U.S. Department of Energy
Grand Junction Office
2597 B 3/4 Road
Grand Junction, CO 81503

SEP 28 2001

Mr. Melvyn Leach, Chief
U.S. Nuclear Regulatory Commission
Fuel Cycle Licensing Branch
Division of Fuel Cycle Safety & Standards
Mail Stop T8A33
Washington, D.C. 20555-0001

Subject: Draft *Site Observational Work Plan* for the Slick Rock, Colorado, UMTRA Site

Dear Mr. Leach:

Enclosed is a copy of the draft *Site Observational Work Plan* for the Slick Rock, Colorado, UMTRA site. Please review this document and provide comments to me by November 30, 2001.

If you have any questions, please call me at (970) 248-7612.

Sincerely,

Donald R. Metzler, P.Hg.
Technical/Project Manager

Enclosure

cc w/enclosure:
M. Fliegel, NRC

cc w/o enclosure:
S. Marutzky, MACTEC-ERS
File GWSKR 1.1 (P. Taylor)

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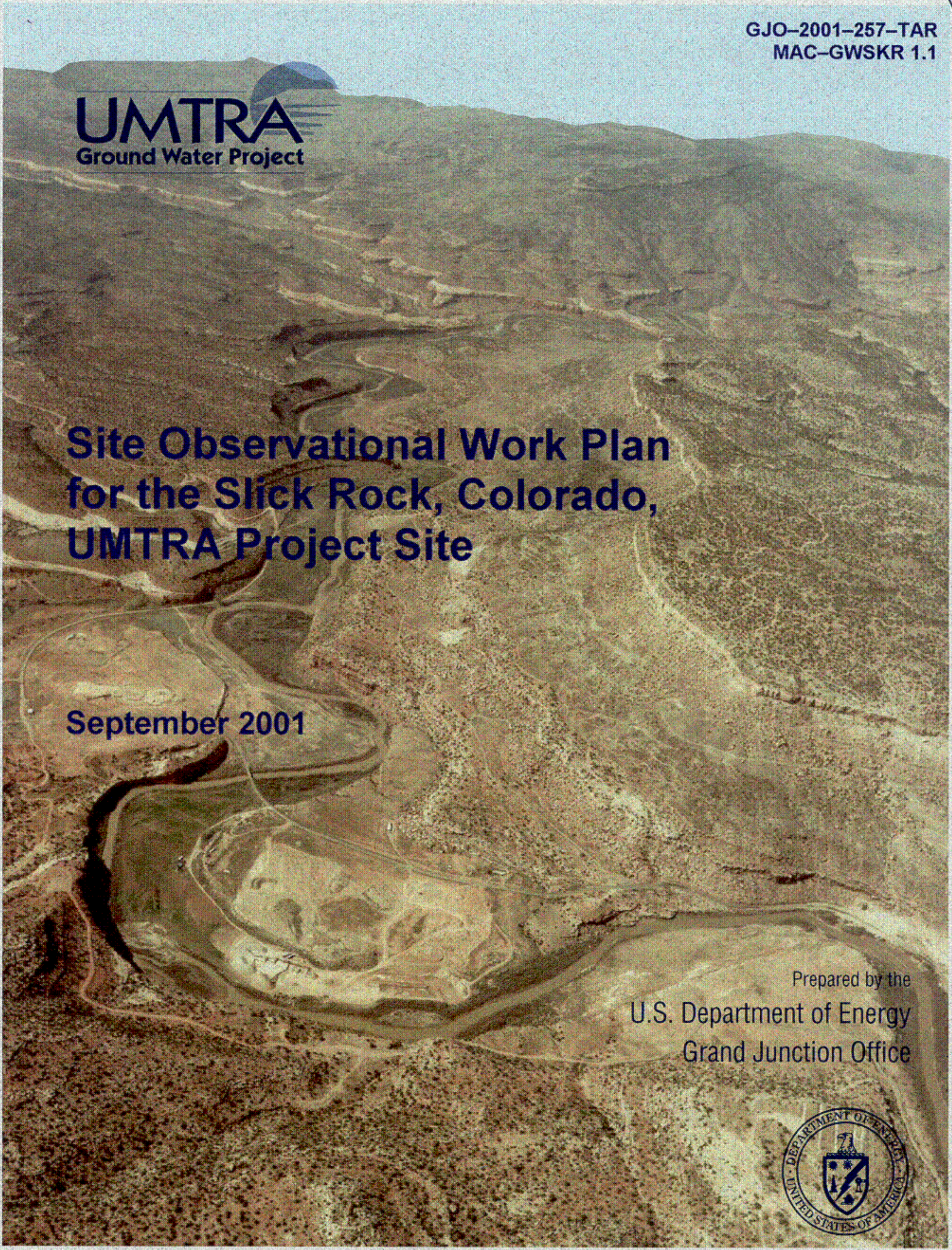

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UMTRA
Ground Water Project

Site Observational Work Plan for the Slick Rock, Colorado, UMTRA Project Site

September 2001

Prepared by the
U.S. Department of Energy
Grand Junction Office

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Site Observational Work Plan for the Slick Rock, Colorado, UMTRA Project Site

September 2001

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Acronyms and Abbreviations

ACL	alternate concentration limit
AES	atomic emission spectrometry
ASTM	American Society for Testing and Materials
BLRA	baseline risk assessment
BTEX	benzene, toluene, ethylbenzene, and xylene
CD	compact disk
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
EA	environmental assessment
ECL	environmental checklist
E-COPC	ecological constituent of potential concern
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESL	Environmental Sciences Laboratory
FOD	frequency of detection
ft	foot (feet)
ft/day	feet per day
ft^2	square feet
g	gram
GCAP	Ground Water Compliance Action Plan
GJO	Grand Junction Office
gpm	gallon per minute
HI	hazard index
HNO_3	nitric acid
HQ	hazard quotient
IC	institutional control
ICP	inductively coupled plasma
Kd	distribution coefficient
LTMP	Long-Term Management Plan
LTSP	Long-Term Surveillance Plan
MAP	Management Action Process
MCL	maximum concentration limit
µg/L	microgram per liter
µm	micrometer(s)
mg	milligram
mg/kg	milligram per kilogram
mg/L	milligram per liter
mL	milliliter
mL/g	milliliter per gram
mL/min	milliliter per minute
mm	millimeter(s)
MS	mass spectrometry
MSL	mean sea level

NC	North Continent
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
NTU	nephelometric turbidity unit
ORP	oxidation-reduction potential
OVA	organic vapor analyzer
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PEIS	Programmatic Environmental Impact Statement
POC	point of compliance
POE	point of exposure
RAP	Remedial Action Plan
RBC	risk-based concentration
Rd	distribution ratio
ROD	record of decision
RRM	residual radioactive material
SDWA	Safe Drinking Water Act
SEE	Site Environmental Evaluation (database)
SOWP	Site Observational Work Plan
TAGR	Technical Approach to Ground Water Restoration
TDS	total dissolved solids
UC	Union Carbide
UCL_{95}	95 percent upper confidence limit
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey

Executive Summary

The Slick Rock Uranium Mill Tailings Remedial Action (UMTRA) Project site consists of two former uranium-ore processing facilities located in San Miguel County, Colorado. These sites are referred to as the North Continent (NC) and Union Carbide (UC) sites. Ground water beneath the sites has been contaminated by past vanadium and uranium milling operations that were conducted from 1931 to 1961. Remediation of uranium mill tailings and other contaminated surface material associated with the former milling operations at the site was completed in 1996 under the UMTRA Surface Project. The contaminated materials were placed in a disposal cell approximately 5 miles east of the Slick Rock site.

An evaluation of historical data indicated additional investigation was needed to complete the characterization of the Slick Rock site and to select a strategy for compliance with UMTRA ground water clean-up standards. A field investigation was conducted in August and September 2000 to address the data deficiencies identified during the evaluation. Data from the investigation were used to finalize the conceptual site model.

Contaminants of potential concern (COPCs) at the NC site are uranium and selenium. Uranium is the most prevalent contaminant, and ground water in the majority of the alluvial wells at the NC site contains uranium in concentrations above the UMTRA Project maximum concentration limit (MCL) of 0.044 milligrams per liter (mg/L); maximum concentrations are up to 2 mg/L. Selenium contamination is less prevalent with samples from only one well that had concentrations exceeding the UMTRA MCL of 0.01 mg/L. The maximum concentration was less than 0.04 mg/L, which is below EPA's primary drinking water standard of 0.05 mg/L for selenium. Bedrock beneath the NC site alluvium consists of interbedded mudstones, siltstones, and sandstones of the Summerville and Morrison Formations. Because of the predominance of fine-grained material in these formations, vertical migration of contaminated alluvial ground water was assumed to be minimal; therefore, the uppermost aquifer at the NC site is defined as the alluvial aquifer.

