gravelly sediments (interbedded sandy gravel and gravelly sands with occasional clay and silt rich intervals) ranging in thickness from 28 to greater than 406 feet. Various bedrock units believed to be of the Triassic Glen Canyon Group and older units, at different depths, underlie the unconsolidated sediments.

Ground water occurs under unconfined conditions in the alluvium beneath the site with depth to the water table ranging from 15 to 50 ft below ground surface. Ground water generally flows to the southeast toward the Colorado River. The alluvial system is recharged by infiltration of precipitation, Moab Wash, and the Colorado River during periods of high flow. An additional source of fresh water may originate from upwelling from the bedrock formation. The extent and magnitude of the upwelling, if any, from the bedrock formation is not known. The alluvial system discharges to the Colorado River during low flow conditions. The alluvial aquifer is chemically stratified by fresh and brine ground water regimes, which is a result of two distinct sources of water with a large disparity in dissolved solids. The fresh water regime is of primary interest because it occupies the upper portion of the alluvial sediments and is the primary system in which the site-derived constituents are transported. The lower brine ground water originates from the dissolution of evaporitic deposits in the Pennsylvanian Paradox Formation that are believed to sub crop near the Colorado River. The northern and vertical extent of the brine zone is not known.

1.2.1 Water Quality

Ground water in the shallow alluvium has been contaminated by uranium milling operations over the years. Constituents of concern (COCs), based on analytical information from several reports, consist of molybdenum, nitrate, selenium, uranium, ammonium, manganese, sulfate, and vanadium (SMI 2001). Distribution of COCs in the vicinity of the Moab site is based on existing characterization data and is shown in several documents (SMI 2001, NRC 1999a/1999b, ORNL 1998). Maximum concentrations are summarized in Table 1–1.

The list of COCs is based on information from several reports, with emphasis on the SMI report that summarizes water quality data from several of the previous sources (SMI 2001, NRC 1999a and 1999b, and ORNL 1998). There is some uncertainty associated with the list because historical sampling has not been consistent with regards to location of sampling points, selection of analytes, and depths in aquifer. Also the previous focus of the monitoring has reflected the Title II bias of short-term compliance with licensing agreements and interim ground water corrective action, and has not represented a comprehensive site-wide investigation that is typically performed at Title I processing sites for determination of the ground water cleanup and compliance strategy. The list of COCs will be confirmed when the Title I baseline risk assessment process is completed for the site.

Table 1-1. Concentrations for Inorganic Constituents in Ground Water at the Moab Site

Constituent	UMTRA MCL	Beneath Tailings Pile	Beneath Millsite Area
Arsenic	0.05	--	--
Barium	1.0	--	--
Cadmium	0.01	--	0.003
Chromium	0.05	--	--
Lead	0.05	--	--
Mercury	0.002	--	0.001
Molybdenum	0.10	10.8	1.73
Nitrate (N)	10	181	152
Selenium	0.01	--	0.024
Silver	0.05	--	--
Radium+	5*	--	--
Uranium+	0.044**	3.97	23.3
Gross alpha	15*	--	--
Ammonium		297	511
Chloride		2150	7460
Manganese		8.06	5.27
Nickel		--	0.03
Sodium		3020	6850
Sulfate		4910	15300
TDS		--	13700
Vanadium		0.015	0.40

Notes: UMTRA MCL for uranium = 0.044 mg/L if in equilibrium
Constituent distribution based on **maximum** sampling result -- sources = SMI (Table 2-20) -- based on **maximum** result from any monitor well from any date from any depth
* = pCi/L

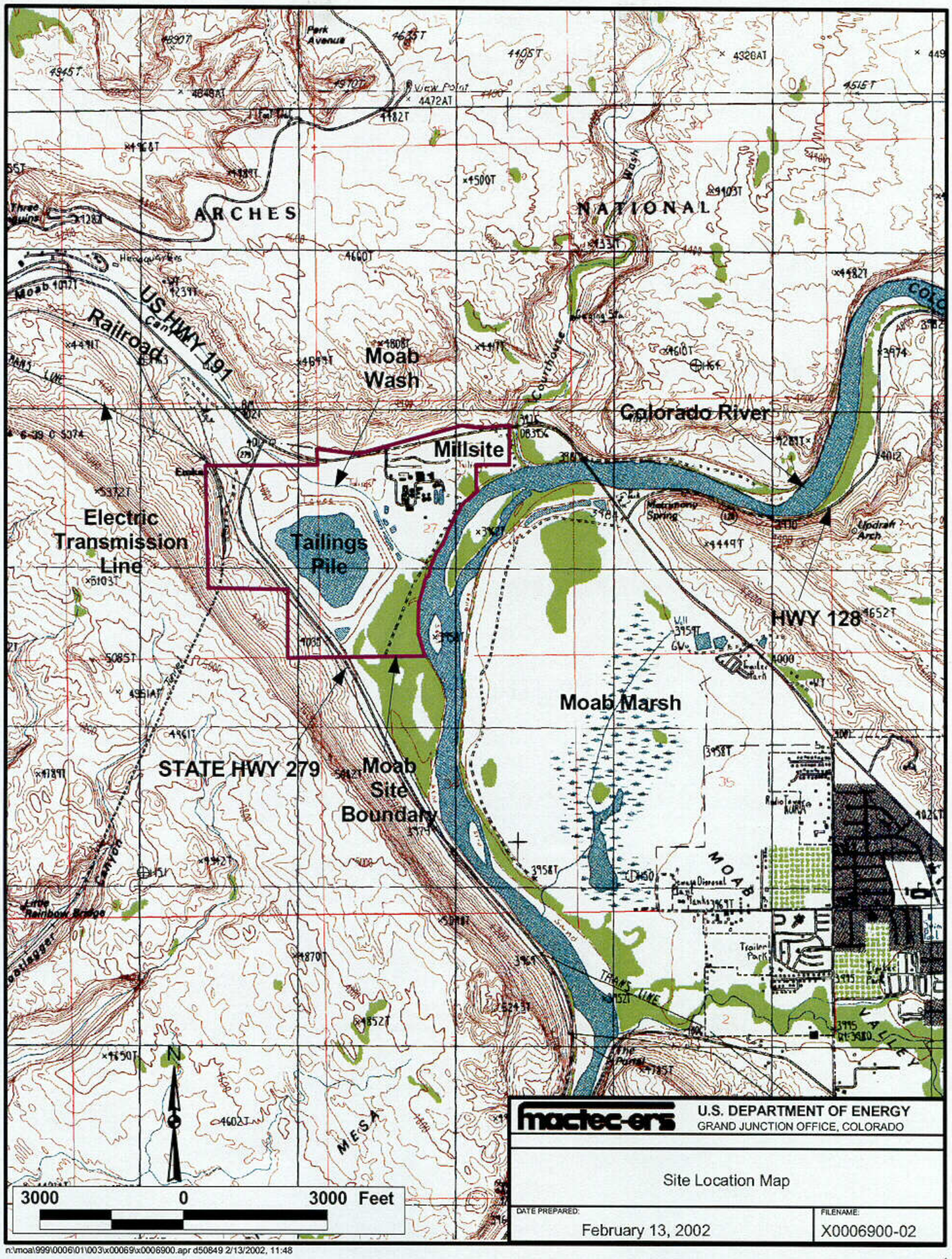

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Figure 1–1. Location of the Moab Project Site

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2.0 Scope

Outlined in this section are subcontract tasks required to collect the following data types.

- Core samples to identify the geologic bedrock formation sub cropping beneath the site.
- Monitor wells completed in the alluvium and in the bedrock formation to evaluate vertical flow gradients near the center of the site and to better estimate lateral recharge to the alluvium near the northern boundaries of the site.
- Sediment samples collected at three locations beneath the tailings pile from a hardened base layer (silt?), the unsaturated zone, and from the upper saturated zone.

2.1 Drilling and Well Installation

Drilling and installation work for monitor wells are listed below (Figure 2–1 and Table 2–1).

- Tailings Pile Boreholes and Wells—The drilling subcontractor shall drill 3 boreholes through the tailings pile and collect undisturbed, representative, and discrete samples of the hardened base layer (silt?), the subpile sediments in the unsaturated and saturated zones, and then core approximately 20-ft into the bedrock formation. The tailings pile is approximately 50-ft. thick. The unsaturated zone is approximately 30-ft thick. The saturated zone is estimated at 60-ft thick. **The subcontractor shall propose a drilling method that ensures the subpile samples are free from cross-contamination from the saturated tailings solid and liquids above the sample interval.** Each borehole shall be completed as a 2-inch inside diameter (I.D.) schedule 40 polyvinyl chloride (PVC) monitor well installed in the upper saturated zone of the alluvium. **The borehole above the upper filter pack shall be completed to ensure that downward leakage of tailings pore fluids and materials are prevented. Open borehole beneath the well screens lower filter pack shall be completed/abandoned in accordance with the State of Utah regulations and to ensure that fluids are prevented from entering the underlying bedrock formation.** The drilling subcontractor shall develop all wells by surging and bailing.

- Site Alluvial Monitor Wells—The drilling subcontractor shall drill and install 2-inch inside diameter (I.D.) schedule 40 polyvinyl chloride (PVC) alluvial monitor wells at six locations beneath the site. The subcontractor shall collect samples of the drill cuttings at five-foot intervals during the drilling and deliver the samples to the MACTEC–ERS geologist for lithologic logging. Three wells shall be completed in the upper saturated zone and three completed in the lower saturated zone of the underlying alluvial system. The drilling subcontractor shall develop all wells by surging and bailing.

- Site Bedrock Monitor Wells—The drilling subcontractor shall drill through the alluvium and core approximately 20-ft into the underlying bedrock formation. The subcontractor shall collect samples of the drill cuttings from the unconsolidated alluvium at five-foot intervals during the drilling and deliver the samples to the MACTEC–ERS geologist for lithologic logging. The drilling subcontractor shall then install 2-inch I.D. schedule 40 PVC wells completed in the bedrock formation. The drilling subcontractor shall develop all wells by surging and bailing.

2.2 Coring and Sampling

Coring and sediment sampling tasks are listed below (Figure 2–1 and Table 2–1).

- Bedrock Coring—The drilling subcontractor shall collect continuous core samples from the bedrock formation at 10 boring locations. Three of the ten borings are located on top of the tailings pile and the borings shall be completed as alluvial monitor wells after the core samples are retrieved (see previous section). The remaining seven borings shall be completed as bedrock monitor wells after the core samples are retrieved and packer tests are completed at three selected boreholes. Approximately 20 ft of core shall be collected at each bedrock boring. The subcontractor shall deliver the core to the MACTEC–ERS geologist for logging and provide core boxes for storage.
- Tailings Base Layer—The drilling subcontractor shall collect undisturbed, representative, and discrete samples of the hardened layer (silt?) at the base of the tailings pile. The estimated depth to the hardened layer is 50-ft. beneath the surface of the pile. The layer thickness is approximately 6-inches. **The subcontractor shall propose a sampling method that ensures the samples are free from cross-contamination from tailings material above the sample interval.** The subcontractor shall deliver the samples to the MACTEC–ERS geologist for logging and provide core boxes for storage.
- Subpile Sediments—The drilling subcontractor shall collect undisturbed, representative, and discrete sediment samples from beneath the tailings pile at 2-ft intervals. Sampling shall continue 10-ft beneath the alluvial water elevation. **The drilling subcontractor shall use a sampling method to ensure that the samples are free from cross-contamination from material above the sample interval.** The subcontractor shall deliver the samples to the MACTEC–ERS geologist for logging and provide core boxes for storage.
- Drill Cuttings—The subcontractor shall collect samples of the drill cuttings at five-foot intervals during the drilling of the site alluvial and bedrock wells. The subcontractor shall deliver the samples to the MACTEC–ERS geologist for lithologic logging.

Table 2–1. Summary of Monitor Wells to be Installed and Estimated Depths.

ID Number	Location Number	Drilling footage	Coring footage	Well Completion zone	Depth to top of screen (ft)	Screen length (ft)
430	1	100	20	Upper bedrock	90	10
431	2	100	20	Upper bedrock	90	10
432	3	60	20	Upper bedrock	50	10
433	4	90	20	Upper bedrock	80	10
434	5	60	20	Upper bedrock	50	10
435	6	80	20	Upper bedrock	70	10
436	7	120	20	Upper bedrock	110	10
437	8	140	20	Upper alluvium under pile	90	10
438	9	140	20	Upper alluvium under pile	90	10
439	10	140	20	Upper alluvium under pile	90	10
440	11	60	0	Shallow alluvium	50	5
441	12	60	0	Shallow alluvium	50	5
442	13	60	0	Shallow alluvium	50	5
443	14	80	0	Deep alluvium	70	10
444	15	60	0	Deep alluvium	50	10
445	16	100	0	Deep alluvium	90	10
Total		1,450	200			145

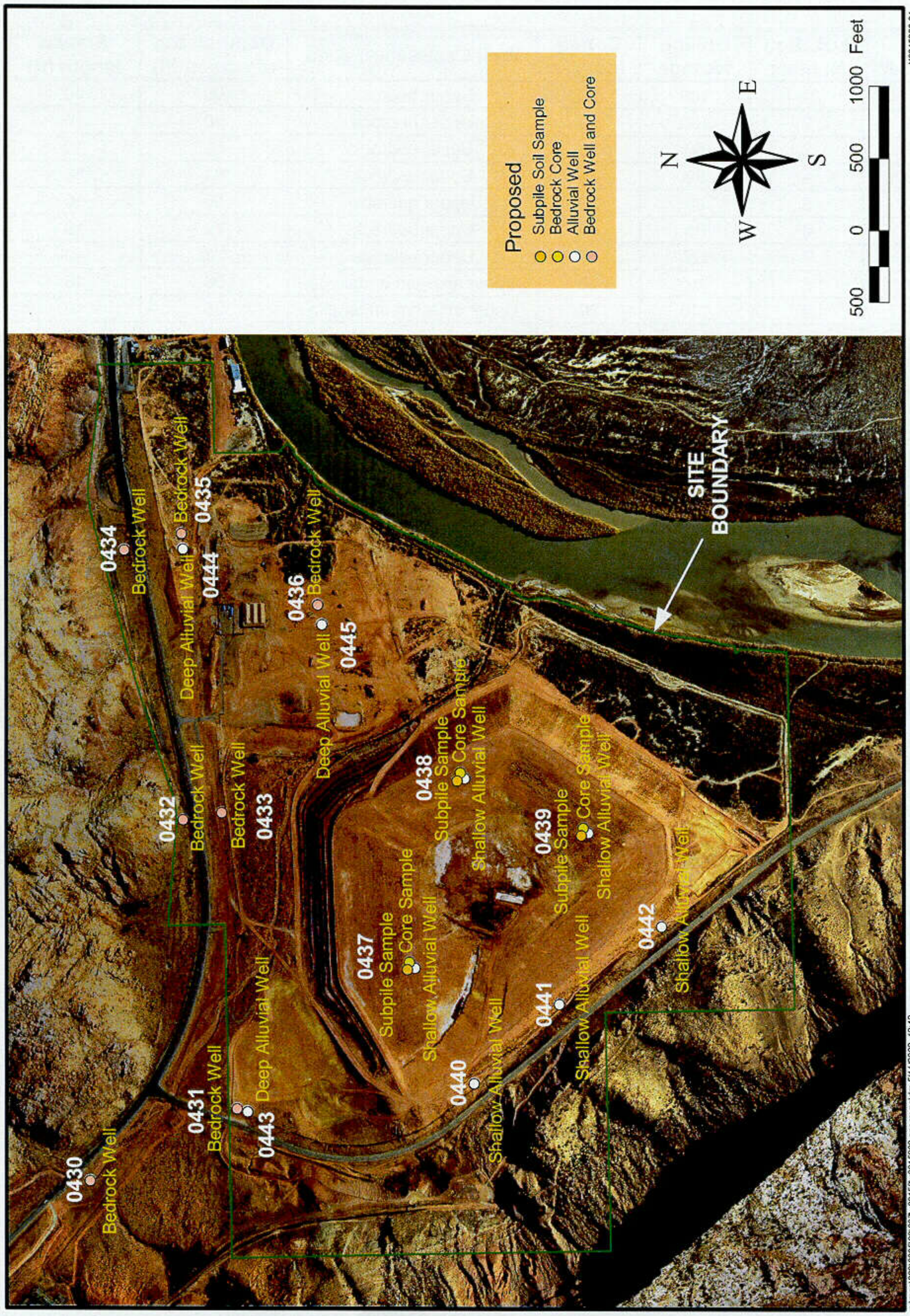

Figure 2–1. Proposed Sample and Well Locations

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3.0 Requirements and Specifications

Specifications and requirements for the drilling and sampling tasks are presented in this section. The MACTEC–ERS task leader (task leader) will establish all well locations, the number of boreholes and wells, samples, well completion materials, and dimensions and depths of wells. These factors are subject to change as additional information is obtained during the work.

The subcontractor shall drill boreholes and install wells that are sufficiently plumb and straight and will have no interference with the installation, alignment, operation, or future removal of pumps or other down-hole equipment. The subcontractor shall use only nonhydrocarbon-based lubricants, such as silicon or Teflon on any downhole equipment or tools. The subcontractor shall not use contaminating additives (e.g., diesel fuel, oil, barite), hydrocarbon-based lubricants (e.g., grease or oil), and biocides (e.g., formaldehyde) in the borehole or well. All well installation materials, e.g., sacks of bentonite, screens, casings, shall be delivered to each well site in factory sealed containers and remain in such until used in the well installation.