At the UC site, COPCs are manganese, molybdenum, nitrate, selenium, radium-226, radium-228, uranium, benzene, and toluene. Manganese, molybdenum, nitrate, and selenium are major contaminants with concentrations one to two orders of magnitude above their respective MCLs (background for manganese) and are widely distributed in the uppermost aquifer. For compliance purposes, the uppermost aquifer is defined as the alluvium and the underlying Entrada Sandstone, which are in hydraulic communication. Minor contaminants include radium-226, radium-228, uranium, benzene, and toluene, which are present in concentrations only marginally exceeding their respective standards or which have been detected in only a small portion of the uppermost aquifer. The Navajo Sandstone, which underlies the Entrada Sandstone, has an upward vertical hydraulic gradient with respect to the uppermost aquifer and has not been affected by site contaminants.

To achieve compliance with Subpart B of 40 CFR 192 at the NC site, DOE is proposing the strategy of natural flushing in conjunction with institutional controls (ICs) and continued monitoring. Ground water flow and transport modeling has predicted that concentrations of uranium and selenium in the alluvial aquifer will decrease to levels below their respective MCLs within 100 years.

To achieve compliance with Subpart B of 40 CFR 192 at the UC site, DOE proposes the strategy of natural flushing for all COPCs in conjunction with an alternate concentration limit (ACL) for selenium. This strategy will include an IC and continued monitoring until cleanup goals are achieved. Ground water flow and transport modeling predicts that concentrations of molybdenum, manganese, nitrate, and uranium will decrease to levels below their respective MCLs within 100 years. For benzene, toluene, radium-226, and radium-228, it is anticipated that natural biological and geochemical processes will reduce these contaminants to MCL levels in the ground water within 100 years.

Ground water flow and transport modeling predicts that concentrations of selenium will not be reduced below the MCL within 100 years; therefore, DOE proposes an ACL at the risk-based human health drinking water benchmark of 0.18 mg/L. The flow and transport modeling predicts that selenium concentrations in the uppermost aquifer will be below the benchmark within 100 years.

An IC will be required at both sites during the natural flushing period to restrict access to the uppermost aquifer in order to protect human health. Because the property overlying the contaminant plumes at both sites is wholly owned by UMETCO, a covenant is being proposed to attach to the respective property deeds that will restrict access to the ground water in the uppermost aquifer for the 100-year time frame or until monitoring shows that the ground water compliance objectives have been met. DOE is currently working with UMETCO to develop deed restriction language similar to what is attached to the deeds of other former millsite locations in Colorado that have been conveyed from the State of Colorado to a local municipality.

A site-specific monitoring program will be implemented at each site to verify protection of the Dolores River, evaluate the progress of natural flushing, and assess compliance with applicable standards and remedial goals. At the end of 10 years, an evaluation will be made in consultation with U.S. Nuclear Regulatory Commission and the State of Colorado to re-evaluate the requirements for future monitoring at the Slick Rock site.

1.0 Introduction

1.1 Purpose and Scope

The Slick Rock Uranium Mill Tailings Remedial Action (UMTRA) Project site consists of two former uranium-ore processing facilities, which are referred to as the North Continent (NC) and Union Carbide (UC) sites. The former Slick Rock processing sites are located along the banks of the Dolores River in San Miguel County, Colorado (Figure 1–1). Steep juniper-covered hillsides and cliffs of the Dolores River Canyon surround the sites. The UC site is approximately 1 mile downstream from the NC site.

The U.S. Department of Energy (DOE) completed surface remediation of abandoned uranium mill tailings and other contaminated surface residual radioactive material (RRM) associated with the former milling operations at the site by relocating the contaminated materials to a disposal cell approximately 5 miles east of the Slick Rock site. Surface remedial action began in 1995 and was completed in 1996. The former processing sites have been regraded with on-site material and reseeded.

DOE's goal is to implement a cost-effective ground water compliance strategy at the Slick Rock site that is protective of human health and the environment. This Site Observational Work Plan (SOWP) documents the site-specific strategy that will allow DOE to comply with UMTRA ground water standards at the Slick Rock site and provides a mechanism for stakeholder participation, review, and acceptance of the recommended remedial alternative. The SOWP is based on UMTRA Project programmatic documents mentioned in Section 1.2. After initial assessment of site characterization information, it was decided to use an abbreviated *Summary of Site Conditions and Work Plan* (DOE 2000a) instead of the traditional SOWP Rev. 0 because the amount of additional work required was thought to be relatively minor. This has expedited the process and led directly to this final version of the SOWP.

Compliance requirements for meeting the regulatory standards at the Slick Rock site are presented in Section 2.0. Site background information, including physical setting, current water and land use, and an overview of the history of the former milling operations and surface remedial activities is reviewed in Section 3.0. A summary of 2000/2001 field investigations is presented in Section 4.0. Site-specific characterization of the physical system and contaminant configuration are synthesized in the conceptual site model in Section 5.0. Assessment of human health and ecological risk is provided in Section 6.0. The process for selecting the ground water compliance strategy is presented in Section 7.0, along with information on institutional controls and monitoring activities.

1.2 UMTRA Project Programmatic Documents

Programmatic documents that guide the SOWP include the *UMTRA Ground Water Management Action Process* (MAP) (DOE 1998), the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project* (PEIS) (DOE 1996), and the *Technical Approach to Ground Water Restoration* (TAGR) (DOE 1993a). The MAP states the mission and objectives of the UMTRA Ground Water Project and provides a technical and management approach for conducting the project. The PEIS is the programmatic decision-

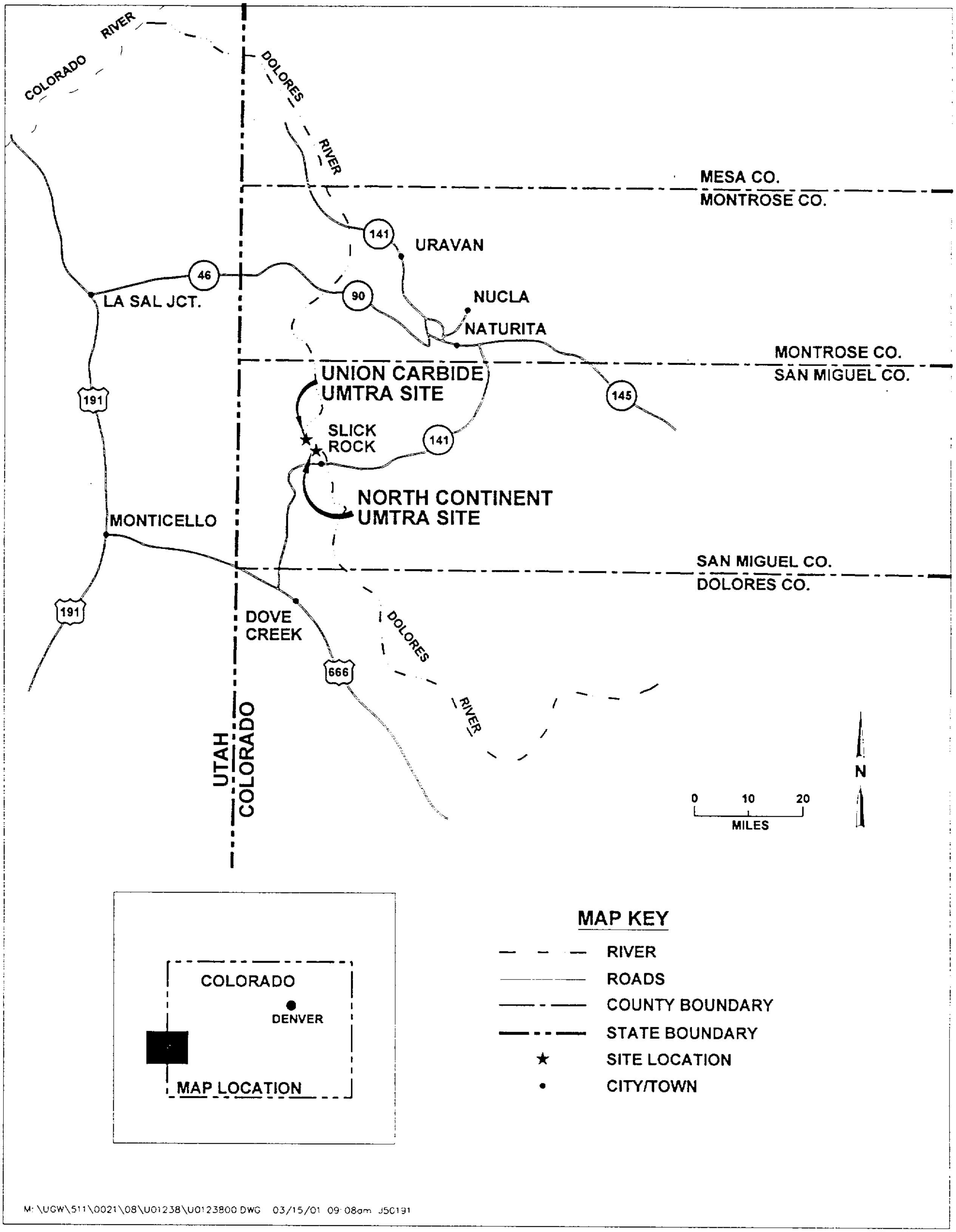

Figure 1–1. Site Location Map

making framework for conducting the UMTRA Ground Water Project. DOE will follow PEIS guidelines to assess the potential programmatic impacts of the Ground Water Project, to determine site-specific ground water compliance strategies, and to prepare site-specific environmental impact analyses more efficiently. Technical guidelines for conducting the ground water program are presented in the TAGR.

1.3 Relationship to Site-Specific Documents

The surface Remedial Action Plan (RAP) (DOE 1995a) provides early site characterization information. This information has been updated in developing this version of the SOWP to strengthen the conceptual site model. After a ground water compliance strategy is selected for the site, a Ground Water Compliance Action Plan (GCAP) will be prepared to document the remediation decision. The GCAP will be the concurrence document for compliance with Subpart B of 40 CFR Part 192 for the former Slick Rock processing sites and will provide details of the required ground water monitoring program.

A Baseline Risk Assessment (BLRA) (DOE 1995b) was prepared that identified potential public health and environmental risks at the site. Potential risks identified in the BLRA are considered and updated in this SOWP to ensure that the proposed compliance strategy is protective of human health and the environment.

After the proposed compliance strategy is identified in the SOWP and described in the GCAP, a site-specific National Environmental Policy Act (NEPA) document (e.g., an environmental checklist [ECL] or an environmental assessment [EA]) will be prepared to determine any potential effects of implementing the proposed compliance strategy.

Since most of the contaminated materials and RRM were removed from the processing sites and stabilized off site, the Long-Term Surveillance Plan (LTSP) required as part of the licensing agreement for disposal sites is not applicable. When DOE relocated RRM, the original processing sites were cleaned up to meet EPA standards. The U.S. Nuclear Regulatory Commission (NRC) did not license the processing sites or require an LTSP (Statements of Consideration for 10 CFR Part 40, April 30, 1992). In lieu of the LTSP, DOE will prepare a Long-Term Management Plan (LTMP), which will also contain the information on ground water monitoring and specify all other long-term surveillance activities and reporting requirements necessary for the site. The LTMP will be a stand-alone document to guide long-term surveillance activities at the former Slick Rock processing sites.

Information for the SOWP is derived primarily from existing documents, from the UMTRA Site Environmental Evaluation for Projects (SEE-Pro) database, and from data in the UMTRA Project files.

End of current text

2.0 Regulatory Framework

A ground water compliance strategy is proposed for the Slick Rock site to achieve compliance with EPA ground water standards applicable to Title I UMTRA Project sites. This section identifies the requirements of the Uranium Mill Tailing Radiation Control Act (UMTRCA), the EPA ground water protection standards promulgated in 40 CFR Part 192 Subpart B, NEPA, and other regulations that are applicable to the UMTRA Ground Water Project.

2.1 Federal Regulations

2.1.1 Uranium Mill Tailings Radiation Control Act

The U.S. Congress passed UMTRCA (42 U.S.C. 7901 *et seq.*) in 1978 in response to public concerns about the potential health hazards from long-term exposure to uranium mill tailings. UMTRCA authorized DOE to control, stabilize, and dispose of mill tailings and other contaminated materials at former uranium-ore-processing sites.

UMTRCA has three titles that apply to uranium-ore-processing sites. Title I designates 24 inactive processing sites to undergo remediation. Title I authorizes EPA to promulgate standards and mandates remedial action in accordance with those standards. This Title also directs remedial action to be selected and performed with the concurrence of NRC in consultation with states and Indian tribes, authorizes DOE to enter into cooperative agreements with the affected states and Indian tribes, and directs NRC to license the disposal sites for long-term care. Title II applies to active uranium mills, and Title III applies to specific uranium mills in New Mexico. The UMTRA Ground Water Project has responsibility for administering only Title I of UMTRCA.

In 1988, Congress passed the Uranium Mill Tailings Remedial Action Amendments Act (42 U.S.C. 7923 *et seq.*) authorizing DOE to extend without limitation the time needed to complete ground water remediation at the processing sites.

2.1.2 EPA Ground Water Standards

UMTRCA requires that EPA promulgate standards for protecting public health and the environment from hazardous constituents associated with processing uranium ore and the resulting RRM. On January 5, 1983, EPA published standards in 40 CFR 192 for the cleanup and disposal of RRM. The standards for ground water compliance were revised, and a final rule was published on January 11, 1995, and codified in 40 CFR 192.

The standards in 40 CFR 192.02(c)(1) require that the Secretary of Energy determine which constituents listed in Appendix I are present in, or reasonably derived from, RRM. Those standards also require the Secretary to determine the areal extent of ground water contamination by listed constituent. Section 6.0 of this document, "Baseline Risk Assessment," complies with these requirements and identifies the constituents of concern at the Slick Rock site.

The standards for cleanup address two ground water contamination scenarios in 40 CFR 192.92(c)(2). The first scenario addresses protection of ground water associated with disposal cells. Future protection of ground water at the disposal sites is being monitored as part of the Long-Term Surveillance and Maintenance Program. The second scenario addresses ground water contaminated as a result of RRM in the uppermost aquifer at the former processing site. The UMTRA Ground Water Project addresses this ground water contamination and is regulated by Subparts B and C of 40 CFR 192.

2.1.2.1 Subpart B: Cleanup Standards

The regulations allow the option of complying with one of four general standards, which include supplemental standards and three numerical standards. The numerical standards set forth in 40 CFR 192.02(c)(3) are:

- Background level—Concentrations of constituents in the uppermost aquifer in an area that was not affected by ore-processing activities.
- Maximum Concentration Limit (MCL)—EPA-defined maximum concentrations for certain hazardous constituents in ground water; these MCLs are specific to the UMTRA Project. The MCLs for inorganic constituents that apply to UMTRA Project sites are given in Table 1 to Subpart A of 40 CFR 192.
- Alternate Concentration Limit (ACL)—An alternate concentration limit may be applied to a hazardous constituent if it does not pose a substantial present or future risk to human health or the environment as long as the limit is not exceeded. An ACL may be applied after considering options to achieve background levels and MCLs.

Natural Flushing

Subpart B also allows the use of natural flushing to meet EPA standards. Natural flushing occurs when the naturally occurring ground water processes reduce contaminant concentrations over time. Natural flushing must meet the ground water standards within 100 years. In addition, institutional controls (ICs) and an adequate monitoring program must be established and maintained to protect human health and the environment during the period of natural flushing.

Subpart C: Implementation

Subpart C provides guidance for implementing methods and procedures to reasonably ensure that standards of Subpart B are met. Subpart C requires that the standards are met on a site-specific basis using information gathered during characterization and monitoring. The plan for implementation must be stated in a site-specific GCAP and must contain a continued monitoring program, if necessary.

Supplemental Standards

DOE may, with NRC concurrence, apply a fourth option to contaminated ground water. Supplemental standards may be applied if any one of the following conditions is met as set forth in 40 CFR 192.21:

(a) Remedial action necessary to implement Subpart A or B would pose a significant risk to workers or members of the public.

(b) Remedial action to meet the standards would directly produce harm to human health and the environment that is clearly excessive when compared to the health and environmental benefits, now or in the future.

(c) The estimated cost of remedial action is unreasonably high relative to long-term benefits, and the RRM does not pose a clear present or future hazard.

(d) The cost of remedial action for cleanup of a building is clearly unreasonably high relative to the benefits.

(e) There is no known remedial action.

(f) The restoration of ground water quality is technically impracticable from an engineering standpoint.

(g) The ground water is considered limited use ground water and it is not a current or potential source of drinking water because

—Concentration of total dissolved solids (TDS) exceeds 10,000 milligrams per liter (mg/L).

—Widespread ambient contamination is present that cannot be cleaned up using treatment methods reasonably employed in public water systems.

—The quantity of water available for sustained continuous use at a well is less than 150 gallons per day.

When the criteria for limited use ground water apply, "supplemental standards shall ensure that current and reasonably projected uses of the affected ground water are preserved" [40 CFR 192.22(d)].

(h) Radiation from radionuclides other than radium-226 and its decay products is present in sufficient quantity and concentration to constitute a significant hazard from RRM.

If supplemental standards are applied, the regulations in 40 CFR 192.22(c) also require DOE to inform anyone affected by the hazardous constituents and to solicit their comments.

One of the four cleanup standards (background, MCLs, ACLs, or supplemental standards) is selected on the basis of risk to human health and the environment. The methods available to achieve compliance include active remediation, natural flushing, no remediation, or any combination of the methods. Section 5.0, "Conceptual Site Model," presents a summary of the geology, hydrology, geochemistry, and ground water modeling of the site. This information provides the basis to select the compliance strategy. Section 7.0, "Ground Water Compliance Strategy," presents a discussion of the proposed compliance strategy that is specific to the two sites. This discussion includes a justification for selecting a natural flushing remediation strategy with ICs and continued monitoring at both sites, and an ACL for selenium at the UC site.