3.1 Drilling, Coring and Sampling Methods

The subcontractor shall propose a cost effective and expedient method and the equipment for drilling and installing the monitor wells, drilling the boreholes, coring, and for obtaining undisturbed, representative, and discrete sediment samples. **The drilling subcontractor shall use a drilling method to ensure that the samples are free from cross-contamination from material above the sample interval. The drilling subcontractor shall use a drilling method to ensure that downward leakage of tailings pore fluids and materials are prevented during and after the drilling operation**. The proposed drilling method and equipment shall be capable and rated to penetrate and advance through clay, loose sand, and gravel with cobbles to the desired depth. Lithologic samples shall be collected at selected intervals during the drilling, as directed by the task leader.

Casing advance systems such as ODEX and rotary vibratory (sonic type) drilling methods are acceptable. However, the relatively high quality of samples collected using sonic drilling makes the sonic drilling method more desirable than other casing advance methods. Mud rotary and hollow stem auger methods will not be considered. Air as the drilling fluid will not be accepted due to the health and safety concern of potentially suspending fine-grained radioactive tailing particles in the breathing zone. If the proposed drilling method proves insufficient for borehole stability and cuttings return, the task leader may authorize the use of approved water as the drilling fluid and non-bentonite drilling additives. If the use of water as a drilling fluid is approved, the subcontractor shall minimize the amount of water used during drilling through the tailings pile to prevent downward leakage of contaminants.

3.2 Sediment Sampling

The subcontractor shall collect samples from the subpile sediments at locations summarized in Table 2–1. **The drilling subcontractor shall use a drilling and sampling method to ensure that the samples are free from cross-contamination from material above the sample interval.** The MACTEC–ERS geologist will describe, mark and store the samples for laboratory analysis. The subcontractor will use a high-pressure steam cleaner (or equivalent method) to decontaminate the sampling equipment and other drilling tools that come in direct contact with the subpile samples before each sample run. Clean, potable water from an approved source will be used for cleaning.

The subcontractor shall also collect drill cuttings of the sediments from the monitor well locations at selected depth intervals as determined by the task leader for lithologic logging purposes.

3.3 Coring

An estimated 200 ft of core shall be collected from the bedrock formation at locations summarized in Table 2-1. Core shall be collected using nominal 5 or 10 ft long, double tube, swivel-type, NWG or NWM wireline core barrel or equivalent system and appropriate bits (see ASTM Standard D 2113-83 [Reproved 1987]). Water shall be used as the circulation medium. A minimum of two core barrels is required. The subcontractor shall use the best state-of-the - industry coring practices to affect the highest core recovery possible.

Core boxes shall be provided by the subcontractor, and shall be constructed of wood or other durable material. The boxes shall have lids and longitudinal separators. Recovered cores shall be laid out as a book would read, from left to right within the longitudinal separators. The beginning point for each box is the upper left hand corner (i.e. core from the shallowest portion of the hole will be placed starting in the upper left hand corner of the box; core representing the deepest portion of the hole will be in the furthest, lower right hand corner). Spacer blocks or plugs (provided by the subcontractor) shall be inserted into the core column within the longitudinal separators where no recovery was noted. All core boxes (including the lids) shall be permanently marked showing top and bottom and the beginning and ending depths for the core. Clean gloves shall be worn by all personnel handling the core.

3.4 Packer Testing

Once coring operations are completed, the subcontractor shall perform formation pressure (packer) testing at three selected locations on the site. These tests shall be run at the direction of the task leader. The tests will be conducted at 5-foot intervals or as directed by the task leader. The pump(s) used for the tests shall be fitted with a pulsation damper to minimize surging and pressure fluctuations. The minimum allowable packer inflation pressure will be 50 PSI over the maximum fluid pressure (higher packer inflation air pressures may be required to seat packers) and fluid pressures may range up to 50 PSI. The subcontractor shall provide all equipment and supplies required to conduct these tests. The subcontractor shall use a standard operating procedure consistent with the procedure published by the University of Missouri - Rolla (Pump-In Permeability Testing. Orlando, University of Missouri - Rolla Seminar for Drillers and Exploration Managers, 1981). A copy of the reference can be provided upon request.

Once the packer testing operations are completed, the subcontractor shall complete the borehole as a 2-inch monitor well.

3.5 Well Installation and Completion

The subcontractor shall begin the installation of the well materials when the desired total depth of the borehole is reached, as determined by the task leader. The subcontractor shall measure the depth of materials to the nearest tenth of a foot and report the measurements to the task leader.

The borehole diameter shall allow a minimum of 2-inch annular space between the borehole and the well casing. The monitor wells shall be constructed using the following materials:

- Johnson well screen (or equivalent), nominal 2-inch diameter, PVC schedule 40, 0.020-inch screen slot, 10-20 Colorado silica sand (or equivalent) for the primary filter pack, 20-40 Colorado silica sand (or equivalent) for the secondary filter pack, PVC schedule 40 blank casing, a 30 percent bentonite grout seal, a lockable j-plug.

The monitor wells shall be constructed in accordance with the following guidelines:

- The subcontractor shall begin installation of the well screen and casing when the desired total depth of the borehole is reached, as determined by the task leader.
- The subcontractor shall continue well installation with the placement of the primary filter pack to 2-ft above the top of the screen or as determined by the task leader. Pre-completion well development shall be performed, if necessary as determined by the task leader, to ensure a uniform and complete filling of the annular space with the filter pack that is free of voids or bridges.
- The subcontractor shall continue well installation with the placement of a minimum 3-ft secondary filter pack.
- When the top of the secondary filter pack is at the correct height, as determined by the task leader, the subcontractor shall then begin placement of a 5-ft bentonite seal (3/8-inch bentonite pellets). The subcontractor shall then hydrate the bentonite pellets by adding 5 gallons of water, if necessary, and allowing at least a 15 minute period for hydration and expansion of the pellets.
- The subcontractor shall install the 30 percent solids bentonite grout seal in the annular space from the top of the bentonite seal to within 3-ft of the ground surface. The subcontractor shall place the grout by pumping it through a tremie pipe in one continuous action completely filling the annular space. The subcontractor shall prepare the grout in accordance with the manufacturer's instructions and supervision of the task leader.

3.6 Well Development

The subcontractor shall develop all wells by a combination of surging or bailing. The subcontractor shall continue well development until the well is free of sediment, as determined by the task leader.

3.7 Well Head Protection

The subcontractor shall provide the following well head protection for the monitor wells:

- A steel casing extending 30 inches above the surface fitted with a locking, weather-proof lid (approximately 2-in of clearance) shall be placed over the riser casing of the well and cemented 3-ft in place, with a 1/8 in drain hole drilled near the base. MACTEC–ERS will supply the locks for the lids.
- The top 2-ft of the borehole shall be excavated and tapered away from the casing to allow the concrete to be placed below the frost line.

- A 3-ft wide, 3-ft long, and 6-in thick concrete pad (centered around the casing) having a slight slope away from the well casing shall be installed around the new monitor well.
- The annular area between the cover and the riser casing shall be filled with 1/4 in pea gravel up to 6-in below the top of the riser. The finished height of the PVC casing shall be cut square and approximately 2.0 ft above ground level. The top of the casing shall be equipped with a schedule 40 PVC cap.

3.8 Source of Water

The subcontractor shall obtain clean potable water from an approved source for drilling and other tasks associated with the work scope. The subcontractor shall have the necessary equipment to obtain, transport, and store water for use at the drill sites.

Tanks, hoses, pumps, and any other equipment used to transport or store the water shall be clean and free from all contamination. Further, the subcontractor shall protect the water from contamination during storage.

3.9 Equipment Cleaning

The subcontractor shall remove debris and any contamination from equipment with a high-pressure steam washer at the beginning of the drilling project and before leaving the project site. Water from the approved water source shall be used for all cleaning operations. The task leader will direct equipment cleaning and verify it clean when it is visibly free of all soil, oil, grease, and previous fluids.

3.10 Drill Cuttings and Fluid Disposal

The subcontractor shall spread drill cuttings and fluids evenly on the ground surface around the borehole after each borehole or well is completed.

3.11 Trash Disposal

The subcontractor shall collect and dispose of job-generated trash in a site approved receptical at least one time per day, at the end of each day, and maintain site housekeeping at all times.

3.12 Equipment Maintenance

The subcontractor may perform equipment maintenance, fueling, and repairs on location with the prior approval of the task leader. If, during this maintenance operation(s), the subcontractor spills any hydrocarbon-based fluid, antifreeze, or any other similar material, it shall immediately cleanup and remove the spilled material at its own time and expense. If, at any time, fluid leakage from any piece of the subcontractor's equipment, the subcontractor shall "diaper" the ground surface with plastic sheeting until the leak is fixed.

4.0 Contingencies and Site Procedures

4.1 Site Access

The drilling and sampling sites are accessible by existing roads or open ground. The subcontractor shall keep off-road driving to a minimum.

4.2 Site Conditions

The subcontractor shall be knowledgeable of general and local conditions that may affect the cost or quality of the performance of the work, including the ability of the subcontractor's equipment to perform the work. Refer to Article 40 of the Terms and Conditions for Subcontracts and Purchase Orders over $25,000 (GJO-PROC-114, August 1997)

4.3 Loss of Drilling Equipment and Hole Abandonment

Refer to Article 38 of the Terms and Conditions for Subcontracts and Purchase Orders over $25,000 (GJO-PROC-114, August 1997).

4.4 Daily Drilling Report

The subcontractor shall furnish to the task leader a completed and signed daily (or shift) drilling log that details all activities, rig functions, depths, pipe tallies, casing and other materials used, as well as any other pertinent project drilling, or safety data (including "tailgate" safety meetings and "rig inspections"). This information shall be recorded on the Drilling Report furnished by MACTEC–ERS (Figure 4–1). The Drilling Report form shall also be examined and signed each day or shift by the task leader. Any errors found on this report by the task leader will be reported to the subcontractor as soon as possible for reconciliation.

4.5 Utilities Clearance

MACTEC–ERS will stake each proposed location 7-days prior to the start of work. The subcontractor shall then notify the utility companies through the Blue Stakes one-call (800-662-4111) utility locate service no earlier than 7-days and no later than 48-hrs prior to start of work (notice does not include weekends or holidays). The subcontractor shall provide the utility locate service with the following street address for the project site:

Former Atlas Millsite
1871 North Highway 191
Moab, UT 84532

MACTEC–ERS site safety personnel will coordinate and escort the utility locators to each site. MACTEC–ERS will verify all utilities located, such as power lines or pipelines, that might reasonably be expected to exist within the work area, prior to commencement of work in accordance with 29 CFR 1926.651(b). The subcontractor shall repair any damage to known utilities during the performance of the work. The liability of other repairs shall be in accordance with Article 73 of the Terms and Conditions (GJO–PROC–114).

Grand Junction Office
2597 B ¾ Road
Grand Junction, CO 81503
(970) 248-6000

Drilling Report

State ________ County __________ Project _________________________ Hole Name _________________________ Hole No. __________

Drilling Contractor _____________________________________ Rig Type _____________________________________ Rig No. ____________

From A.M. P.M	To A.M. P.M.	Footage			Drilling (check)					Description of Work
		From	To	Hole Size	Dri	Cor	Rem	Agr	Sam	

Materials Used (e.g., casing, cement, water, mud, etc.)	Remarks
	Drill Crew
	Driller ______________________
	Helper ______________________
	Helper ______________________
	Other ______________________

Contract Foreman ________________________ GJO Representative ________________________ Report No. ________________ Date________

GJPO 1706 White—Return to GJO with Invoices(s) Canary—GJO Field Copy Pink—Rig Copy
Rev. 10/96

Figure 4–1. Drilling Report Form

4.6 Quality Assurance

A MACTEC–ERS representative will be present during the field activities. The subcontractor shall perform all fieldwork in accordance with the requirements, specifications, and procedures set forth herein. Periodic surveillance visits by other contractor personnel may be performed to verify the subcontractor's compliance with the requirements, specifications, and procedures set forth herein.

Upon request, the offeror shall provide additional information about previous site investigation work.

4.7 Permits and Licenses

MACTEC–ERS will provide all necessary access permits, well permits, and any permits for cuttings/fluid disposal as required by Federal, State, or other controlling agencies. The subcontractor shall acquire any drilling and/or contractor license(s) and any other permits required by Federal, State, or other controlling agencies.

4.8 Material Storage Facility

The subcontractor shall provide and maintain covered storage for items that could be affected by inclement weather. MACTEC–ERS will provide a lockable fenced area for drilling supplies. All material stored in this facility shall remain the property of the subcontractor until such time that the material is used or consumed by the project requirements. The storage facility is subject to Occupational Safety and Health Administration (OSHA) requirements for such things as housekeeping and fire protection.

4.9 Inventory

Prior to commencing work, the subcontractor and the task leader shall conduct an inventory to ensure adequate materials and supplies to perform the work are on the site and usable.

4.10 Site Sanitation Facilities

Portable toilet facilities are available at the job site.

End of current text

5.0 Health and Safety

5.1 Safety Requirements and Briefings

The task leader, in collaboration with MACTEC–ERS Site Safety Supervisor, will be responsible for operational health and safety coverage during the drilling activities. All subcontractor personnel shall comply with the MACTEC–ERS operational health and safety regulations as outlined in the *Drilling Health and Safety Requirements*, MAC–2012, Revision 3, October 2000. The "Statement of Understanding" contained in the *Drilling Health and Safety Requirements* shall be signed by all subcontractor personnel prior to working on this project. All subcontractor personnel working on this project shall be required to attend a pre-work briefing as soon as practical after the subcontractor has mobilized its equipment to the project site.

The subcontractor shall hold a safety tailgate meeting prior to the start of each day's work. All subcontractor personnel and MACTEC–ERS personnel working on that days shift shall attend. The topic of discussion and attendee signatures will be recorded on a form. A copy of each daily record will be submitted to the MACTEC–ERS task leader.

All work will be suspended by the task leader or the subcontractor when an unsafe practice or condition is observed. Work will not proceed until the unsafe practice or condition is corrected and the task leader, or designee, approves the resumption of work. The subcontractor will not be compensated for efforts required to correct any unsafe practice or condition created by its actions.

Drilling rig trucks and/or carriers shall conform to all applicable Federal, State, and local safety requirements and regulations. Each truck or carrier shall be equipped with two U.S. Department of Transportation (DOT) approved, fully charged 2A:40BC dry chemical fire extinguishers, with current inspection tags.

5.2 Training Requirements

All subcontractor personnel are required to have a minimum of 40 hour Hazardous Waste Site training and Radiation Worker Level II (2 days). MACTEC–ERS can provide the Radiological Work II training at no cost to the subcontractor. Additionally, the subcontract crew will be working in personal protective equipment (PPE) consisting of booties and gloves over Tyvek® coveralls.

5.3 Equipment Inspections

The task leader will inspect the subcontractor's drilling rig and all other subcontractor furnished equipment at the start of the project and at other times, as necessary, and record the conditions on an appropriate form. The subcontractor shall inspect its drilling equipment on a daily basis and record this on the Drilling Report each day. The subcontractor shall maintain and operate all of its equipment in accordance with all applicable regulations.

End of current text

6.0 Subcontractor Qualifications, Performance, and Requirements

6.1 Subcontractor Qualification

Due to the technical nature of the work, the subcontractor shall be a first-tier subcontractor to MACTEC–ERS, shall have a minimum of 5 years business experience in environmental and hazardous waste site water well drilling, and shall have the ability to provide the necessary and required drilling equipment. The subcontractor's driller shall have a minimum of 4 years in casing advance drilling experience and environmental and hazardous waste site well installations.

The successful subcontractor shall be mobilized to the site and ready to commence drilling immediately upon completion of the Green River drilling project. The subcontractor shall submit a work schedule with its proposal.

In the event of an award, the equipment proposed herein shall be the equipment used to perform the work.

6.2 Work Day and Rotation Schedule

The normal workday will consist of a minimum of 8 hours per day or through completion of a given well or boring. The workday shall be limited to the period of time starting no earlier than one-half hour before sunrise and ending no later than one-half hour after sunset. In all cases, MACTEC–ERS reserves the right to limit the length of the workday based on safety concerns. The subcontractor is responsible for obeying all Federal and State labor laws, rules, and regulations. Holidays excepted, the normal work schedule will consist of a "10 days on, 4 days off" rotation and will begin on a Tuesday and end on Thursday of the following week, or as mutually agreed.

6.3 Weather Day

The subcontractor shall not be compensated for any delays caused by weather. A "weather day" applies to any normal workday when weather conditions deteriorate to the point that fieldwork is neither safe, nor practical. The task leader, in consultation with the subcontractor, will decide whether or not to continue work.

6.4 Standby Time

Standby time is lost work time caused by MACTEC–ERS activities. The subcontractor shall be paid in accordance with the stipulated standby time rate. Standby time will only be paid when authorized by the task leader. Standby time will not be paid for subcontractor equipment breakdown, missing subcontractor equipment, insufficient supplies, or missing or tardy subcontractor personnel.

6.5 Submittals

The submittals are listed below in Table 6–1.