2.1.3 Cooperative Agreements

UMTRCA requires that compliance with ground water standards be accomplished with the full participation of the states and Indian tribes on whose lands uranium mill tailings (RRM) are located. Section 103(a) of UMTRCA directs DOE to enter into cooperative agreements for remedial actions with the states and tribes.

2.1.4 National Environmental Policy Act (NEPA)

UMTRA is a major federal action that is subject to the requirements of NEPA. DOE NEPA regulations are codified in 10 CFR Part 1021, "National Environmental Policy Act Implementing Procedures." Pursuant to NEPA, DOE finalized a PEIS for the UMTRA Ground Water Project (DOE 1996) to analyze potential effects of implementing the alternatives for achieving ground water compliance at the UMTRA Project processing sites.

A Record of Decision (ROD) was published in April 1997 in which DOE's preferred alternative was selected on the basis of information available at the time. This ROD gave DOE the option of implementing one or a combination of the following compliance strategies:

- Active ground water remediation
- Natural flushing
- No ground water remediation

A Slick Rock site-specific ECL will be prepared to determine the need for an EA. If required, an EA will be prepared to recommend the preferred remediation alternative and to address all environmental issues associated with the selected alternative.

2.1.5 Other Federal Regulations

In addition to EPA ground water standards and requirements of NEPA, DOE must comply with presidential executive orders, such as those related to pollution prevention and environmental justice, that may be relevant to the work being performed. Other federal regulations include those that require protection of wetlands and floodplains, threatened and endangered species, and cultural resources.

2.2 DOE Orders

A number of environmental, health and safety, and administrative DOE orders apply to the work being conducted under the UMTRA Ground Water Project. DOE orders prescribe the manner in which DOE will comply with federal and state laws, regulations, and guidance, and the manner in which DOE will conduct operations that are not prescribed by law. DOE guidance for complying with federal, state, and tribal environmental regulations is given in the DOE Order 5400.1 series, which is partially superseded by DOE Order 231.1. DOE Order 5400.5 requires public protection from radiation hazards. DOE guidance for NEPA compliance is given in DOE Order 451.1, and specific guidance pertaining to environmental assessments is provided in *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* (DOE 1993b).

2.3 State Regulations

DOE must comply with state regulations in situations where federal authority has been delegated to the state. These situations include compliance with state permits required for drilling, completing, and decommissioning monitoring wells; water discharge; and waste management.

End of current text

3.0 Site Background

The former Slick Rock processing sites are located in a remote area of southwest Colorado near the former Slick Rock Post Office. The Slick Rock site consists of two former processing sites designated as the NC and UC sites. Previous investigations are summarized in the *Summary of Site Conditions and Work Plan, Slick Rock, Colorado* (DOE 2000a). Section 3.0 presents an overview of the site's physical setting and climate, land and water use, history of the former milling operations, and surface soil remediation.

3.1 Physical Setting and Climate

The Slick Rock processing sites are located along the Dolores River at an elevation of approximately 5,500 feet (ft) above mean sea level (MSL). The sites are surrounded by the steep hillsides and cliffs of the Dolores River Canyon, which rise to an elevation of 6,500 ft above MSL. After removal of surface contamination in 1996, the sites were regraded with on-site material and reseeded. The UC site is approximately 1 mile downstream of the NC site. Figure 3–1 is a recent aerial photograph of the region in April of 2001.

The Slick Rock vicinity has an arid to semiarid climate with high evaporation, low precipitation, low humidity, and large temperature variations. The official weather station closest to the Slick Rock site is located at Uravan, Colorado. This weather station (station number 058560) is part of the Western Regional Climate Center network and is located approximately 26 miles north of the Slick Rock site at an elevation of 5,000 ft above MSL. Because of the proximity and similar elevation, the Uravan weather station can be used to estimate the meteorological conditions at the Slick Rock site. Meteorological data collected from the Uravan weather station from 1960 to 2000 are summarized in Table 3–1. As shown in the table, the average annual precipitation is approximately 13 inches, with 10 inches of snow annually. Rainfall occurs during the summer as high-intensity, short-duration, late-afternoon thunderstorms.

Table 3–1. Summary of Meteorological Data from Uravan, Colorado

Month	Air Temperature		Precipitation (inches)	Snowfall (inches)
	Average Maximum	Average Minimum		
January	42.2	15.3	0.91	4.2
February	49.9	22.4	0.72	0.7
March	58.6	29.0	1.03	0.4
April	67.4	35.4	1.06	0.2
May	78.2	44.3	1.03	0
June	89.0	52.1	0.51	0
July	94.9	59.0	1.28	0
August	92.1	58.0	1.36	0
September	83.5	48.3	1.41	0
October	71.6	36.7	1.49	0.1
November	54.9	26.6	1.10	0.6
December	43.1	17.8	0.91	3.8
Annual	**68.8**	**37.1**	**12.79**	**9.9**

3.2 Land and Water Use

3.2.1 Land Use

The NC and UC sites are currently owned by UMETCO. The NC site is not fenced and is currently used for livestock grazing. Most of the UC site is enclosed with a barbed wire fence. Land between the two sites is privately owned. Land use between the two sites includes irrigated alfalfa fields, livestock grazing, and gravel mining. Water used to irrigate the alfalfa is pumped from the Dolores River.

3.2.2 Ground Water Use

There is no current use of alluvial ground water beneath the former processing sites. Historically, a hand-dug alluvial well located between the two sites (0675) was used as a domestic source, but the well is no longer used. Recent water level measurements indicate the well is dry.

Ground water use from the Entrada Sandstone is limited. Water from the Entrada Sandstone is used to water livestock via a "collector system." The collector system consists of a plastic pipe installed into the cliff face formed by the Entrada Sandstone. Water discharges from the pipe into a stock tank at a rate of approximately 1 liter per minute. The collector system is located northwest and upgradient of the UC site. This location (0807) has been sampled periodically since 1986 and represents background water quality.

Ground water used in the Slick Rock area is primarily supplied by the Navajo Sandstone aquifer. Currently, a domestic well completed in the Navajo Sandstone (0672) provides water to two residents and their livestock. Well 0672 has been sampled periodically since 1986, and results indicate no site-related impacts to the aquifer. Historically, wells completed in the Navajo Sandstone provided water for the milling operations and for the mill community at the UC site.

3.3 History of Operations

3.3.1 NC Site

The NC mill was built in 1931 by the Shattuck Chemical Company. In 1934, the site was acquired by North Continent Mines, Inc. The mill was designed to extract vanadium and radium salts from locally mined ores. In 1945, the federal government acquired control of the site through the Union Mines Development Corporation with the specific purpose of supplying uranium for the Manhattan Project. Union Carbide became the owner of the site in 1957 (DOE 1995b). The NC site is currently owned by UMETCO, which has been acquired from Union Carbide by DOW Chemical.

From 1931 to 1942, vanadium was extracted from ore using a sulfuric acid leaching process. In 1942, the extraction techniques included an initial salt roast circuit with an acid-leach process to recover vanadium, uranium, and radium concentrates (Merritt 1971).