Table 6–1. Submittal Schedule

Submittal	Schedule
MSDS sheets for all materials to be brought on site and chemical inventory. Include type and brand of downhole tool lubricants to be used.	At date of mobilization or delivery to the site
Copies of reports, logs, and other State of Utah required documents	With final invoice
Specifications for casing, screen, and bentonite	With proposal
OSHA 200 log for 2000 and 2001	With proposal
Radiation Worker Level II training (2-days) certificate	With proposal
SARA 40-hr hazardous waste site training certificate	With proposal

Appendix B

Statement of Work
Direct-Push Piezometer Installations and Soil Conductivity Measurements
Moab, Utah

EXHIBIT A

Moab Project

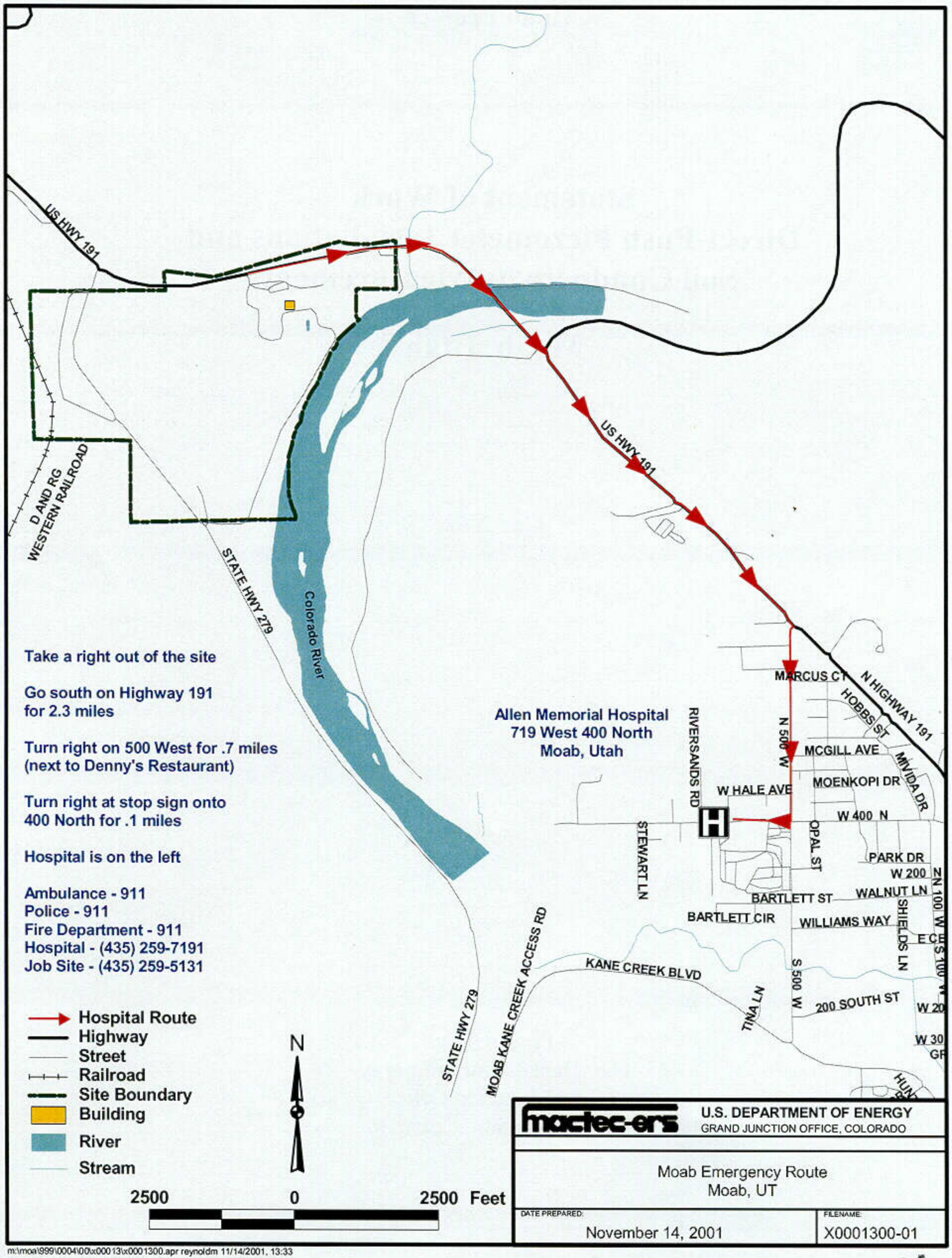
Statement of Work
Direct-Push Piezometer Installations and Soil Conductivity Measurements

Moab, Utah

May 2002

Prepared by
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract Number DE–AC13–96GJ87335
Task Order Number MAC02–16



C-06

Location and Hospital Route Map

Contents

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Tables

1.0 Introduction

1.1 Site Location and Background

The Moab Project Site (Moab site) is located at a former uranium-ore processing facility approximately 3 miles northwest of the city of Moab in Grand County, Utah (Figure 1–1). The plant was constructed in 1956 by the Uranium Reduction Company, which operated the mill until 1962 when the assets were sold to the Atlas Minerals Corporation (Atlas). Operations continued under Atlas until 1984. When the processing operations ceased in 1984, the mill had accumulated an estimated 10.5 million tons of uranium mill tailings in an unlined impoundment in the floodplain of the Colorado River. The tailings pile covers approximately 130 acres, is about 0.5 mile in diameter, averages about 94 feet in height above the surface of the Colorado River terrace, and is located about 750 feet west of the Colorado River. Atlas placed an interim cover over the tailings pile as part of decommissioning activities on going between 1988 and 1995. In October 2001, the title of the property and responsibility for remediation of the tailing pile and contaminated groundwater beneath the site were transferred to the U.S. Department of Energy (DOE).

DOE is currently in the process of preparing a plan to remediate the surface and ground water contamination at the Moab site. The subsurface hydrogeology and geochemistry are complex in the vicinity of the Moab site and tailings area, which leads to uncertainties in defining the conceptual site model. Additional characterization data is needed to better define the water balance, assess the potential for a continuing source of contamination in the subpile sediments, and to perform a risk assessment for the site. This drilling statement of work (SOW) outlines selected data collection activities and procedures for additional groundwater and tailings pile characterization required to support the plan for remediation.

1.2 Site Conditions

The Moab site is located three miles northwest of Moab adjacent to an outside meander of the Colorado River at the northwest end of Moab Valley (Figure 1–1). The ephemeral Moab Wash crosses the property just northeast of the tailings pile. The Moab site overlies Quaternary deposits derived mainly from the Colorado River, Moab and Courthouse Washes, and from cliffs located west of the site. The deposits include alluvium, talus, and eolian sediments. The "shallow alluvium" consists of sandy sediments (lenticular deposits of fine-grained, well-graded sands and silts with some gravels and clays, ranging in thickness from 8 to 30 feet. The "deeper alluvium" consists of gravelly sediments (interbedded sandy gravel and gravelly sands with occasional clay and silt rich intervals) ranging in thickness from 28 to greater than 406 feet. Various bedrock units believed to be of the Triassic Glen Canyon Group and older units, at different depths, underlie the unconsolidated sediments.

Ground water occurs under unconfined conditions in the alluvium beneath the site with depth to the water table ranging from 15 to 50 ft below ground surface. Ground water generally flows to the southeast toward the Colorado River. The alluvial system is recharged by infiltration of precipitation, Moab Wash, and the Colorado River during periods of high flow. An additional source of fresh water may originate from upwelling from the bedrock formation.

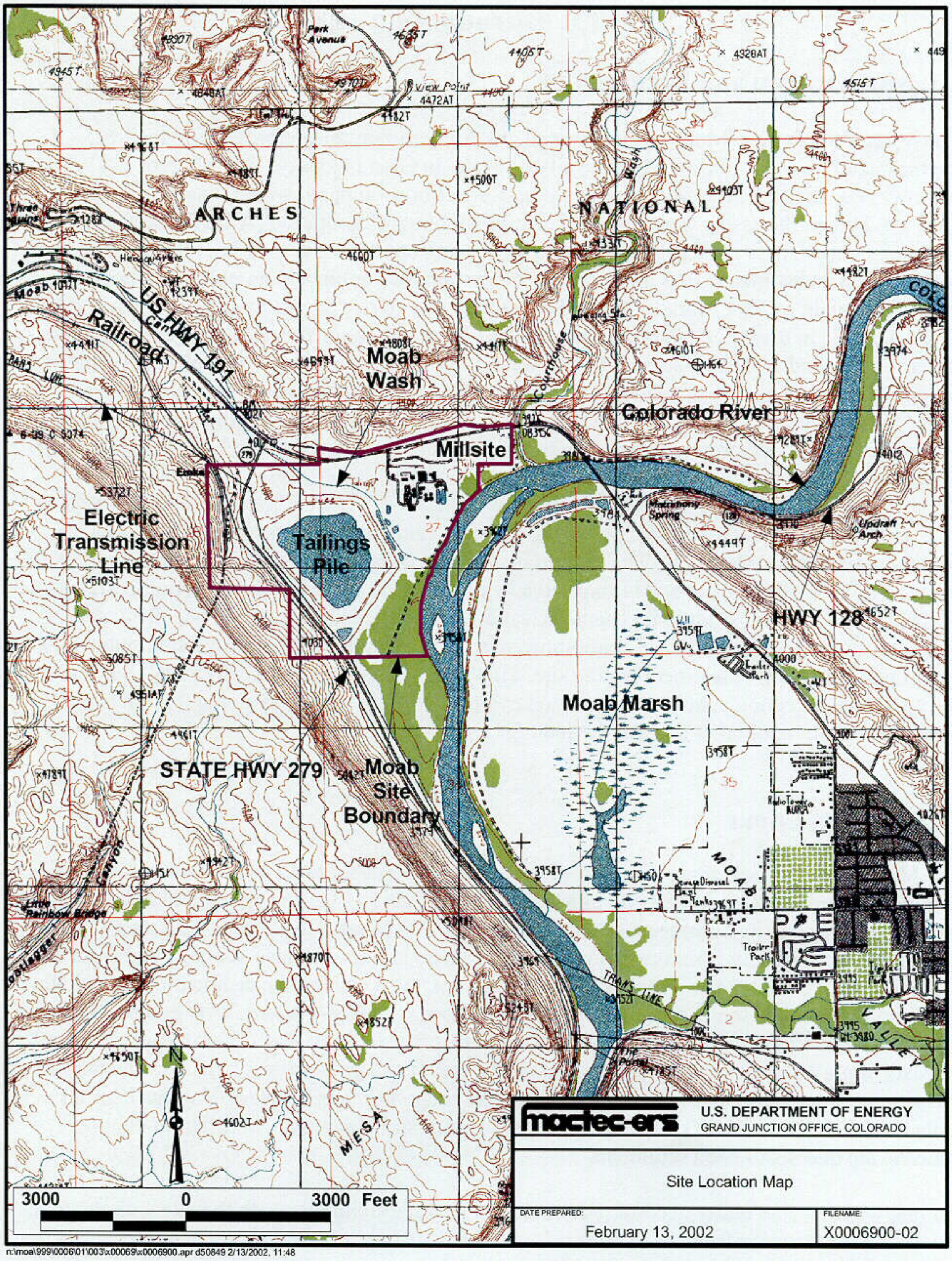

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Figure 1–1. Location of the Moab Project Site

The extent and magnitude of the upwelling, if any, from the bedrock formation is not known. The alluvial system discharges to the Colorado River during low flow conditions. The alluvial aquifer is chemically stratified by fresh and brine ground water regimes, which is a result of two distinct sources of water with a large disparity in dissolved solids. The fresh water regime is of primary interest because it occupies the upper portion of the alluvial sediments and is the primary system in which the site-derived constituents are transported. The lower brine ground water originates from the dissolution of evaporitic deposits in the Pennsylvanian Paradox Formation that are believed to sub crop near the Colorado River. The northern and vertical extent of the brine zone is not known.

Radioactive tailings are piled in an area that cover approximately 130 acres, is about 0.5 mile in diameter, averages about 94 feet in height above the surface of the Colorado River terrace, and is located about 750 feet west of the Colorado River. The pile consists of an outer compacted embankment of coarse tailings and an inner impoundment of both coarse and fine tailings. A thin interim cover of unconsolidated earth covers the tailings. Dewatering operations to remove excess liquid from the tailings is on going.

End of current text

2.0 Scope

The subcontractor shall propose a cost effective and expedient method and the equipment for installing piezometers and for mapping the brine zone in the alluvial aquifer. The subcontractor shall perform the following tasks as part of this SOW.

- Install 6 vibrating-wire piezometers in the tailings pile.
- Install 9 vibrating-wire piezometers in the alluvial aquifer along the Colorado River.
- Perform soil conductivity measurements at 12 locations in the former millsite area to map the extent of the underlying brine zone in the lower alluvial aquifer.

Presented in this section are the specifications and requirements for each task listed above. The MACTEC–ERS task leader (task leader) will establish all locations, depths, and quantities of piezometer installations and soil conductivity measurements. MACTEC–ERS will provide the vibrating-wire piezometers, anticipated to be Geokon Model 4500DP, or equivalent for installations in the tailings and Geokon Model 4500S, or equivalent for installations in the alluvial aquifer. These factors are subject to change as additional information is obtained before or during the work.

2.1 Piezometer Installations in Tailings Pile

The possibility of flux coming from the interior of the tailings pile will be investigated by monitoring internal pressure distributions with vibrating-wire piezometers. The subcontractor shall install six piezometers at the locations (415–420) shown in Figure 2–1. Piezometers will be installed in pairs at 20-ft and 40-ft below the surface into the saturated tailings slimes (fine grained tailings).

The subcontractor shall use a direct-push method to install the piezometers to the specified depth at a rate that will not create dynamic pore pressures that exceed the manufactures recommendations (Geokon Model 4500DP or equivalent).

2.2 Piezometer Installations in the Alluvial Aquifer

Measuring the direction and magnitude of flow gradients in the alluvial aquifer at several locations down gradient from the toe of the tailings pile will provide insight in how contaminants are discharging into the river. Interactions between the alluvial aquifer, the Colorado River, and the underlying brine zone will be investigated by monitoring internal pressure distributions with vibrating-wire piezometers. The subcontractor shall install nine piezometers at the locations (421–429) shown in Figure 2–1. Piezometers will be installed in nests of three at 20, 60, and 100 ft below the surface into the alluvial aquifer (sand, gravel and cobbles).

The subcontractor shall use a drilling method to advance one borehole to approximately 100-ft. at each of the three nested locations. The subcontractor shall install 3 piezometers at their specified depths (i.e. 20, 60, and 100-ft) in each borehole. MACTEC-ERS will provide the piezometers (Geokon Model 4500S or equivalent). The subcontractor shall provide all other equipment and installation materials as per manufacturer specifications for the piezometers.

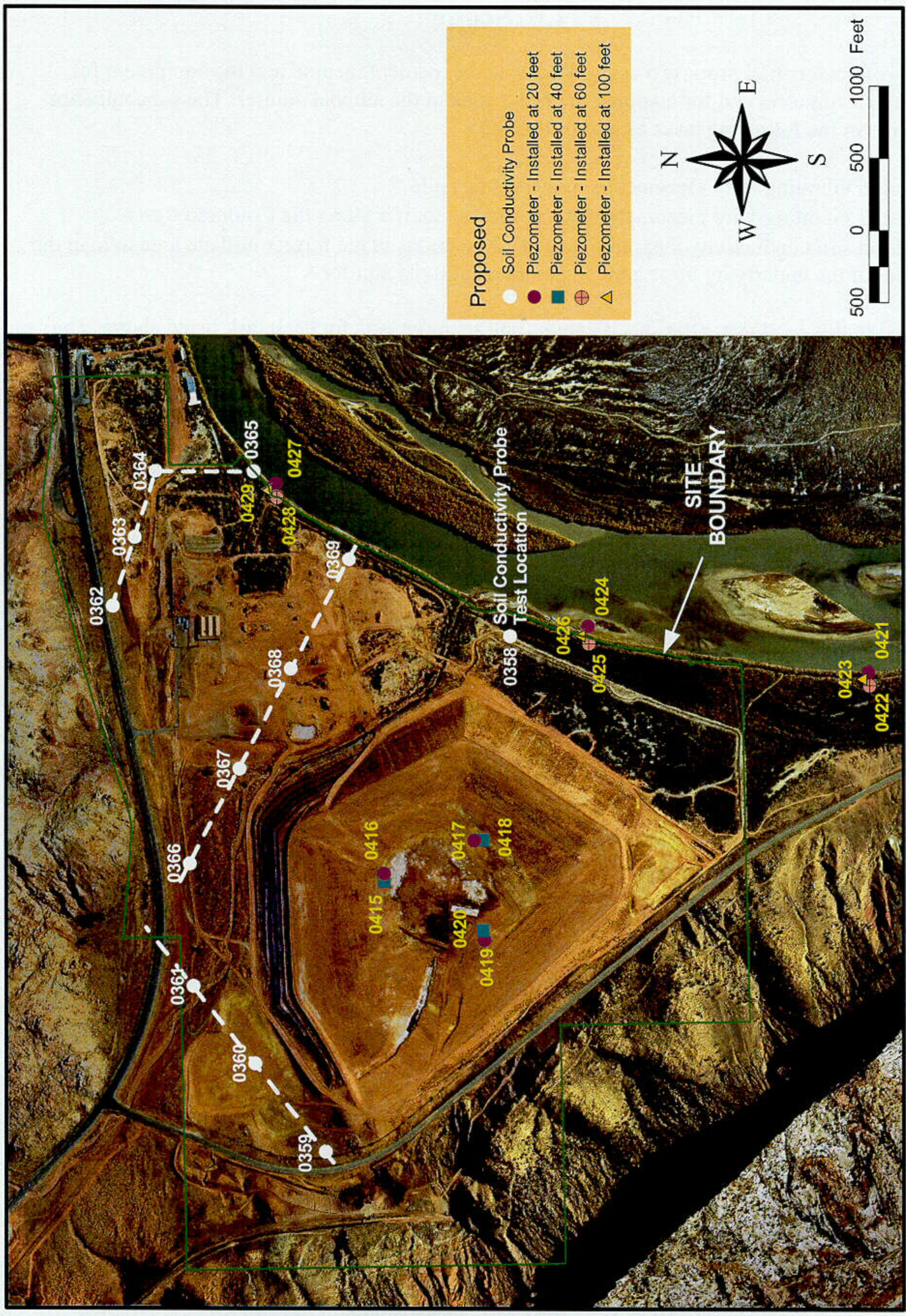

Figure 2–1. Proposed Piezometer and Soil Conductivity Probe Locations

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2.3 Soil Conductivity Logs

Specific conductance of the alluvial groundwater varies from 1,000 microSiemens per centimeter (µS/cm) to 100,000 µS/cm across the site. The depth of the contact between the fresh water system and the denser brine zone may be greater than 100-ft in places. The subcontractor shall propose a direct-push method in combination with a drilling method to measure electrical conductivity at 12 locations (358–369, Figure 2–1) to identify the nature and extent of the underlying brine groundwater system. The subcontractor shall calibrate the electrical conductivity instrument at the first location (358) where specific conductance measurements have been performed by MACTEC–ERS on water samples collected from discrete intervals from monitor well SMI–PW–02. Successful results of probing at this first test location will be used by the task leader to decide if additional probing at the other proposed locations is warranted.

The subcontractor shall use an electrical conductivity logging system that provides real-time display of conductivity versus depth and probing speed versus depth. A hard copy (chart) of the conductivity log and an electronic ASCII data file or equivalent shall be provided to the task leader for each location probed within 1-hr of the completion of a probing. Hard copy output shall consist of a computer-generated graph with the depth scale in units of feet and conductivity in microSiemens/meter. These plots will be plotted in an exact engineering scale, (i.e. at a scale easily read with a common engineering scale rule). In addition, points where the push is interrupted to add rods shall be noted on the graphs.

The subcontractor shall make every attempt to advance the electrical conductivity probe a minimum of 10 ft into the brine zone as determined by the task leader. Due to the nature of the substrata (i.e. sand, gravel, and cobbles) the subcontractor shall provide equipment that is capable of drilling through obstructions that cause refusal of the electrical conductivity probe advanced by direct-push. The proposed drilling method shall be used to advance the borehole at 5-ft intervals in the event of refusal of the direct-push electrical conductivity probe. The subcontractor shall backfill the borehole with drill cuttings after each probing is completed. Any excess drill cuttings shall be spread on the ground surface around the borehole after each probing is completed.

End of current text

3.0 Contingencies and Site Procedures

3.1 Site Access

The locations where piezometers are to be installed and where soil conductivity measurements will be performed are accessible by existing roads or open ground. The subcontractor shall keep off-road driving to a minimum.

3.2 Site Conditions

The subcontractor shall be knowledgeable of general and local conditions that may affect the cost or quality of the performance of the work, including the ability of the subcontractor's equipment to perform the work. Refer to Article 40 of the Terms and Conditions for Subcontracts and Purchase Orders over $25,000 (GJO-PROC-114, August 1997)

3.3 Loss of Drilling Equipment and Hole Abandonment

Refer to Article 38 of the Terms and Conditions for Subcontracts and Purchase Orders over $25,000 (GJO-PROC-114, August 1997).

3.4 Source of Water

If needed, the subcontractor shall obtain clean potable water from an approved source for drilling and other tasks associated with the work scope. The subcontractor shall have the necessary equipment to obtain, transport, and store water for use at the site.

Tanks, hoses, pumps, and any other equipment used to transport or store the water shall be clean and free from all contamination. Further, the subcontractor shall protect the water from contamination during storage.

3.5 Equipment Cleaning

The subcontractor shall remove debris and any contamination from equipment with a high-pressure steam washer at the beginning of the drilling project and before leaving the project site. Water from the approved water source shall be used for all cleaning operations. The task leader will direct equipment cleaning and verify it clean when it is visibly free of all soil, oil, grease, and previous fluids. Radiological surveys will be performed by MACTEC–ERS radiation control technicians prior to release of equipment from the site.

3.6 Drill Cuttings and Fluid Disposal

The subcontractor shall backfill the borehole with drill cuttings and spread excess drill cuttings on the ground surface around the borehole after each probing is completed.

3.7 Trash Disposal

The subcontractor shall collect and dispose of job-generated trash in a site approved receptacle at least one time per day, at the end of each day, and maintain site housekeeping at all times.

3.8 Equipment Maintenance

The subcontractor may perform equipment maintenance, fueling, and repairs on location with the prior approval of the task leader. If, during this maintenance operation(s), the subcontractor spills any hydrocarbon-based fluid, antifreeze, or any other similar material, it shall immediately cleanup and remove the spilled material at its own time and expense. If, at any time, fluid leakage from any piece of the subcontractor's equipment, the subcontractor shall "diaper" the ground surface with plastic sheeting until the leak is fixed.

3.9 Daily Drilling Report

The subcontractor shall furnish to the task leader a completed and signed daily (or shift) drilling log that details all activities, rig functions, depths, pipe tallies, casing and other materials used, as well as any other pertinent project, or safety data (including "tailgate" safety meetings and "rig inspections"). This information shall be recorded on the Drilling Report furnished by MACTEC–ERS (Figure 3–1). The Drilling Report form shall also be examined and signed each day or shift by the task leader. Any errors found on this report by the task leader will be reported to the subcontractor as soon as possible for reconciliation.

3.10 Utilities Clearance

MACTEC-ERS will stake each proposed location 7-days prior to the start of work. The subcontractor shall then notify the utility companies through the Blue Stakes one-call (800-662-4111) utility locate service no earlier than 7-days and no later than 48-hrs prior to start of work (notice does not include weekends or holidays). The subcontractor shall provide the utility locate service with the following street address for the project site:

Former Atlas Millsite
1871 North Highway 191
Moab, UT 84532

MACTEC-ERS site safety personnel will coordinate and escort the utility locators to each site. MACTEC–ERS will verify all utilities located, such as power lines or pipelines, that might reasonably be expected to exist within the work area, prior to commencement of work in accordance with 29 CFR 1926.651(b). The subcontractor shall repair any damage to known utilities during the performance of the work. The liability of other repairs shall be in accordance with Article 73 of the Terms and Conditions (GJO–PROC–114).

3.11 Quality Assurance

A MACTEC–ERS representative will be present during the field activities. The subcontractor shall perform all fieldwork in accordance with the requirements, specifications, and procedures set forth herein. Periodic surveillance visits by other contractor personnel may be performed to verify the subcontractor's compliance with the requirements, specifications, and procedures set forth herein.

Upon request, the offeror shall provide additional information about previous site investigation work.

Grand Junction Office
2597 B ¾ Road
Grand Junction, CO 81503
(970) 248-6000

Drilling Report

State ________ County __________ Project ____________________ Hole Name ____________________ Hole No. __________

Drilling Contractor ______________________________ Rig Type ______________________________ Rig No. __________

From A.M. P.M	To A.M. P.M.	Footage			Drilling (check)					Description of Work
		From	To	Hole Size	Drl	Cor	Rem	Agr	Sam	

Materials Used (e.g., casing, cement, water, mud, etc.)	Remarks
	Drill Crew
	Driller ____________________
	Helper ____________________
	Helper ____________________
	Other ____________________

Contract Foreman ____________________ GJO Representative ____________________ Report No. ________________ Date__________

GJPO 1706 White—Return to GJO with Invoices(s) Canary—GJO Field Copy Pink—Rig Copy
Rev. 10/96

Figure 3–1. Drilling Report Form

3.12 Permits and Licenses

MACTEC–ERS will provide all necessary access permits, well permits, and any permits for cuttings/fluid disposal as required by Federal, State, or other controlling agencies. The subcontractor shall acquire any drilling and/or contractor license(s) and any other permits required by Federal, State, or other controlling agencies.

3.13 Material Storage Facility

The subcontractor shall provide and maintain covered storage for items that could be affected by inclement weather. MACTEC–ERS will provide a lockable fenced area for drilling supplies. All material stored in this facility shall remain the property of the subcontractor until such time that the material is used or consumed by the project requirements. The storage facility is subject to Occupational Safety and Health Administration (OSHA) requirements for such things as housekeeping and fire protection.

3.14 Inventory

Prior to commencing work, the subcontractor and the task leader shall conduct an inventory to ensure adequate materials and supplies to perform the work are on the site and usable.

3.15 Site Sanitation Facilities

Portable toilet facilities are available at the job site.

End of current text

4.0 Health and Safety

4.1 Safety Requirements and Briefings

The task leader, in collaboration with MACTEC–ERS Site Safety Supervisor, will be responsible for operational health and safety coverage during the drilling activities. All subcontractor personnel shall comply with the MACTEC–ERS operational health and safety regulations as outlined in the *Drilling Health and Safety Requirements*, MAC□2012, Revision 3, October 2000. The "Statement of Understanding" contained in the *Drilling Health and Safety Requirements* shall be signed by all subcontractor personnel prior to working on this project.

The subcontractor shall hold a safety tailgate meeting prior to the start of each day's work. All subcontractor personnel and MACTEC-ERS personnel working on that days shift shall attend. The topic of discussion and attendee signatures will be recorded on a form. A copy of each daily record will be submitted to the MACTEC–ERS task leader.

All work will be suspended by the task leader or the subcontractor when an unsafe practice or condition is observed. Work will not proceed until the unsafe practice or condition is corrected and the task leader, or designee, approves the resumption of work. The subcontractor will not be compensated for efforts or down time required to correct any unsafe practice or condition created by its actions.

Rigs, trucks and/or carriers shall conform to all applicable Federal, State, and local safety requirements and regulations. Each truck or carrier shall be equipped with two U.S. Department of Transportation (DOT) approved, fully charged 2A:40BC dry chemical fire extinguishers, with current inspection tags.

4.2 Training Requirements

All subcontractor personnel are required to have a minimum of 40 hour Hazardous Waste Site training and Radiation Worker Level II (2 days). If needed, the Radiation Worker Level II training will be provided to the subcontractor at no cost. Additionally, the subcontract crew will be working in PPE consisting of booties and gloves over Tyvek® coveralls provided by MACTEC–ERS at no cost to the subcontractor.

All subcontractor personnel working on this project shall be required to attend a pre-work briefing as soon as practical after the subcontractor has mobilized its equipment to the project site.

4.3 Equipment Inspections

The task leader will inspect the subcontractor's rig and all other subcontractor furnished equipment at the start of the project and at other times, as necessary, and record the conditions on an appropriate form. The subcontractor shall inspect its drilling equipment on a daily basis and record this on the Drilling Report each day. The subcontractor shall maintain and operate all of its equipment in accordance with all applicable regulations.

End of current text

5.0 Subcontractor Qualifications, Performance, and Requirements

5.1 Subcontractor Qualification

Due to the technical nature of the work, the subcontractor shall be a first-tier subcontractor to MACTEC–ERS, shall have a minimum of 3 years business experience in installation of piezometers and collection of soil conductivity measurements at environmental and hazardous waste sites, and shall have the ability to provide the necessary and required equipment. The subcontractor's operator shall have a minimum of 2 years experience in direct-push methods and collection and interpretation of soil conductivity data at environmental and hazardous waste sites.

The successful subcontractor shall be mobilized to the site and ready to commence work no later than June 18, 2002. An earlier start date may be acceptable. The subcontractor shall submit a work schedule with its proposal.

In the event of an award, the equipment proposed herein shall be the equipment used to perform the work.

5.2 Work Day and Rotation Schedule

The normal workday will consist of a minimum of 8 hours per day or through completion of a given piezometer installation or soil conductivity boring. The workday shall be limited to the period of time starting no earlier than one-half hour before sunrise and ending no later than one-half hour after sunset. In all cases, MACTEC–ERS reserves the right to limit the length of the workday based on safety concerns. The subcontractor is responsible for obeying all Federal and State labor laws, rules, and regulations. Holidays excepted, the normal work schedule will consist of a "10 days on, 4 days off" rotation and will begin on a Tuesday and end on Thursday of the following week, or as mutually agreed.

5.3 Weather Day

The subcontractor shall not be compensated for any delays caused by weather. A "weather day" applies to any normal workday when weather conditions deteriorate to the point that fieldwork is neither safe, nor practical. The task leader, in consultation with the subcontractor, will decide whether or not to continue work.

5.4 Standby Time

Standby time is lost work time caused by MACTEC–ERS activities. The subcontractor shall be paid in accordance with the stipulated standby time rate. Standby time will only be paid when authorized by the task leader. Standby time will not be paid for subcontractor equipment breakdown, missing subcontractor equipment, insufficient supplies, or missing or tardy subcontractor personnel.

5.5 Submittals

The submittals are listed below in Table 5–1.

Table 5–1. Submittal and Deliverable Schedule

Submittal	Schedule
MSDS sheets for all materials to be brought on site and chemical inventory. Include type and brand of downhole tool lubricants to be used.	At date of mobilization or delivery to the site
Copies of reports, logs, and other State of Utah required documents	Submit with final invoice
Specifications for soil conductivity probe and associated data collection equipment.	Submit with proposal
OSHA 200 log for 2000 and 2001	Submit with proposal
Radiation Worker Level II training (2-days) certificate	Submit with proposal
SARA 40-hr hazardous waste site training certificate	Submit with proposal
Final report documenting the work performed, copies of conductivity logs, ASCII data files, and a summary of the results and analysis.	20-days after completion of work

Appendix C

Standard Operating Procedures

(DOE [continually updated]. Grand Junction Office Environmental Procedures Catalog, GJO–6, U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado)

GENERAL SAMPLING PROCEDURES

Standard Practice for Field Documentation Processes [GT–1(P)]
Standard Practice for Sample Labeling [GT–2(P)]
Standard Practice for Chain–of–Sample–Custody Control and Physical Security of Samples [GT–3(P)]

GROUND WATER SAMPLING PROCEDURES

Standard Test Method for the Measurement of Water Levels in Ground Water Monitoring Wells [LQ–2(T)]
Standard Practice for Purging of Monitoring Wells [LQ–3(P)]
Standard Test Method for the Field Measurement of pH [LQ–4(T)]
Standard Test Method for the Field Measurement of Specific Conductance [LQ–5(T)]
Standard Test Method for the Field Measurement of the Oxidation–Reduction Potential (Eh) [LQ–6(T)]
Standard Test Method for the Field Measurement of Alkalinity [LQ–7(T)]
Standard Test Method for the Measurement of Temperature [LQ–8(T)]
Standard Test Method for the Measurement of Dissolved Oxygen [LQ–9(T)]
Standard Practice for the Use of a Flow Cell for Field Measurements [LQ–10(P)]
Standard Practice for the Sampling of Liquids [LQ–11(P)]
Standard Practice for the Collection, Filtration, and Preservation of Liquid Samples [LQ–12(P)]
Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells [LQ–18(P)]
Standard Test Method for Turbidity in Water [LQ–24(T)]

SOIL SAMPLING PROCEDURES

Standard Practice for Sampling Surface Soil, Sediments and Sludge [SL–3(P)]
Standard Practice for Operation of the Power Auger, Corer, and Demolition Hammer [SL–4(P)]

AQUIFER TESTING PROCEDURES

Standard Practice for Analyzing Slug Test Data for Estimating the Hydraulic Conductivity of Saturated Porous Media [LQ–15(P)]
Standard Test Method for Performing a Water Injection Test [LQ–17(T)]
Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells [LQ–18(P)]
Standard Test Method for Conducting Slug Tests in Aquifers [LQ–22(T)]
Technical Comments on ASTM D 5092—Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers [LQ–14(P)]

MAC-MOA 19.1.2

Sensitivity Analysis of Groundwater Flow and Transport Models for the Moab Project Site

Letter Report

June 2002

DRAFT FINAL

Prepared by
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract Number DE-AC13-96GJ87335
Task Order Number MAC02-16

MOAB PROJECT

Introduction

The U.S. Department of Energy (DOE) Grand Junction Office is developing an update to their Plan for Remediation for the Moab Project Site. The groundwater compliance strategy presented in the draft Plan for Remediation was formulated on the basis of modeling predictions prepared by the former trustee and its consultant Shepherd-Miller, Inc. (SMI). This report presents a review of the model and results of a sensitivity analysis performed by MACTEC–ERS (MACTEC) to better understand uncertainties in the groundwater compliance strategy presented in the draft Plan for Remediation. Results of the model review and sensitivity analysis will be used to update the site conceptual model and to lay the foundation for an updated flow and transport model.

During MACTEC's review of the SMI model (SMI 2001), it was discovered that Southwest Research Institute, a U.S. Nuclear Regulatory Commission (NRC) contractor, had completed an earlier modeling effort. MACTEC also evaluated that model, hereafter referred to as the NRC model.