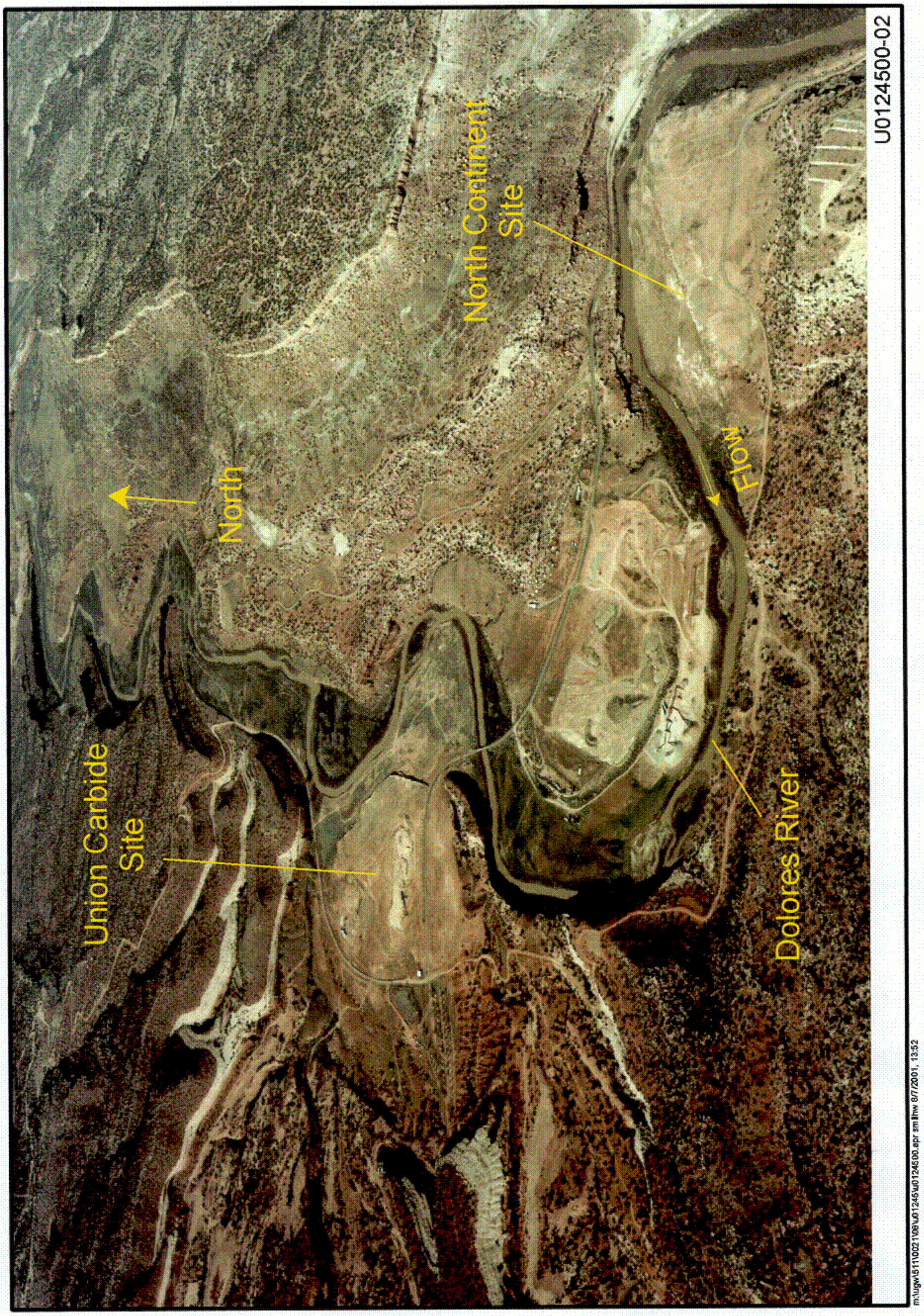

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Figure 3–1. Recent Aerial Photograph of the Slick Rock Area

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3.3.2 UC Site

The UC mill began operation in 1957 using a uranium-vanadium upgrading technique to process ore mined from the surrounding area. The milling process at the UC site included an initial step to dry-grind the coarse-grained sandstone, separating the fines from the coarser ore.

The coarse ore fraction was combined with a recirculated sulfuric acid solution. Following this step, a sand-slime separation process obtained a second uranium product. The sand product was further acid-leached, washed, and discharged to the tailings pile. A third uranium product resulted from an ammonia neutralization step on part of the pregnant solution. The upgraded material, which was comprised of all three products, was shipped to the Union Carbide mill at Rifle, Colorado, for further processing. Because the finer fraction was shipped off site, the tailings pile at the UC site was composed of fine-grained sand with virtually no slimes. A photograph of the UC mill while it was still operating is shown in Figure 3–2. The UC mill closed in December 1961 (Merritt 1971), and the site is currently owned by UMETCO.

3.4 Surface Remediation

Surface remediation at the Slick Rock site commenced in 1995 and was completed in 1996. Tailings and other contaminated surface material were placed in a disposal cell approximately 5 miles east of the Slick Rock site.

3.4.1 NC Site

Contaminated material at the NC site consisted of the tailings pile and windblown contamination, which together covered approximately 12 acres and contained approximately 135,500 cubic yards of contaminated material (DOE 1997). Figure 3–3, Figure 3–4, and Figure 3–5 show the NC site prior to surface remediation, during surface remediation, and after surface remediation, respectively.

3.4.2 UC Site

Contaminated material at the UC site consisted of the tailings pile, mill area, and windblown/waterborne contaminated areas. The tailings pile and contaminated land covered approximately 55 acres and contained approximately 642,600 cubic yards of contaminated material (DOE 1997). Figure 3–6, Figure 3–7, and Figure 3–8 show the UC site prior to surface remediation, during surface remediation, and after surface remediation, respectively. Supplemental standards were applied to soil contamination left in place around a natural gas pipeline at the UC site and to soil contamination left in place at a former vicinity property located across the river from the UC site (DOE 1997); supplemental standards areas are shown in Figure 3–8.

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Figure 3–2. UC Mill During Operation

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Figure 3–3. NC Site Prior to Remediation

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Figure 3–4. NC Site During Remediation

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C05

Figure 3–5. NC Site After Remediation

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Figure 3–6. UC Site Prior to Remediation

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C07

Figure 3–7. UC Site During Remediation

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C08

Figure 3–8. UC Site After Remediation

C09

4.0 Summary of 2000/2001 Field Investigations

An evaluation of existing data at the Slick Rock site was presented in the *Summary of Site Conditions and Work Plan, Slick Rock, Colorado* (DOE 2000a). The evaluation indicated that additional investigation was needed to complete the SOWP and select a strategy for compliance with EPA's UMTRA ground water cleanup standards. That evaluation is summarized in Table 4–1.

Table 4–1. Summary of the Slick Rock Field Investigation

Data Deficiency	Objective	Action
Background alluvial water quality at both sites	Distinguish between site contributions and background; establish contaminants of potential concern (COPCs).	Install background wells 0300 and 0301; sample collection and analysis.
All alluvial wells abandoned at the NC site	Input water quality and elevation into the ground water flow and transport model.	Install wells 0302 to 0309; sample collection and analysis; water level measurements.
Hydraulic conductivity at the NC site	Input into the ground water flow and transport model.	Install wells 0306, 0307, 0308, and 0327; conduct aquifer pumping tests.
Extent of alluvial aquifer contamination at the NC site	Determine if contamination is migrating north of the river between the two sites. Input elevations into the ground water flow model.	Install wells 0310 to 0312 and 0328 to 0331; sample collection and analysis; water level measurements.
Hydraulic conductivity at the UC site	Input into the ground water flow and transport model.	Install wells 0314, 0315, 0316, 0317, 0321, 0322, and 0323; conduct aquifer pumping tests.
Alluvial wells abandoned at the UC site	Input water quality and elevation measurements into the ground water flow and transport model.	Install wells 0313 to 0316 and 0318 to 0320; sample collection and analysis; water level measurements.
Entrada wells abandoned at the UC site	Determine if Entrada has been affected by site activities; determine flow direction.	Install wells 0317, 0324, 0325, and 0326; sample collection and analysis; water level measurements.
Extent of organic contamination at the UC site	Determine the nature and extent of organic contamination in the alluvial aquifer.	Install wells 0332 to 0338; sample collection and analysis.
Dolores River elevation	Determine interaction between Dolores River and alluvial aquifer. Input into the flow model.	Obtain USGS discharge data and rating curve; install measuring stakes along river; install data loggers in selected alluvial wells.
Vertical gradient between aquifers	Determine potential ground water movement between aquifers.	Install Entrada wells 0317 and 0324; water level measurements.
Subpile soil contamination	Determine if contamination (other than Ra-226) exists in the subpile soils.	Subpile soil sampling and analysis.
Aquifer transport properties	Input into the ground water flow and transport model.	Determine distribution ratios for selected COPCs.
Ground water remedial action – natural flushing alternative	Determine if contaminants will flush within the 100-year UMTRA time frame.	Ground water flow and transport modeling.
Geology at the NC site	Determine subsurface geology.	Drill and log borehole 0275.
Survey data	Develop accurate site map, determine ground water surface elevations; ground water flow direction; river elevation.	Survey horizontal coordinates and vertical elevation at all sampling locations; aerial photography of the site.

Additional data were required for input into the ground water flow and transport model. Data requirements include determining hydraulic parameters, background water quality, and extent of contamination in the alluvial aquifer. In addition, data were collected to determine subpile soil chemistry, effects on bedrock ground water quality, interaction between ground water and surface water, bedrock geology at the NC site, and interaction between the aquifers and the Dolores River. Obtaining this information required installing additional wells, conducting aquifer pumping tests, obtaining Dolores River stream flow data, and performing additional sampling and analysis. A summary of these activities is presented in this section.

4.1 Ground Water Monitor Well Installation

In August and September 2000, 32 monitor wells were installed during the field investigation using the rotosonic drilling method, which enabled collection of continuous samples through the entire interval drilled. Monitor wells were installed according to the "Standard Practice for Design and Installation of Ground Water Monitor Wells in Aquifers" (GJO 1998). Lithologic descriptions of the aquifer material were recorded at each well according to the "Standard Practice for the Description and Identification of Soils" (GJO 1998) and the "Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)" (GJO 1998). Completion diagrams for each well, along with the lithologic description, are included in Appendix B (CD-ROM format). A construction diagram of a typical monitor well installed during the Slick Rock field investigation is shown in Figure 4–1. A summary of the monitor well installation program at the Slick Rock site is shown in Table 4–2, and monitor well locations are shown in Figure 4–2 and Figure 4–3. Results of water quality sampling are discussed in Section 5.2.