The model evaluation was designed to address the following questions:

- What are the sensitive parameters for the current models?
- Are the site conceptual models and numerical models supported by site-characterization data?
- Do the current models adequately assess the effectiveness of the proposed remedial alternatives?
- Do the current models provide plausible estimates of time to achieve compliance?

Figure 1 shows a flow chart of the model evaluation process. SMI and NRC each used a transient model to evaluate three alternatives: no action, cap-in-place and source removal. This review describes and compares both the transient and steady-state models that were used by SMI and NRC. After the site conceptual model and numerical models are updated, DOE will compare the effectiveness of the cap-in-place and the relocate alternatives.

Steady-State Models

The steady-state models indicate how SMI and NRC conceptualized the site. The conceptual models are strikingly different. Figures 2 and 3 summarize the parameter values used in the SMI and NRC models, respectively. Figures 4, 5, and 6 present in plan view the distribution of boundary conditions and hydraulic parameters for both models.

Both SMI and NRC created models consisting of three layers. The NRC model is horizontally discretized (divided) into 90 rows and 70 columns having uniform widths of 100 feet (ft). Vertically, the NRC model consists of three layers having thicknesses of less than 20 ft, 30 ft, and 30 ft, from top to bottom, respectively. Hydraulic conductivity in the NRC model is uniform in the horizontal and vertical directions. In layers 1, 2, and 3, the horizontal hydraulic conductivities are 22 ft/day, 22 ft/day, and 2.2 ft/day, respectively. The origin for the NRC model is $x = 2185491.0$, $y = 6659578.9$, and rotation is 35 degrees.

The SMI model was discretized into 100-ft by 100-ft nodes using 78 rows and 75 columns. The thickness of the model layers varies. The total thickness of the model varies from approximately 10 to 140 ft. Horizontal hydraulic conductivity of the SMI model varies from 35 to 175 ft/day. The origin for the SMI model is $x = 2185907.3$, $y = 6659565.1$, and rotation is 42 degrees. The SMI model contains inactive cells in Layer 3 beneath the tailings pile. The purpose of these cells is to simulate assumed no-flow conditions in the Paradox Group that arguably underlie a portion of the site. The existence of, and depth to, this bedrock group below the site has not been confirmed with drill-hole data.

The SMI model was calibrated to water levels measured at 11 locations. The NRC model was calibrated to match the general pattern of head distribution rather than the head at a specific point. According to NRC, the calibrated model "matched measured interpolated water levels within ± 1.5 ft" (NRC 1998, p.4-1). To compare how well both models fit the same set of observed heads, head targets used by SMI were imported into the NRC model. Table 1 compares how both models matched the target heads. The ratio of standard deviation to range (in head) conveys a sense of how well both models match observed water levels. If the ratio of the root-mean-squared (RMS) error to the total head loss in the system is small, the errors are only a small part of the overall model response (Anderson and Woessner 1992). James Rumbaugh (Environmental Simulations, Inc., personal communication, July 13, 1998) uses as a goal to reduce the standard deviation/range-in-head to below 10 percent, and if practical, below 5 percent. SMI's ratio of 16 percent, versus NRC's ratio of 6.2 percent, indicates that the NRC model matches the observed water levels better than the SMI model.

NRC's model, however, has considerable bias, as evidenced by the negative residuals. SMI's model has the opposite bias because the residuals are positive. In an ideal model, the residuals should be evenly distributed about zero (Anderson and Woessner 1992). For example, the number of predicted heads that exceed measured heads should roughly equal the number of predicted heads that do not exceed.

Table 2 shows the sources and sinks for the water in both flow models. The SMI model assumes that bedrock units contribute approximately 80 percent of the water in the system. The NRC model assumes no bedrock recharge and that areal recharge and constant-head (Moab Wash) account for 60 percent and 40 percent of the water in the system, respectively. The SMI model, however, is transmitting approximately 10 times more water than the NRC model.

Approximately 75 percent of the outflow from the SMI model occurs as discharge to the Colorado River. The SMI model uses river cells, which function as head-dependent flux, to simulate the Colorado River. Conductance values and head values for the riverbed material are necessary to fully define river cells. SMI did not document whether actual field data support the choice of parameters used for the river cells. In contrast, the NRC model uses constant-head cells to simulate the river.

The remaining 25 percent of outflow from the SMI model is evapotranspiration (ET) from the salt cedar plant community. The SMI model simulates ET with the MODFLOW recharge package and represents the ET with a constant negative-recharge flux. The flux rate used in the model was obtained from a study of a salt cedar community in southeastern New Mexico (Weeks 1987). Use of the MODFLOW recharge package rather than the ET package implies that the salt cedar community constantly removes water from the aquifer, regardless of the depth to water and depth of root penetration. The ET package removes groundwater from the model as a function of the depth to water and root penetration.

From Table 2 it is clear that the bedrock formations are an important source of water in the SMI model. However, only a few drill holes at the site ever contacted bedrock (probably Moenkopi), and they were not instrumented to measure hydraulic head in the bedrock. Consequently, the assumed contribution of fresh water from Glen Canyon Group bedrock aquifers is not supported by data. Two water supply wells that tap the Glen Canyon Group do exist near the entrance to Arches National Park and obtain high quality water from along the Moab Fault Zone. One of them produces 12 gallons per minute (gpm) from a depth of 123 ft, and the other produces 30 gpm from a depth of 172 ft (Blanchard 1990). Static water level in both wells is approximately 100 ft below ground surface, indicating minimal artesian pressure.

In addition, recent salinity measurements made by MACTEC suggest that salinity increases with depth at the site. For upwelling to be an important source of freshwater at the site, the deeper groundwater would require a freshwater signature. Also, artesian pressures would increase with depth. Recent data collected at the site do not support either of these conditions.

SMI confirmed earlier work by others that brine exists beneath a lens of freshwater at the site. To explicitly account for the physical hydrologic system, the groundwater model should include the ability to simulate variable density. SMI represented the top of the brine with a no-flux boundary condition and used MODBRINE, an external FORTRAN program, to adjust the MODFLOW layer in accordance with the Ghyben-Herzberg relation to account for brine encroachment into the freshwater/brine transition zone. NRC did not account for the movement of the brine at all.

The NRC model assumes that constant-head exists at the mouth of Moab Wash. Although there may be some contribution to ground water from Moab Wash during runoff events, and possibly a baseflow component, there does not appear to be a constant head. The term "constant head" implies that a truly limitless source of water exists at that location. The Colorado River, for example, is considered a constant head. Because Moab Wash only flows ephemerally, it cannot be considered a limitless source of water. The use of a constant head boundary at this location, coupled with a constant head boundary along the Colorado River, results in overprescribed boundaries in this model. It will be shown later that the NRC model is practically insensitive to the choice of flow parameters because the boundaries are overprescribed.

Figure 7 presents the steady-state water level contours for both models. As shown in Figure 7, a large portion of the SMI model contains dry cells in Layer 1. The dry cells probably form because the model cells in Layer 1 are excessively thin and do not intersect the groundwater. Elimination of dry cells in the SMI model would improve overall reliability of the model. The NRC model has no dry cells.

Sensitivity Analysis

According to Anderson and Woessner (1992), "The purpose of sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses, and boundary conditions. During a sensitivity analysis the calibrated values for hydraulic conductivity, storage parameters, recharge, and boundary conditions are systematically changed within the previously established plausible range."

Sensitivity analyses are conducted to identify model parameters and boundary conditions that influence model results. Figures 2 and 5 show that hydraulic conductivity in the SMI model covers a range of 139 individual zones and that the highest hydraulic conductivities occur downgradient of the tailings pile. Many of these hydraulic conductivity zones have such limited areal extent that varying them has little effect on the simulated water levels. This is illustrated in Figure 8 by selecting the five zones with the largest areal extent and evaluating their sensitivity. K zones 35, 49, 50, 60, and 99 (ft/day) each have the five largest areal extents and practically no sensitivity over model outcome. Therefore, zones with smaller areal extent would be even less sensitive.

Layers 1 and 2 of the NRC model are each composed of hydraulic conductivity values of K = 22 ft/d, while layer 3 is set to 2.2 ft/d. As shown in Figure 8, there is practically no effect on simulated water levels if the hydraulic conductivity of just one layer is varied. However, if the hydraulic conductivity of Layers 1 and 2 is reduced by more than 50 percent, the residual error increases markedly. The absence of a conductive layer is what forces the water table higher when Layers 1 and 2 conductivities are lowered.

Model sensitivity to recharge and boundary conditions was also evaluated. Figure 9 presents the results of these evaluations for the SMI and NRC models. These analyses show that the SMI model is somewhat sensitive to 10-fold reductions in riverbed conductance in Layer 1 and general-head boundary conductance in Layer 3. In addition, the model is affected by intensifying the negative-recharge parameter that describes the salt cedar community. Figure 9 shows that the NRC model is sensitive to recharge if it increases twofold over the baseline condition.

Table 1. Comparison Summary of Head Calibration for SMI and NRC Models.

Location	Error in SMI Model	Error in NRC Model
AMM-3	1.702225	−1.201362
MW-2-R	−0.200000	−0.781634
TP-03	0.093928	−0.559923
AMM-2	1.159346	−0.960588
ATP-2-S	1.832740	−0.926606
ATP-3	−0.548388	−0.495153
TP-01	0.160512	Located in no-flow region
TP-02	0.074529	−0.630841
TP-08	1.535670	−1.034620
TP-09	1.430725	−0.914757
AMM-1	0.257954	−0.034251
Res. std. dev	0.816904	0.318721
Sum of squares	12.453255	6.700590
Range	5.100000	5.100000
Std/range	0.160177	0.062494

Table 2. Water Balance Summary for SMI and NRC Models

Model	Flow Component	Inflow (ft^3/day)	Outflow (ft^3/day)	Percent Error
SMI	Lateral inflow from bedrock	22,802		
	Vertical upwelling from bedrock	62,744		
	Colorado River[a]	15,469	76,941	
	Recharge	3866		
	"Negative" recharge[b]		24,800	
	Total	104,881	101,741	3.0
NRC	Constant head	4796	10,729	
	Recharge	5976		
	Total	10,772	10,729	0.4

[a]Includes minor contribution from Courthouse Wash
[b]Consists of evapotranspiration in salt cedar plant community

UCODE Simulations

Model evaluation was performed using UCODE (Poeter and Hill 1998), a universal inverse modeling program developed as a collaborative project between the U.S. Geological Survey and the International Groundwater Modeling Center at the Colorado School of Mines, in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station. Inverse modeling, or parameter estimation modeling, is an automated calibration technique that works by finding parameter values (e.g., hydraulic conductivities, recharge) that minimize the sum of the squares errors, also called the objective function or objective function value, for a given model configuration.

For this application, the goal was not to obtain optimal calibrated parameter values; rather, it was assumed that the parameter values in the models were optimal. UCODE was only used to determine the sensitivities, parameter calibration statistics (standard deviation and 95 percent confidence intervals), and correlations, if any, of the calibrated parameters used in the two models.

With UCODE, it is possible to evaluate the head component of head-dependent boundaries rather than simply the conductance component. Therefore, the UCODE simulations are especially diagnostic when head-dependent boundaries are being investigated.

SMI Model

Table 3 summarizes the UCODE results for the SMI model. The results show that regardless of target type most parameters are relatively insensitive. The exceptions are heads associated with the general-head and river boundaries. Insensitive parameters are difficult to calibrate because changes in parameter values produce minimal changes in the predicted target values. However, parameter sensitivity can sometimes be improved with use of different or additional targets.

Due to the relatively large number of parameters to be evaluated and the shortage of targets, not all the parameters could be evaluated simultaneously for the head-target, and head-target and flux-target evaluations. There were sufficient targets to evaluate all parameters simultaneously when using head, flux, and prior information. To calculate 95 percent confidence intervals, standard deviations, and correlations, the number of targets must exceed the number of parameters to be estimated by at least one (Poeter and Hill 1998). To overcome this limitation, the UCODE evaluation was performed by dividing the parameters into three groups: (1) hydraulic conductivities and recharge, (2) hydraulic conductivities and general-head conductances and heads, and (3) hydraulic conductivity and river conductances and heads. The statistics generated by UCODE are a function of the number of parameters estimated. Thus, the reported statistics are not completely representative of the statistics for the entire parameter ensemble. However, comparison of the magnitude of the calculated hydraulic conductivity 95 percent confidence limits for the three evaluation groups shows that values change minimally, suggesting that the reported values do provide some indication as to how representative the targets are.

In general, regardless of target types used in the evaluation, the predicted 95 percent confidence intervals for the parameters are large, indicating the targets used to calibrate the model do not contain enough information to uniquely calibrate the flow model. The confidence intervals for the five hydraulic conductivity parameters are greatly reduced with the introduction of prior information about those parameters. However, prior information should be used judiciously, because the prior information may not be entirely representative.

In general, parameters cannot be estimated independently if their correlation factors exceed 0.95 (Poeter and Hill 1998). Significant parameter correlation occurs in the SMI model when head targets and head-and-flux targets are used to calibrate the model. In these cases, parameters cannot be estimated independently; rather, one of the correlated parameters must be fixed before model calibration can proceed.

In summary, the targets used to calibrate the SMI groundwater flow model do not hold enough information to uniquely calibrate the flow model, as shown by the relatively low parameter sensitivities, large ranges in the 95 percent confidence interval, and significant correlation between parameters.

NRC Model

Table 4 summarizes the NRC model UCODE results. Each of the parameters is relatively insensitive, regardless of target type. Insensitive parameters are difficult to calibrate because changes in parameter values produce minimal changes in the predicted target values.

The large range between the upper and lower 95 percent confidence intervals for the head-target and head-and-flux target scenarios indicate that the parameters are insensitive. The confidence intervals represent the likely precision of the parameter estimates for a given set of targets. Different target types, locations, and numbers will result in different 95 percent confidence intervals. Thus, 95 percent confidence intervals quantify how well the target values represent the model as configured and not the accuracy of the simulated conceptual model. The simulated conceptual model may or may not be representative; the targets simply do not contain enough information to prove or disprove the configuration.

Table 3 : Summary of Parameter Estimation Results for the SMI Model

Scenario	Head Targets				
Parameter	**Lower 95 percent CI**	**Calibrated Value**	**Upper 95 percent CI**	**Standard Deviation**	**Composite Sensitivity**
K1	-4.53e4	35	4.54e4	1.05e4	0.02
K2	-8.34e3	50	8.44e3	1.95e3	0.24
K3	-8.15e3	75	8.30e3	1.91e3	0.13
K4	-1.12e4	100	1.14e4	2.63e3	0.32
K5	-1.63e4	175	1.66e4	3.82e3	0.06
Recharge 1	-8.81e-1	2.28e-4	8.81e-1	2.05e-1	0.03
Recharge 2	-5.05e-1	4.46e-4	5.06e-1	1.17e-1	0.05
Recharge 3	-1.34	-8.00e-3	1.33	3.10e-1	0.28
RIV 1 Con	-5.42e4	2500	5.92e4	1.78e4	0.14
RIV 2 Con	-2.95e5	2500	3.00e5	9.36e4	0.03
RIV 1 Head	-	variable	-	4.08e-8	1.02e12
RIV 2 Head	-2.64e3	3951.91	1.05e4	5.19e2	345
GHB 1 Con	-6.12e4	50	6.13e4	4.82e3	0.07
GHB 2 Con	-2.63e4	50	2.64e4	2.08e3	0.55
GHB 1 Head	-1.48e4	3958	2.27e4	1.47e3	111.00
GHB 2 Head	3.91e3	3958	4.01e3	3.87	15110.0
Head and Flux Targets					
K1	-7.32e3	35	7.39e3	2.63e3	0.15
K2	-9.34e2	50	1.03e3	3.54e2	1.22
K3	-1.90e3	75	2.05e3	7.10e2	0.73
K4	-9.50e2	100	1.15e3	3.78e2	3.63
K5	-7.90e3	175	8.25e3	2.91e3	0.05
Recharge 1	-2.98e-2	2.28e-4	3.03e-2	1.08e-2	0.26
Recharge 2	-5.00e-2	4.46e-4	5.09e-2	1.82e-2	0.16
Recharge 3	-1.17e-1	-8.00e-3	1.01e-1	3.94e-2	2.98
RIV 1 Con	-3.77e4	2500	4.27e4	1.56e4	0.43
RIV 2 Con	-3.12e4	2500	3.62e4	1.31e4	0.25
RIV 1 Head	-	variable	-	4.43e-12	9.33e11
RIV 2 Head	3.81e3	3951.91	4.09e3	1.13e-2	2471
GHB 1 Con	-4.01e3	50	4.11e3	1.28e3	0.38
GHB 2 Con	-2.12e2	50	3.12e2	8.23e1	4.41
GHB 1 Head	3.74e3	3958	4.18e3	6.91e1	518.00
GHB 2 Head	3.96e3	3958	3.96e3	5.69e-1	14220.0
Head, Flux, and Prior Information Targets					
K1	3.3	35	66.7	13.8	0.15
K2	4.7	50	95.3	19.6	1.22
K3	7.1	75	143.0	29.5	0.73
K4	9.4	100	191.0	39.3	3.63
K5	16.4	175	334.0	68.8	0.05
Recharge 1	-1.76e-3	2.28e-4	2.21e-3	8.61e-4	0.26
Recharge 2	4.73e-5	4.46e-4	8.45e-4	1.73e-4	0.16
Recharge 3	-1.04e-1	-8.00e-3	8.84e-2	4.18e-2	2.98
RIV 1 Con	2.35e2	2500	4.76e3	9.82e2	0.43
RIV 2 Con	2.35e2	2500	4.77e3	9.82e2	0.25
RIV 1 Head	-	variable	-	1.08e-8	9.33e11
RIV 2 Head	3.89e3	3951.91	4.02e3	2.74e1	2.47e3
GHB 1 Con	4.70	50	95.3	1.96e1	0.38
GHB 2 Con	4.70	50	95.3	1.96e1	4.41
GHB 1 Head	3.82e3	3958	4.09e3	5.92e1	518.00
GHB 2 Head	3.94e3	3958	3.97e3	5.93	14220.0

Parameter Correlation

Head Targets	Head and Flux Targets	Head, Flux and Prior Information Targets
Kx1 – Kx2 : 0.96 Kx1 – R3 : -0.97 R1 – R2 : -0.97 Kx4 – GHB1 head : 0.98 RIV2 conductance – RIV2 head : -0.96	RIV2 conductance – RIV2 head : -0.96 GHB1 conductance – GHB1 head : -0.99	None greater than absolute 0.95.