Seven additional wells were installed in December 2000 to delineate organic contamination discovered during the drilling of well 0319. Soil borings were drilled at 23 locations with a Geoprobe rig to delineate the contamination. Each soil boring was scanned with an organic vapor analyzer (OVA) to determine the relative level of contamination in the soil. The OVA readings were used to guide the placement of well points. Seven well points (0332 to 0338) were installed with the Geoprobe rig in the alluvial aquifer. All well points and two alluvial monitor wells were sampled for volatile organic compounds. Results of the organic characterization are presented in Section 5.2.

4.2 Aquifer Pumping Tests

Aquifer tests were performed at well clusters 0306, 0314, and 0321 during the field investigation to determine the hydraulic parameters of the alluvial aquifer underlying both the NC and UC sites and the Entrada Sandstone aquifer underlying the UC site. The 0306 well cluster is located on the NC site, the 0314 well cluster is on the UC site, and the 0321 well cluster is just downgradient (north-northwest) of the UC site. During each test, water level data were collected from the pumping wells and nearby observation wells. All data associated with the aquifer tests completed at the Slick Rock site are in Appendix G.

An initial round of testing was completed during September 2000, at which time it was determined that the newly installed pumping wells had noticeably lower sustainable pumping rates compared to previously installed wells located within the clusters. The drilling technique used to install the pumping wells may have adversely affected the wells' ability to transmit ground water.

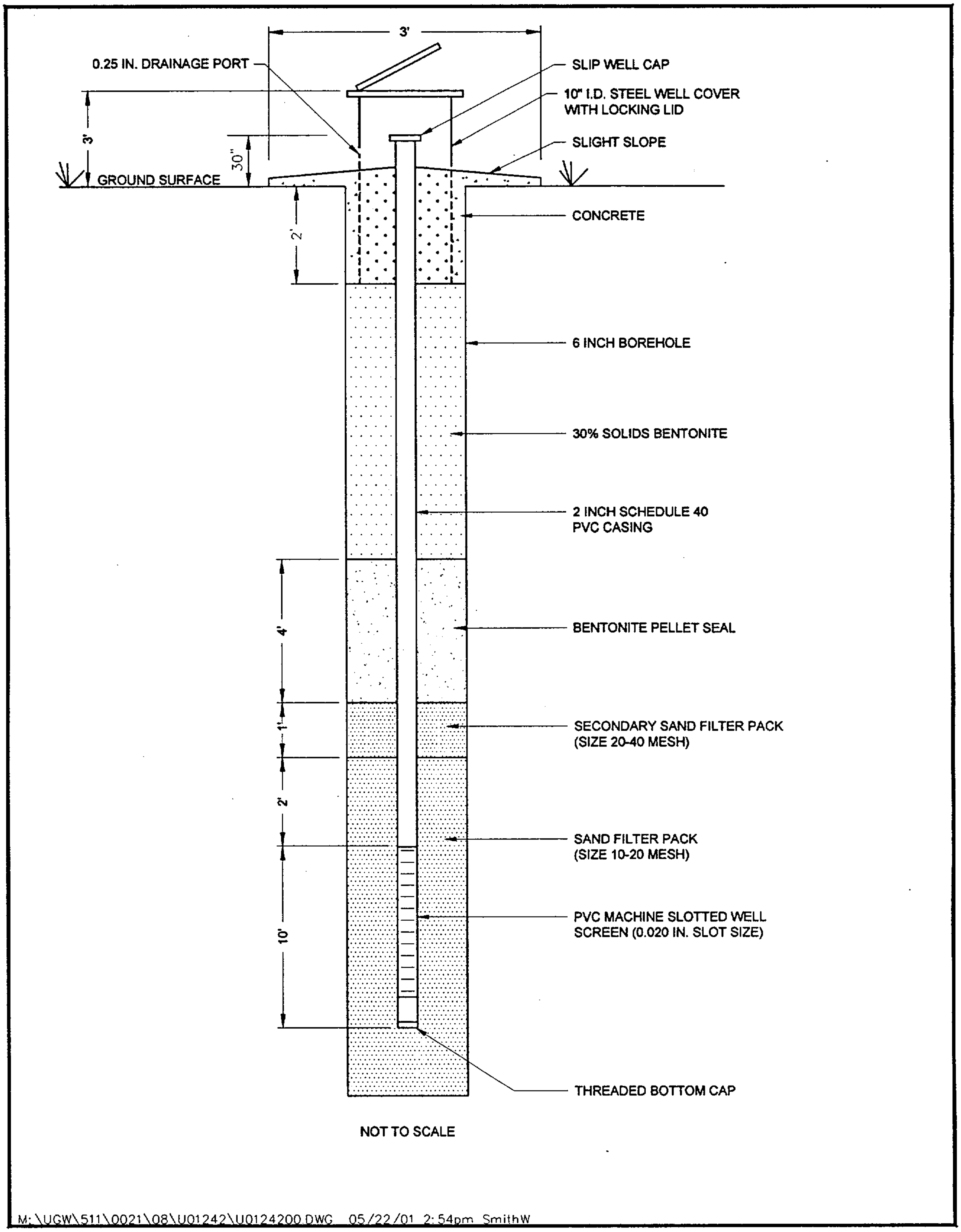

Figure 4–1. Typical Monitor Well Construction Diagram

Table 4–2. Slick Rock Field Investigation Monitor Well Installation Summary

Well Number	Site	Location	Formation	Well Depth (ft)	Screened Interval (ft)	Purpose
0300	NC/UC	Upgradient	Alluvium	20	9.5–19.5	Background water quality
0301	NC/UC	Upgradient	Alluvium	20	9.5–19.5	Background water quality
0302	NC	On site	Alluvium	15.5	5–15	Water quality/water level
0303	NC	On site	Alluvium	14.8	4.3–14.3	Water quality/water level
0304	NC	On site	Alluvium	15	4.5–14.5	Water quality/water level
0305	NC	On site	Alluvium	20.2	8.7–18.7	Water quality/water level
0306	NC	On site	Alluvium	15.6	4.8–14.8	Pumping well
0307	NC	On site	Alluvium	14.9	4.4–14.4	Observation well
0308	NC	On site	Alluvium	15	4.5–14.5	Observation well
0309	NC	On site	Alluvium	20.7	10.2–20.2	Water quality/water level
0310	NC	Downgradient	Alluvium	20.2	14.7–19.7	Water quality/water level
0311	NC	Downgradient	Alluvium	19.6	14.1–19.1	Water quality/water level
0312	NC	Downgradient	Alluvium	20.1	14.6–19.6	Water quality/water level
0313	UC	On site	Alluvium	18.6	13.1–18.1	Water quality/water level
0314	UC	On site	Alluvium	17	6.1–16.1	Pumping well
0315	UC	On site	Alluvium	16.7	6.2–16.2	Observation well
0316	UC	On site	Alluvium	15.3	4.8–14.8	Observation well
0317	UC	On site/floodplain	Entrada	40	19.5–39.5	Water quality/water level
0318	UC	On site/floodplain	Alluvium	15.5	5–15	Water quality/water level
0319	UC	On site/floodplain	Alluvium	15	4.5–14.5	Water quality/water level
0320	UC	On site/floodplain	Alluvium	10.5	5–10	Water quality/water level
0321	UC	Downgradient	Alluvium	20.3	14.4–19.4	Pumping well
0322	UC	Downgradient	Alluvium	19.6	9.1–19.1	Observation well
0323	UC	Downgradient	Alluvium	19.6	9.1–19.1	Observation well
0324	UC	On site/floodplain	Entrada	36.2	15.7–35.7	Water quality/water level
0325	UC	On site/Terrace	Entrada	71	40.5–70.5	Water quality/water level
0326	UC	On site/Terrace	Entrada	71.2	55.7–70.7	Water quality/water level
0327	NC	On site	Alluvium	17.1	6.6–16.6	Observation well
0328	NC	Downgradient	Alluvium	21.2	10.7–20.7	Water quality/water level
0329	NC	Downgradient	Alluvium	17.9	7.4–17.4	Water quality/water level
0330	NC	Downgradient	Alluvium	17.4	6.9–16.9	Water quality/water level
0331	NC	Downgradient	Alluvium	20.2	9.7–19.7	Water quality/water level
0332	UC	On site	Alluvium	10.25	5–10	Organic characterization
0333	UC	On site	Alluvium	12.5	7.25–12.25	Organic characterization
0334	UC	On site	Alluvium	9.5	4.25–9.25	Organic characterization
0335	UC	On site	Alluvium	7.5	2.25–7.25	Organic characterization
0336	UC	On site	Alluvium	10.25	5–10	Organic characterization
0337	UC	On site	Alluvium	10.5	5.25–10.25	Organic characterization
0338	UC	On site	Alluvium	6.5	1.25–6.25	Organic characterization

As a result, a number of tests were re-run using the previously installed wells as the pumping wells. Pumping rates ranged from 1 to 10.3 gallons per minute (gpm); the length of the pumping phase ranged from 3 to over 25 hours. Recovery data were collected from all tests.