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Table 4 : Summary of Parameter Estimation Results for the NRC Model

Scenario	Head Targets				
Parameter	Lower 95 percent CI	Calibrated Value	Upper 95 percent CI	Standard Deviation	Composite Sensitivity
K1	-7.37e2	22	7.81e2	3.10e2	1.19
K2	-8.93e3	22	8.98e3	3.66e3	0.10
K3	-5.61e3	2.2	5.62e3	2.29e3	0.01
Recharge 1	-6.76e-3	2.00e-4	7.16e-3	2.84e-3	1.27
	Head and Flux Targets				
K1	-1.24e3	22	1.29e3	5.35e2	1.67
K2	-2.09e4	22	2.10e4	8.86e3	0.13
K3	-1.28e4	2.2	1.29e4	5.43e3	0.01
Recharge 1	-3.79e-3	2.00e-4	4.19e-3	1.69e-3	2.98
	Head, Flux, and Information Targets				
K1	15.3	22	28.7	2.99	1.67
K2	15.1	22	28.9	3.08	0.13
K3	1.51	2.2	2.89	0.31	0.01
Recharge 1	7.28e-5	2.00e-4	3.27e-4	5.71e-5	2.98

Parameter Correlation

Head Targets	Head and Flux Targets	Head, Flux and Prior Information Targets
None greater than absolute 0.95.	Kx1 and Kx2 : -1.00 Kx2 and Kx3 : -0.95 Kx3 and R1 : 1.00	None greater than absolute 0.95.

In general, parameters having correlation factors greater than 0.95 or less than –0.95 cannot be estimated independently (Poeter and Hill 1998). For the NRC model, significant parameter correlation exists when both heads and flux targets are used simultaneously. As shown in Table 4, hydraulic conductivities of zones 1 and 2 are perfectly inversely correlated. Similarly, hydraulic conductivities of zones 2 and 3 are almost perfectly inversely correlated. Finally, hydraulic conductivity of zone three and recharge are perfectly correlated. Correlated parameters cannot be estimated independently; rather, one of the correlated parameters must be fixed before model calibration can proceed.

In summary, the targets used to calibrate the NRC groundwater flow model do not hold enough information to uniquely calibrate the flow model, as shown by the relatively low parameter sensitivities, large 95 percent confidence interval range, and significant correlations (for head and flux targets) between parameters.

Transient Simulations

Predictive simulations for DOE's remediation plan are based on three alternatives: no action, cap in place, and source removal.

As a rule, initial conditions, or initial heads, must be specified in order to run a transient model. SMI and NRC each used outputs from their steady-state models to set initial heads for their respective transient models. In addition, the SMI transient model used K_d values obtained from literature for the ammonium and uranium of 0.00637, and 0.00159 (assumed units of ft^3/lb_{mass}), respectively. These K_d values were also assigned to the NRC Model to conduct this study.

No Action Alternative

Table 5 shows the processes that were considered in the no action alternative. The no action alternative assumes that the tailings pile is left in place in its present condition. The assumed long-term infiltration rate through the pile is 1×10^{-7} centimeters per second (cm/s) (3.9 gpm). This infiltration rate represents 14 percent of average annual precipitation. Transient drainage of water stored in the tailings pile occurs during the first 25 years of the simulation; it conveys 21.6 million cubic feet of water to the alluvial ground water system during the 25-year period. The transient-flow contribution is derived from modeling done by SRK Consulting (2000). Because vertical band drains were installed in the tailings pile during the past 2 years, and the volume of water recovered from those drains has not been monitored continuously, the transient flow component is considered a sensitive model parameter. Figure 10 shows time-concentration plots of the predicted ammonia and uranium concentrations using both the SMI and NRC models for the no action alternative. These results show that the no action alternative will not meet the 0.044 mg/L ground water standard for uranium within 100 years. The SMI model indicates that concentrations would decrease markedly and that uranium levels would begin dropping below the standard after approximately 200 years. The NRC model shows that little to no reduction in concentrations would occur through the entire simulation. The difference in the two models is that the observation wells in the SMI model are located in the salt cedar zone, where negative recharge removes contaminated ground water at a constant rate and eventually restores the aquifer. Particle tracking simulations show that the particles originating at the tailings pile would be captured in the salt cedar zone.

Cap-in-Place Alternative

Table 5 summarizes the cap-in-place alternative. The conceptualization of this scenario is similar to the no action alternative except infiltration through the tailings pile is restricted to a rate of 1×10^{-8} cm/s (0.39 gpm) with a cover constructed of engineered fill. Transient drainage from the tailings pile is assumed to occur for 25 years, as in the no action alternative. Figure 11 presents the results for SMI's and NRC's cap-in-place simulations. Both models predict that this alternative would fail to achieve compliance with standards within 100 years. However, SMI's cap-in-place model shows that concentrations would decline faster than with the no action alternative. NRC's cap-in-place model shows that concentrations would be one order of magnitude lower than with the no action alternative.

Source Removal Alternative

Table 5 summarizes the source removal alternative. The concept of this alternative is that the tailings are removed and no longer provide a source of contaminated pore water. The area of the model formerly occupied with tailings has a recharge that matches the areal recharge value of approximately1 $\times 10^{-7}$ cm/s. The K_d values for the ammonium and uranium are practically zero, as mentioned above. However, using K_d values that are practically zero, the most favorable of scenarios for groundwater cleanup, natural flushing still fails to reduce the uranium concentrations in the floodplain aquifer even after 100 years. Figure 12 presents the results for the SMI and NRC source removal models.

Table 5. Summary of Processes Considered During This Evaluation

Remedial Action Alternative	Processes Considered
No action	• Initial conditions from steady-state model • Transient drainage considered • 1×10^{-7} cm/s infiltration rate through cell • Pore water chemistry of cell • Initial concentrations of NH_4, U, and SO_4 • 500-year projection
Cap in place (with natural flushing)	• Initial conditions from steady-state model • Transient drainage considered • 1×10^{-8} cm/s infiltration rate through cell • Pore-water chemistry of cell • Initial concentrations of NH_4, U, and SO_4 • 500-year projection
Source removal	• Initial conditions from steady-state model • Transient drainage considered • 1×10^{-7} cm/s infiltration rate through cell • Pore water concentration = 0 at tailings site • 500-year projection
Cap in place (with active treatment)	Not evaluated

Conclusions

- UCODE modeling shows that both models contain boundary conditions that may be correct; however, the conditions are not supported with existing data. Therefore, neither model can adequately assess the effectiveness of the proposed remedial action.

- Single-parameter sensitivity analysis and UCODE modeling show that both models are insensitive to the choice of boundary conditions and parameter values—K, recharge, general-head, and river-cell conductances and heads.

- Both models are based on site conceptual models that may be correct; however, they are not consistent with data sets. An alternate conceptual model should be developed that matches the existing data sets more closely.

- The SMI and NRC models are at opposite ends of the spectrum with respect to the water budget: the SMI model is on the high end, and the NRC model is on the low end. Neither model shows that natural flushing will be effective as a stand-alone strategy at removing uranium concentrations to levels below the 0.044 mg/L standard in 100 years. Because the two existing models probably bracket the actual water budget for the site, it is probably safe to conclude that natural flushing will be an ineffective strategy if relied upon exclusively.

SMI Model

- The SMI model assumes that lateral inflow and upwelling from the Glen Canyon Group contributes 80 percent of the freshwater in the flow system; however, there are no site characterization data that support the assumption. Moreover, previous borehole logs at the site identified bedrock as Moenkopi Formation.

- UCODE modeling results show that SMI's choice of head and conductance values in the general-head boundaries and river-cell arrays may be correct; however, they are not supported with data collected at the site.

- The SMI model uses negative recharge to remove groundwater from the flow system. The negative recharge flux value is obtained from a study performed in southeastern New Mexico and is unconfirmed with site data. In the model, negative recharge is 100-percent efficient; therefore, it does not account for the depth to groundwater, evapotranspiration-extinction depth, and seasonal fluctuations.

- Transient drainage from the tailings is assumed to occur over 25 years and contribute 21.6×10^6 ft^3 of pore water to the flow system. This estimate is based on modeling performed by SRK Consulting (2000). The value does not account for consolidation water already drained from the tailings pile and is thus conservative.

- The SMI model uses a spatially variable hydraulic conductivity field that honors the point hydraulic conductivity measurements at three locations, and contains interpolated values elsewhere.

- SMI represented the top of the brine with a no-flux boundary condition and used MODBRINE, an external FORTRAN program, to adjust the layer thickness in MODFLOW to account for brine encroachment into the freshwater/brine transition zone.

- For a model of floodplain alluvium, the SMI model contains an excessive number of dry cells. These cells do not add value to either the steady-state model or the transient model that uses the steady-state heads for initial conditions.

NRC Model

- The NRC model assumes that constant head exists at the mouth of Moab Wash. Although there may be some contribution of water from Moab Wash due to underflow and ephemeral flow, the use of constant head is not supported with site data.

- Head calibration for the NRC model meets minimum acceptance criteria recommended by leaders in the modeling profession; however, there is considerable bias in all the calibration targets.

- Because constant head cells are established on both the upgradient and downgradient faces of the flow model, the NRC model is overprescribed with head boundaries. Single parameter sensitivity analysis and UCODE modeling show the model is not particularly sensitive to either hydraulic conductivity or recharge.

- The NRC model did not account for variable density effects of the brine.

- Transient drainage from the tailings is assumed to occur over 25 years and contribute 21.6×10^6 ft^3 of pore water to the flow system. This estimate is based on modeling performed by SRK Consulting (2001). The value does not account for consolidation water already drained from the tailings pile and is thus conservative.

Recommendations

(1) Develop a revised site conceptual model. The revised site conceptual model would be developed from appropriate field data described in (2) below. Components of the revised site conceptual model would consist of defining the following:

- Boundary conditions at the mouth of Moab Wash.
- Flux component along the contact regions between the alluvium and bedrock.
- Flux component from underlying bedrock (Paradox Formation and Glen Canyon Group).
- Boundary conditions at the mouth of Courthouse Wash.
- Contribution of water and chemical mass from the tailings pile.
- Magnitude of evapotranspiration flux.
- Chemical source conditions near the uranium "hot spot" near the former millsite.
- Water budget values for each flow component.
- Location of and equivalent freshwater head values for brine and brackish ground waters.
- 3-dimensional schematic drawing of the site showing all boundaries and fluxes.

(2) Obtain the following characterization data:

- Identify subcropping bedrock formations and measure top of bedrock elevations.
- Nested monitoring wells to monitor bedrock/alluvium interaction.
- Collect piezometer data in the tailings pile.
- Density of equivalent freshwater head values for brine and brackish ground waters.
- Measure the volume of all liquids released during consolidation of the tailings pile.
- Characterize evapotranspiration along salt cedar zones.

(3) Ensure the numerical model contains verifiable targets, boundary conditions, and flow parameter values.

(4) Establish head targets and flux targets; define calibration-acceptance criteria for future numerical modeling.

(5) Identify a numerical code that accounts for variable density explicitly and begin 2-dimensional cross-section simulations of flow and transport.

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FIGURES

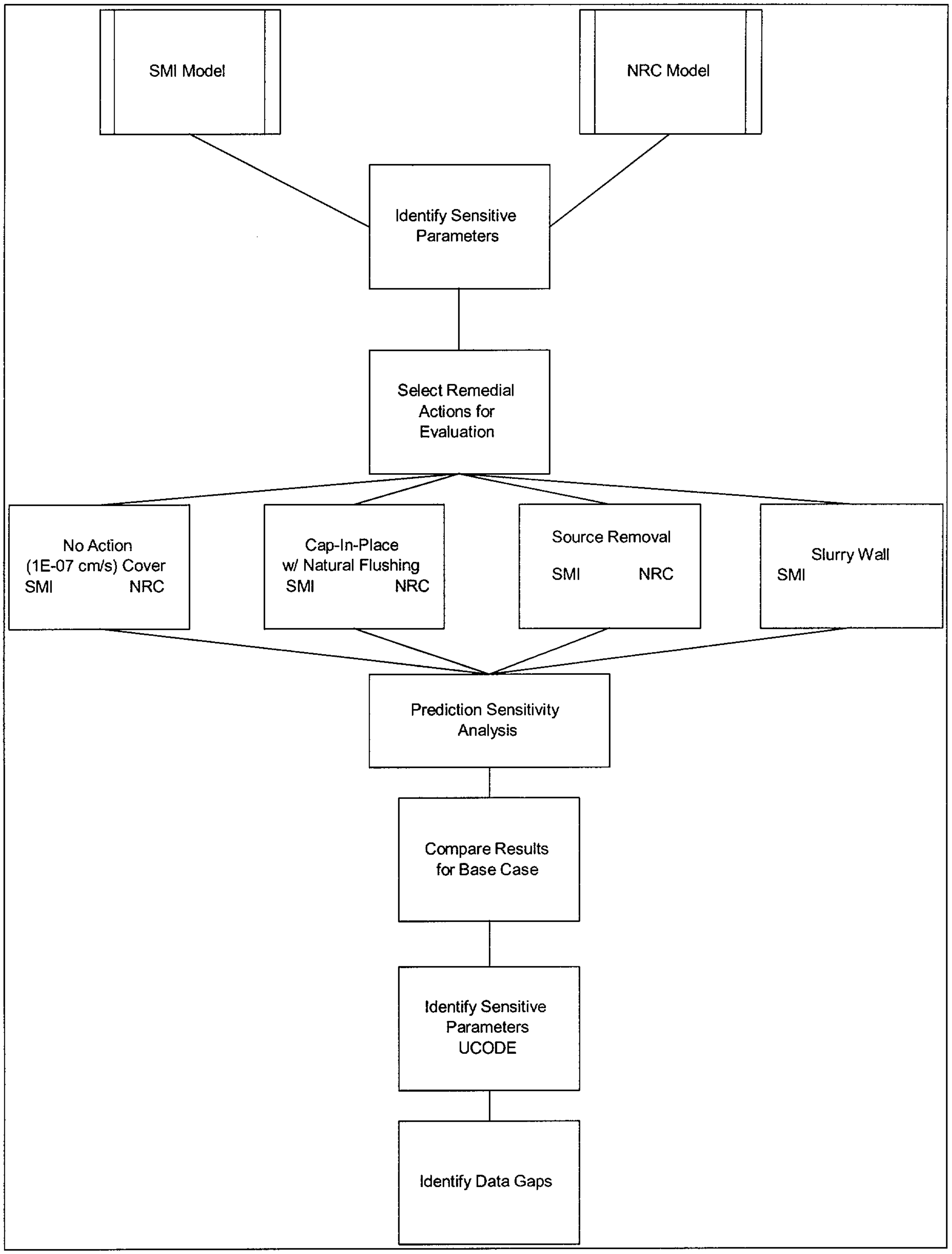


Figure 1. Model Review Process

SMI's steady state model

Steady-State Model
Aquifer Properties

Parameter	Dimensions	Layer 1	Layer 2	Layer 3	
Aquifer Flow Hydraulic Parameters					
Horizontal hydraulic conductivity (K_h)	feet per day	Ranges 35–50	Ranges 49–174	Ranges 60–174	
Vertical hydraulic conductivity (K_v)	feet per day	Ranges 4.2–6.0	Ranges 5.9–20.9	Ranges 7.2–20.9	
Specific yield (S_y)	dimensionless	0.25	Ranges 0.1–0.28	Ranges 0.1–0.276	
Storage coefficient (S)	dimensionless	0.0077	Ranges 0.0002–0.0092	Ranges 0.0002–0.009	
Porosity	dimensionless	0.35	0.35	0.35	
Aquifer Transport Parameters					
K_d	cubic feet per pound	0	0	0	
Aquifer bulk density		157	157	157	
Dispersivity	feet	0	0	0	

Recharge Amounts

Area/Feature	Recharge Rate (ft/day)
Areal recharge	0.000228
Disposal cell	0.000446
Evapotranspiration areas	–0.008