Data were analyzed using various analytical methods. The saturated thickness of the alluvial aquifer ranges from approximately 6 to 7 ft across both the NC and UC sites; both the pumping and observation wells fully penetrate the aquifer. As a result, the Theis Unconfined Approximation (Environmental Simulations 1999), the Cooper and Jacob Straight-Line

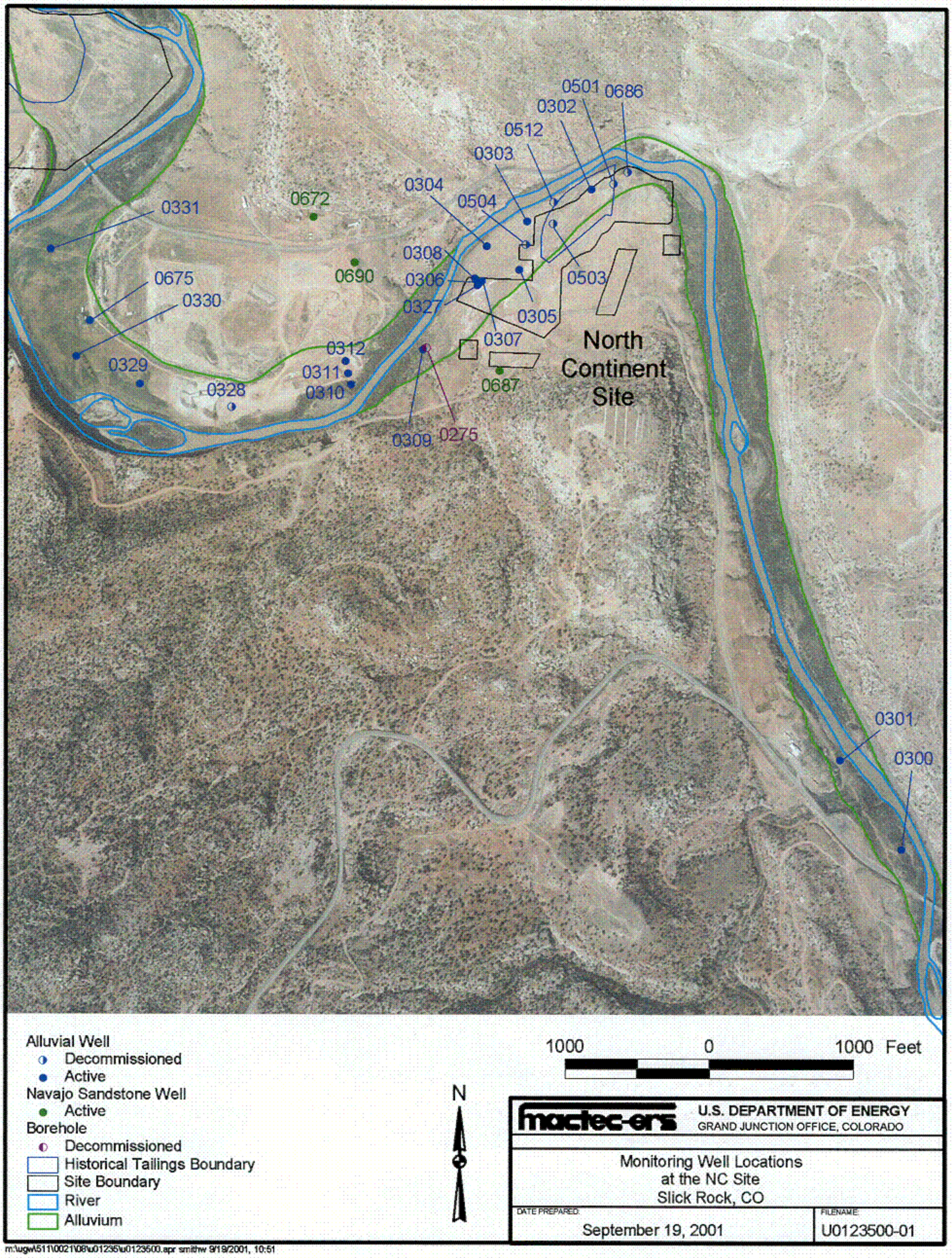

Figure 4–2. Monitor Well Locations at the NC Site

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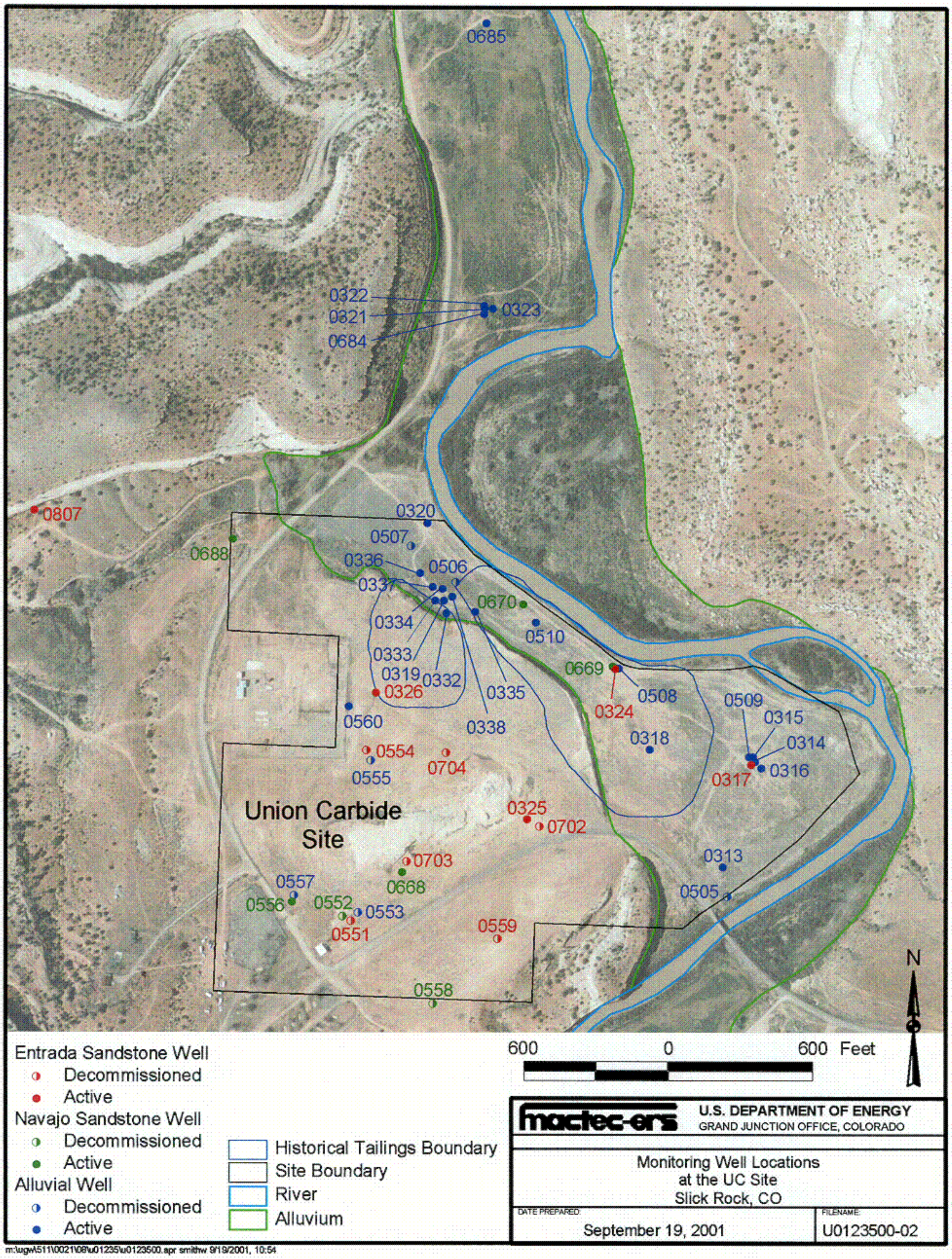

Figure 4–3. Monitor Well Locations at the UC Site

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Approximation for Unconfined Aquifers (Cooper and Jacob 1946), and the Neuman Method for Unconfined Aquifers (Neuman 1972) provided the analytical solutions that best represent the conditions under which these data were collected. Inverse modeling was also used to estimate the hydraulic conductivity of the alluvial aquifer.

The hydraulic conductivity of the alluvial aquifer near the NC and UC sites ranges from 13 to 357 feet per day (ft/day), with a geometric mean of 121 ft/day and a standard deviation of 86. The large range of hydraulic conductivity is attributed to the heterogeneity of the alluvial aquifer caused by differential deposition of fine-grained material. The data also suggest a specific yield ranging from 0.03 to 0.39.