Figure 2. Summary of Parameters for SMI Steady-State Model

Steady-State Model
Aquifer Properties

Parameter	Dimensions	Layer 1	Layer 2	Layer 3
Aquifer Flow Hydraulic Parameters				
Horizontal hydraulic conductivity (K_h)	feet per day	22	22	2.2
Vertical hydraulic conductivity (K_v)	feet per day	22	22	2.2
Specific yield storage coefficient (S_y)	dimensionless	0.01	0.01	0.01
Storage coefficient (S)	dimensionless	0.01	0.01	0.01
Porosity	dimensionless	0.01	0.01	0.01
Aquifer Transport Parameters				
K_d	cubic feet per pound	0	0	0
Aquifer bulk density	pounds per cubic foot	157	157	157
Dispersivity	feet	0	0	0

Recharge Amounts

Area/Feature	Recharge Rate (feet per day)
Areal recharge	0.0002
Disposal cell	0.0002
Evapotranspiration areas	0.0002

Figure 3. Summary of Parameters used in NRC Steady-State Model

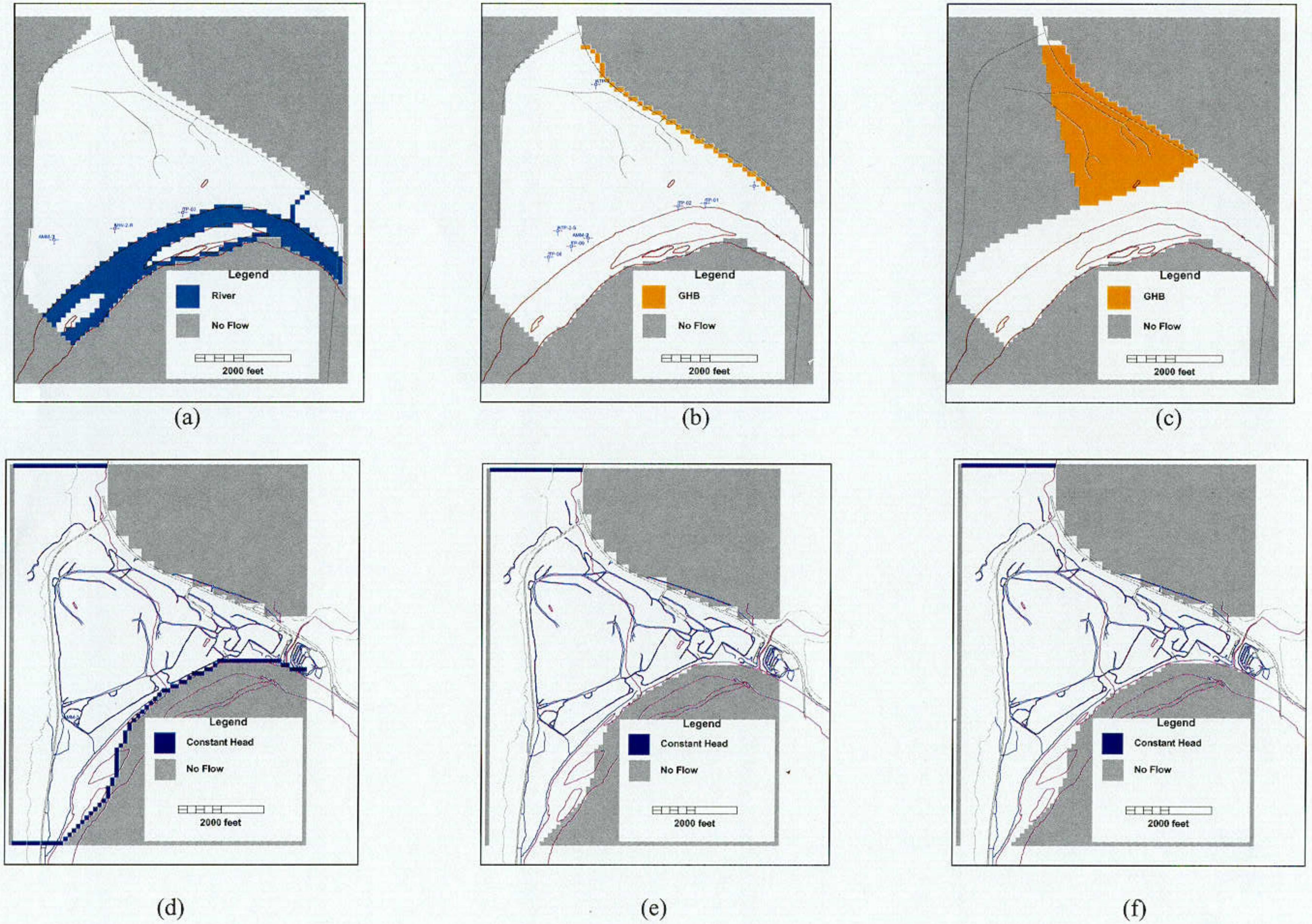


Figure 4. Boundary Conditions for SMI Model (a) Layer 1, (b) Layer 2, (c) Layer 3, and NRC Model (d) Layer 1, (e) Layer 2, (f) Layer 3

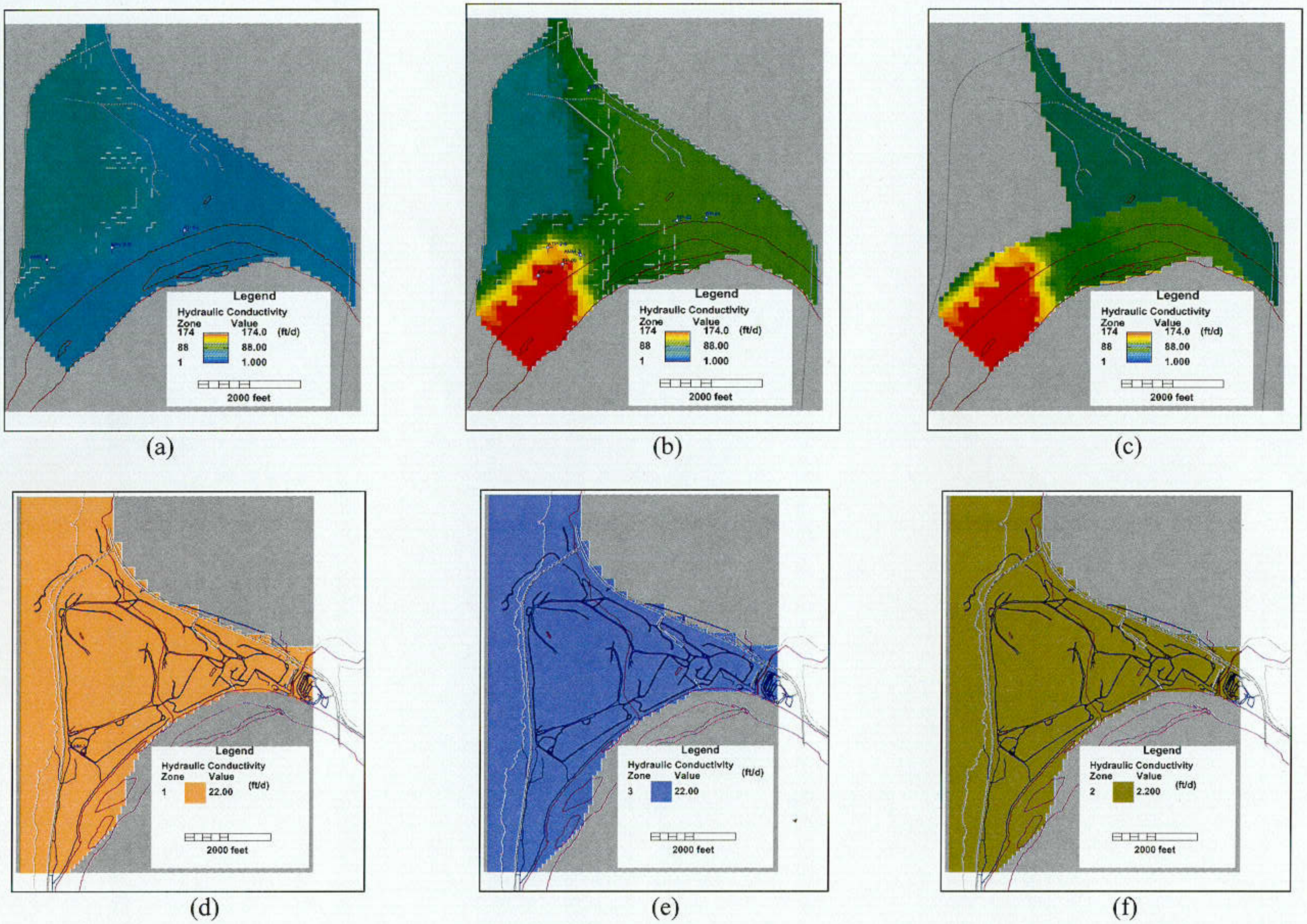
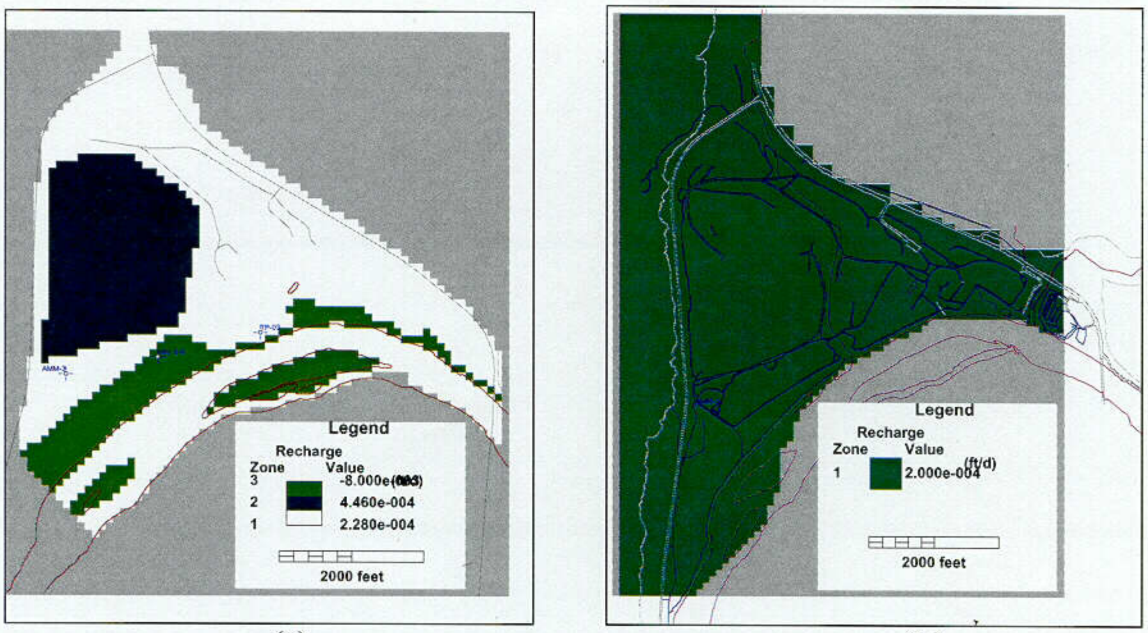
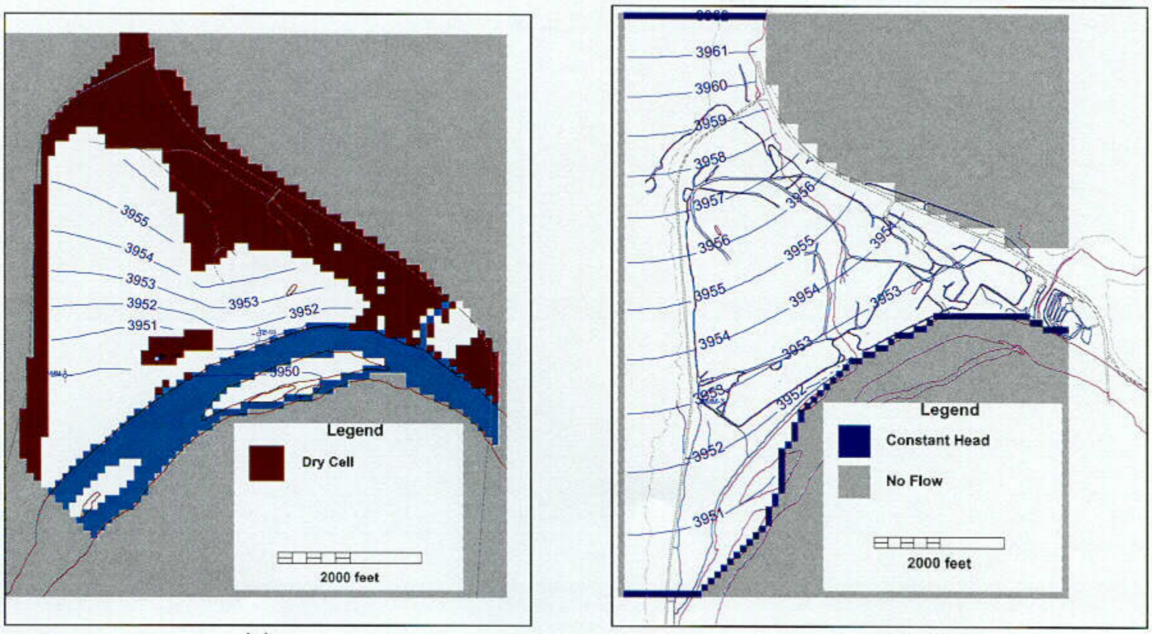


Figure 5. Hydraulic Conductivity for SMI Steady-State Model (a) Layer 1, (b) Layer 2, (c) Layer 3, and NRC Steady-State Model (d) Layer 1, (e) Layer 2, (f) Layer 3



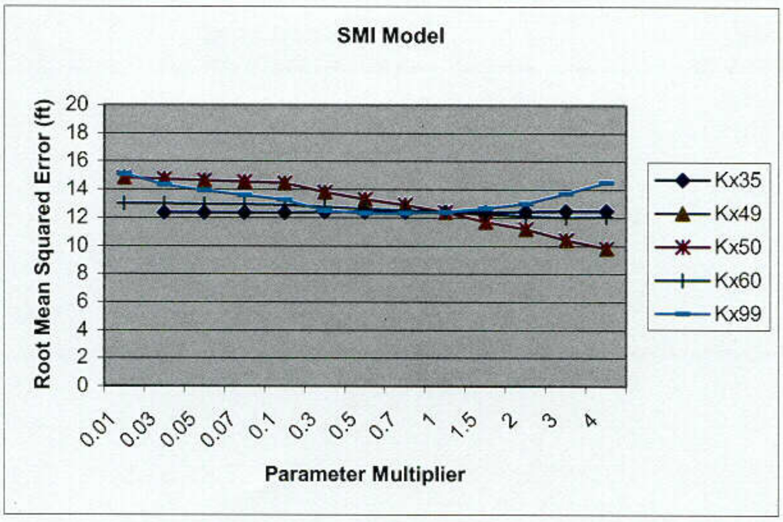
(a) (b)

Figure 6 Recharge Values for (a) SMI Steady-State Model and (b) NRC Steady-State Model



(a) (b)

Figure 7. Simulated Groundwater Contours in Layer 1 of (a) SMI Steady-State Model, and (b) NRC Steady-State Model



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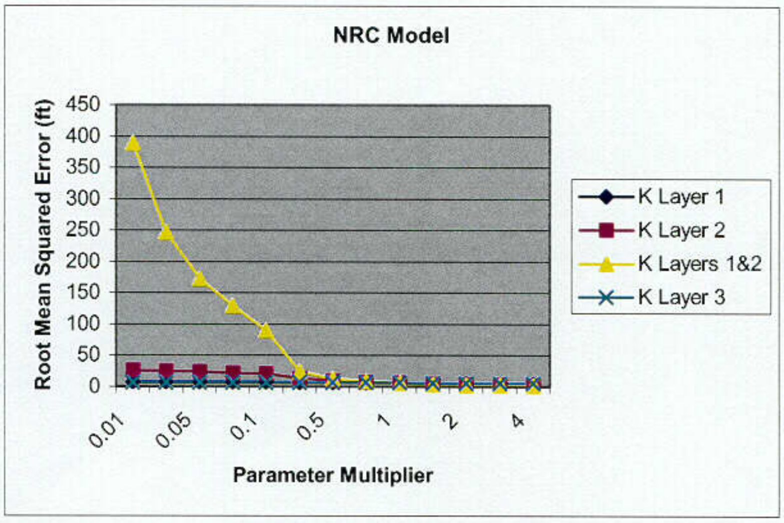
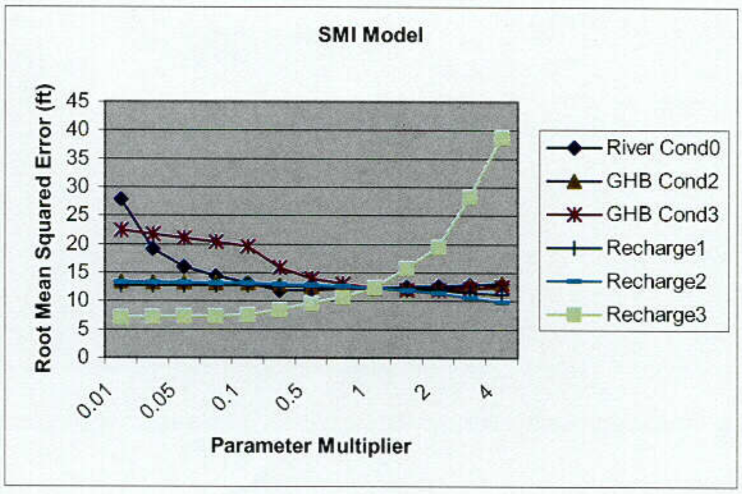


(b)

Figure 8. Sensitivity Analysis of Hydraulic Conductivity Parameter for (a) SMI Model and (b) NRC Model



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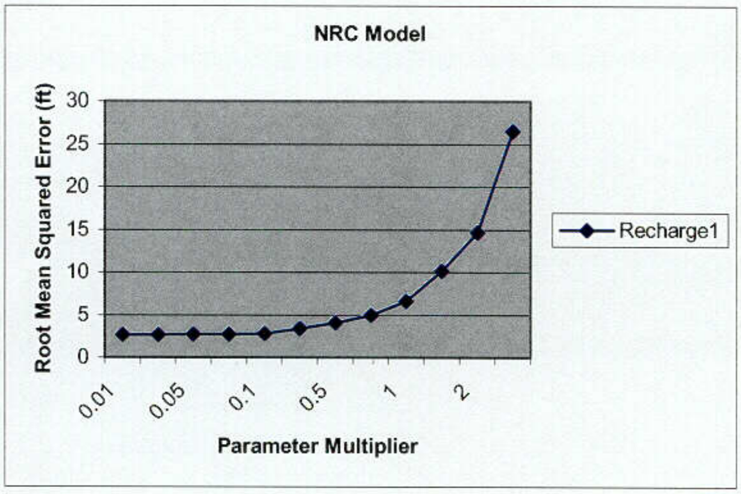
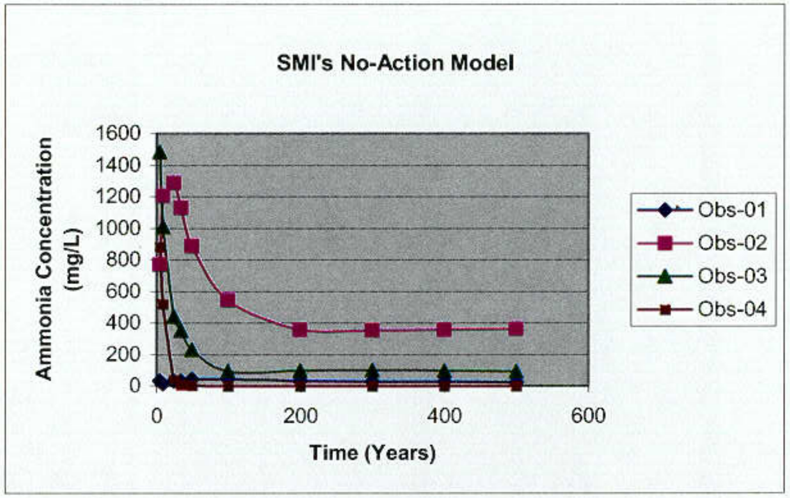


(b)

Figure 9. Sensitivity Analysis of (a) Boundary Conditions and Recharge for SMI Model and (b) Recharge for NRC Model



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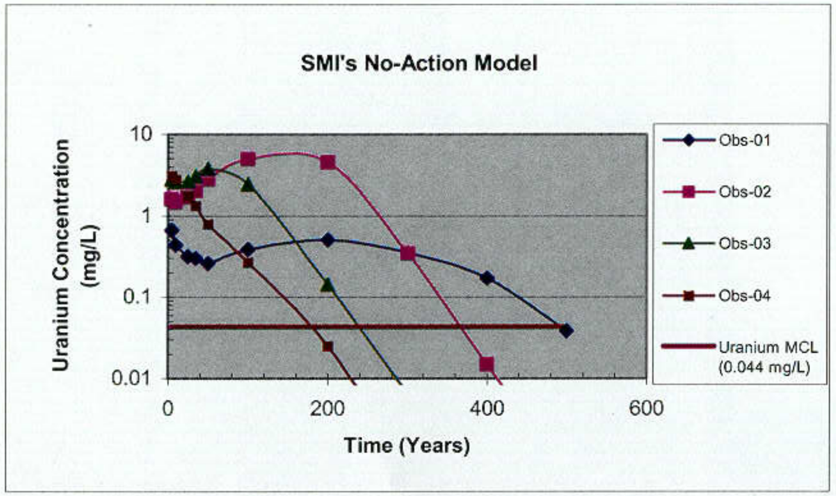

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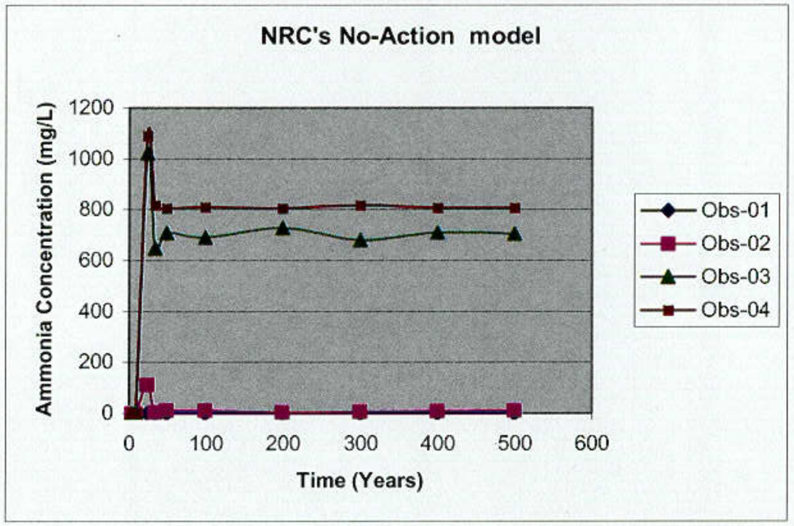

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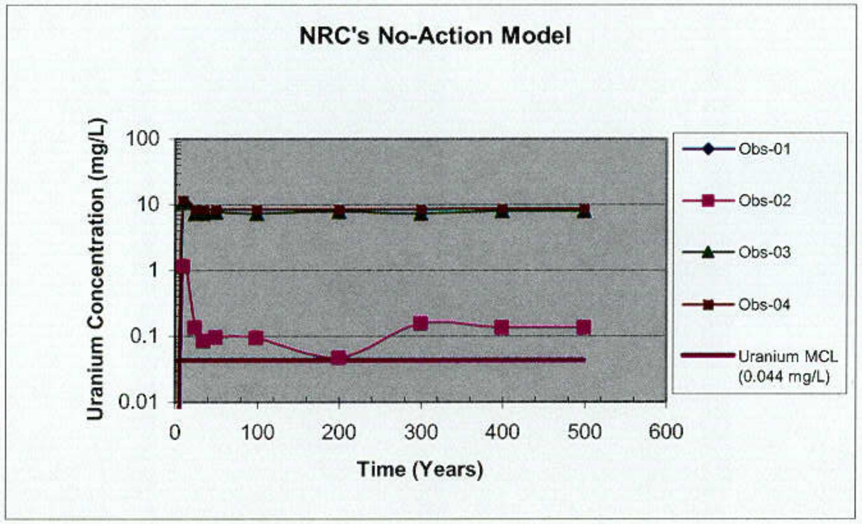
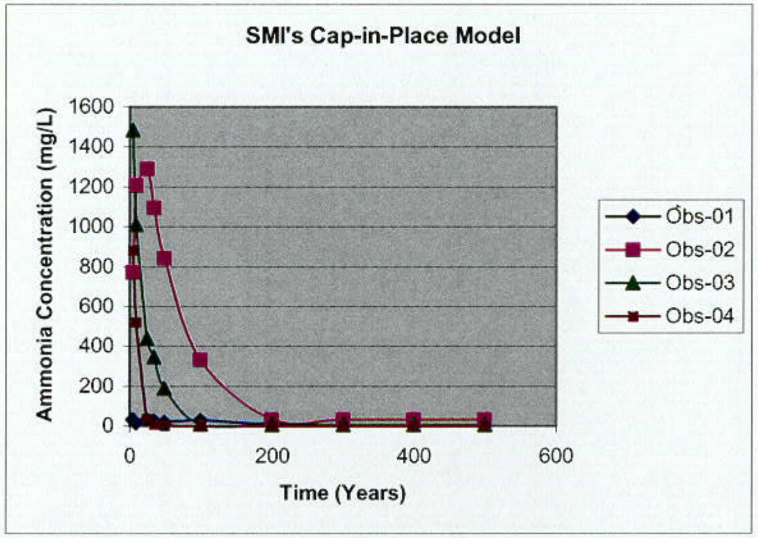
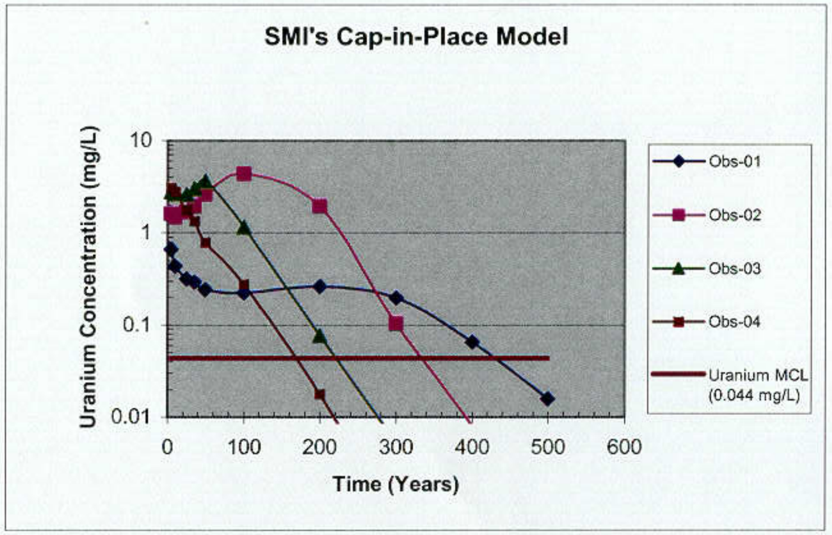


(d)

Figure 10. Comparison of Model-Predicted Concentrations of (a) Ammonia and (b) Uranium Computed with SMI No Action Model Versus (c) Ammonia and (d) Uranium Concentration Computed with NRC No Action Model



(a)



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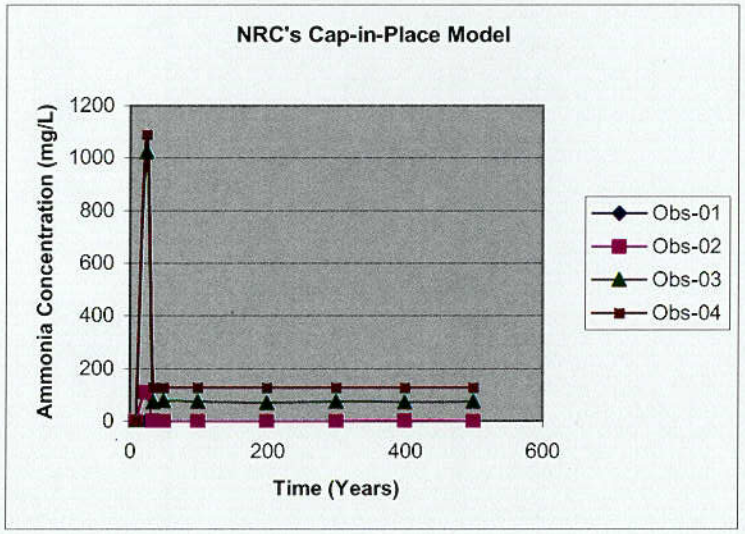
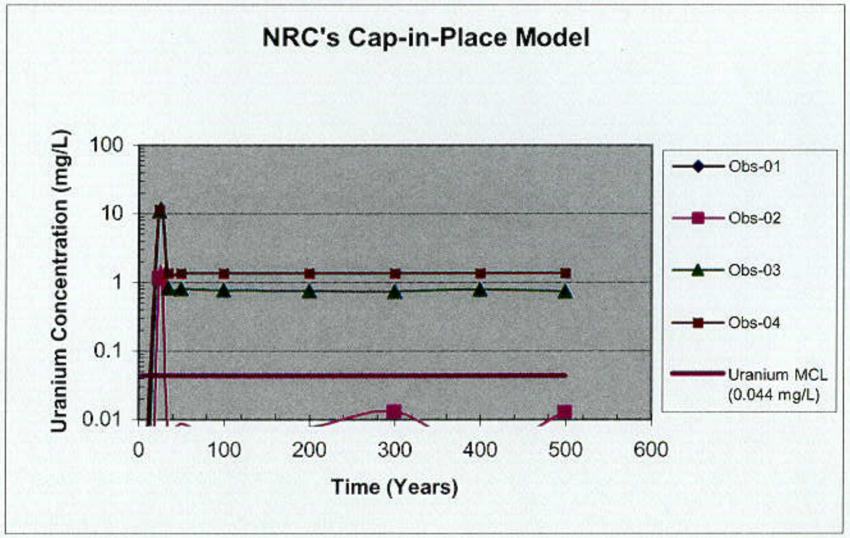


(c)



(d)

Figure 11. Comparison of Model-Predicted Concentrations of (a) Ammonia and (b) Uranium Computed with SMI Cap-in-Place Model Versus (c) Ammonia and (d) Uranium Concentration Computed With NRC Cap-in-Place Model

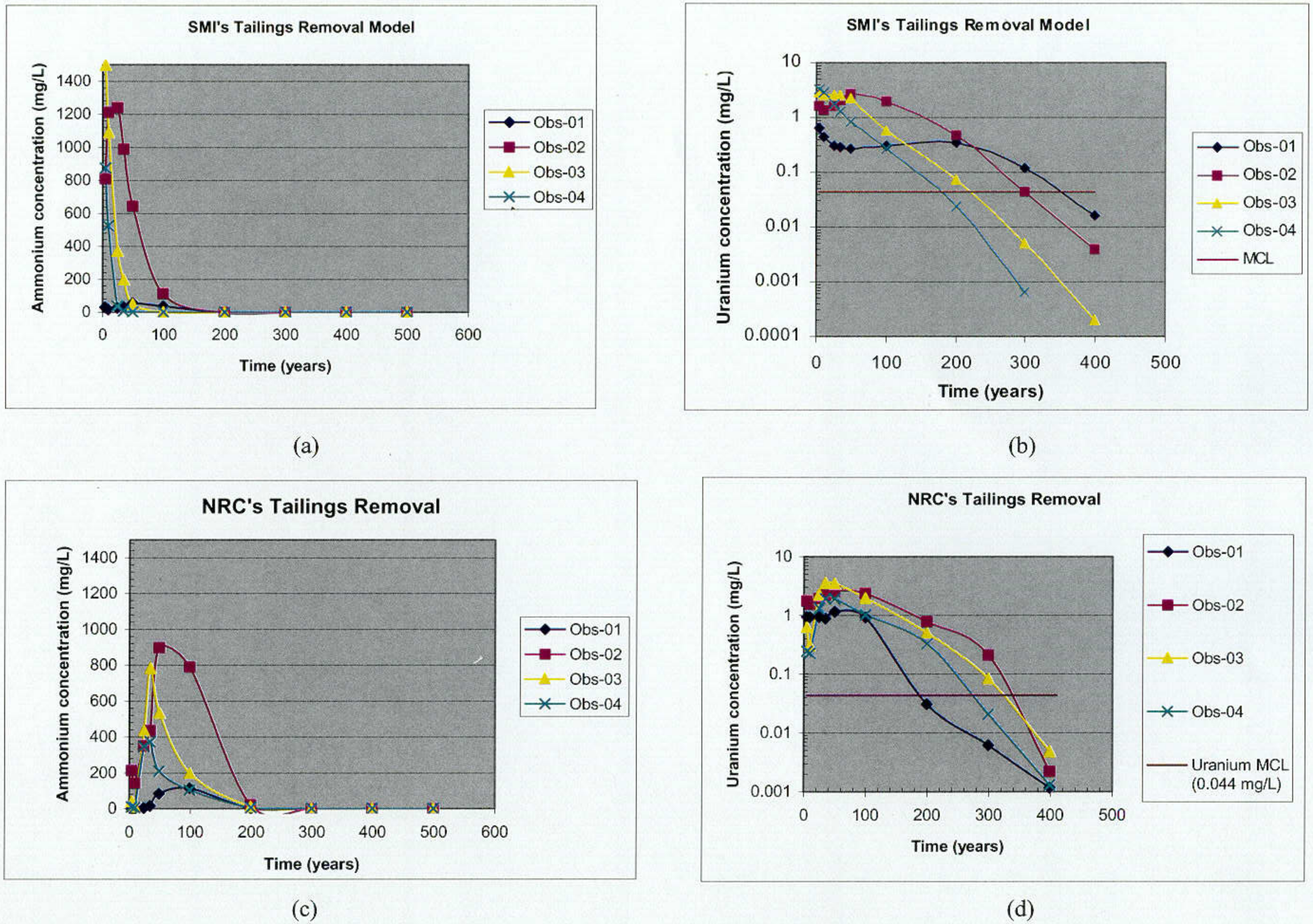


Figure 12. Comparison of Model-Predicted Concentrations of (a) Ammonia and (b) Uranium Computed with SMI Source-Removal Model Versus (c) Ammonia and (d) Uranium Concentration Computed with NRC Source-Removal Model