The estimated hydraulic conductivity of the Entrada Sandstone aquifer is 1.5 ft/day, based on data collected during the aquifer test conducted on well 0317.

4.3 Subpile Soil Sampling

This section describes the sample locations, the methods used, and the results of a uranium and vanadium leaching study of subpile soils from the Slick Rock site. This information was obtained to assess the magnitude of the residual contamination source, if any. The full report describing this endeavor was published in February 2001 (DOE 2001a).

4.3.1 Contaminants of Interest

Uranium and vanadium were selected as the contaminants of interest because they were listed as contaminants of potential concern (COPCs) in the BLRA (DOE 1995b). Also, uranium represents contaminants that are easily leached, and vanadium represents contaminants that are more difficult to leach (DOE 2000a). Because uranium and vanadium occur naturally, concentrations from the former tailings areas were compared to concentrations in a background location.

4.3.2 Sample Locations

UMTRA Ground Water Project personnel collected samples from 15 locations. Six locations were at the NC site and eight locations were at the UC site. Two samples were collected at a location several thousand feet hydraulically upgradient of the former ore-processing areas to evaluate background concentrations.

The background samples were collected at a location that could not have been affected by the milling operation but that has lithology similar to that of the Slick Rock ore-processing sites. A comparison of background and on-site samples digested in the same manner is useful for determining if the on-site samples contain releasable mill-related contaminants.

4.3.3 Methods

Samples were collected from cores obtained by rotosonic drilling at locations 0261 through 0274 and 0300 as shown on Figure 4–4. Two samples were collected at each location. One was collected from immediately below the fill and the other approximately 3 ft deeper. All samples were collected above the water table. Samples at the NC site were collected at 3 to 5 ft and 5 to 8 ft, respectively. At the UC site, the depths for the upper samples ranged from 3 to 7 ft, depending on the thickness of the fill material. Depths for the lower samples at the UC site ranged from 5 to 10 ft. The two background samples were collected at 3 to 5 ft and 5 to 8 ft.

Samples were prepared for extraction at the Grand Junction Office (GJO) Environmental Sciences Laboratory (ESL). All samples were air-dried (no oven heat) and sieved to a < 2 millimeter (mm) (10 mesh) size fraction before any chemical treatment (ESL procedure CB[BT–1], DOE 1999a). The < 2 mm fraction constituted approximately 33 percent of the sample with a range of 10.2 to 55.6 percent. This percentage is based on measurements performed at the ESL.

4.3.3.1 Chemical Extraction

All extractions were performed at the ESL. The extraction procedure consisted of leaching 2 grams (g) of sample with 50 milliliters (mL) of 5 percent HNO_3 at room temperature with end-over-end agitation for 4 hours (ESL procedure CB[BT–1], DOE 1999a).

4.3.3.2 Chemical Analysis

Samples were analyzed in the GJO Analytical Chemistry Laboratory. Procedure AS–5 Rev. 06 was used for vanadium and AS–6 Rev. 06 was used for uranium. Both procedures employ an inductively coupled plasma (ICP) for an excitation source. The vanadium is quantified by atomic emission spectrometry (AES) and the uranium by mass spectrometry (MS).

4.3.4 Results

This subsection describes the distribution of uranium and vanadium at the NC and UC sites based on the sample locations and methods described in Sections 4.3.2 and 4.3.3. Table 4–3, Table 4–4, and Table 4–5 present the data obtained.

Table 4–3. Summary of Uranium and Vanadium Results in Subpile Soils at the North Continent Site

Location	Soil Concentrations			
	Uranium (mg/kg)		Vanadium (mg/kg)	
	Range	Average	Range	Average
Background	NA	0.45	2.21–2.54	2.38
Shallow (underneath fill)	0.81–11.8	4.01	2.55–14.8	6.07
Deep (about 3 ft below fill)	0.87–9.31	3.35	2.2–5.35	3.98

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Figure 4–4. Subpile Soil Sample Locations

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Table 4–4. Summary of Uranium and Vanadium Results in Subpile Soils at the Union Carbide Site

Location	Soil Concentrations			
	Uranium (mg/kg)		Vanadium (mg/kg)	
	Range	Average	Range	Average
Background	NA	0.45	2.12–2.54	2.38
Shallow (underneath fill)	0.19–1.87	0.8	3.81–54.3	17.05
Deep (about 3 ft below fill)	0.17–2.09	0.96	3.64–102	24.77

Table 4–5. Concentrations of Uranium and Vanadium in Individual Subpile Soil Samples

Sample	Location Number	Depth (ft)	Uranium (mg/kg)	Vanadium (mg/kg)
North Continent Site				
271450	0261	3–5	1.09	4.18
271451	0261	5–8	1.28	3.56
271452	0262	3–5	11.8	14.8
271453	0262	5–8	2.02	4.93
271454	0263	3–5	3.03	2.55
271455	0263	5–8	2.3	3.68
271456	0264	3–5	1.9	5.38
271457	0264	5–8	4.33	4.18
271458	0265	3–5	0.81	3.29
271459	0265	5–8	0.87	2.2
271460	0266	3–5	5.47	6.22
271461	0266	5–8	9.31	5.35
Union Carbide Site				
271462	0267	5–7	0.53	54.3
271463	0267	7–10	0.48	28.2
271464	0268	5–7	0.19	19.3
271465	0268	7–10	0.17	20
271466	0269	3–5	0.41	26.8
271467	0269	7–9	2.08	102
271468	0270	5–7	0.86	6.12
271469	0270	7–10	0.61	18.6
271470	0271	5–7	1.31	11.1
271471	0271	7–10	2.09	8.11
271472	0272	4–5	0.4	3.81
271473	0272	6–7	0.82	5.06
271474	0273	3–5	0.83	7.75
271475	0273	5–7	0.72	12.6
271476	0274	5–6	1.87	7.23
271477	0274	6–7	0.74	3.64
271478	0300	3–5	0.45	2.21
271479	0300	5–8	0.45	2.54

4.3.4.1 Background Sample

The background sample was collected at location 0300, which is approximately 4,000 ft upstream from the processing areas. The uranium concentrations from both the 3 to 5 ft and 5 to 8 ft samples were reported as 0.45 milligrams per kilogram (mg/kg). The vanadium concentrations are 2.21 mg/kg at 3–5 ft and 2.54 mg/kg at 5–8 ft. Table 4–6 compares these concentrations with concentrations obtained with ESL procedures for background samples collected at other UMTRA Project sites. Background uranium values from the Slick Rock site are consistent with those from the previous studies, demonstrating that location 0300 was suitable for a background determination.

Table 4–6. Comparison of Slick Rock Background Sample With Background Samples from Other UMTRA Sites

Site	Report No.	Uranium (mg/kg)		Vanadium (mg/kg)	
		Range	Average	Range	Average
Slick Rock, Colorado	This report	NA	0.45	2.21–2.54	2.38
Shiprock, New Mexico	ESL–RPT–99–04[a]	0.18–0.62	0.39	ND[b]	ND
Shiprock, New Mexico	ESL–RPT–2000–08[c]	0.12–0.62	0.32	ND	ND
Rifle, Colorado	ESL–RPT–2000–10[d]	<0.1–0.38	0.18	1.5–4.3	2.5

[a] DOE 1999b
[b] ND = not determined
[c] DOE 2000b
[d] DOE 2000c and DOE 1999b

4.3.4.2 North Continent Site

Uranium: The highest uranium concentrations were identified in samples obtained nearest the river (Figure 4–5). The concentrations from location 0262 at 3 to 5 ft (11.8 mg/kg) and location 0266 at 5 to 8 ft (9.31 mg/kg) are greater than 20 times background. The next highest uranium concentrations (4.33–5.47 mg/kg) are approximately 10 times background (location 0266 at 3 to 5 ft and location 0264 at 5 to 8 ft). In contrast, the lowest concentrations (0.81–1.28 mg/kg, samples from both depths at locations 0265 and 0261) are approximately twice background. As indicated by Table 4–5 and Figure 4–5, concentrations do not vary systematically with sampling depth.

Vanadium: The highest vanadium concentration at the NC site (14.8 mg/kg) was identified in the sample with the highest uranium concentration (location 0262 at 3 to 5 ft). This concentration is approximately six times background. The next highest vanadium concentration (6.22 mg/kg, location 0266 at 3 to 5 ft) is less than half as high and only about 2.5 times the background result. Half (six) of the vanadium results are less than twice background.

4.3.4.3 Union Carbide Site

Uranium: UC sample concentrations are consistent with the more efficient uranium processing operation at the UC site (Figure 4–6). Of the 16 samples leached from the UC area, the concentrations from 12 samples (0.17 to 0.86 mg/kg) are essentially indistinguishable from the background value of 0.45 mg/kg. Concentrations in the remaining four samples range from 1.31 to 2.09 mg/kg, no more than 3 to 4 times background.

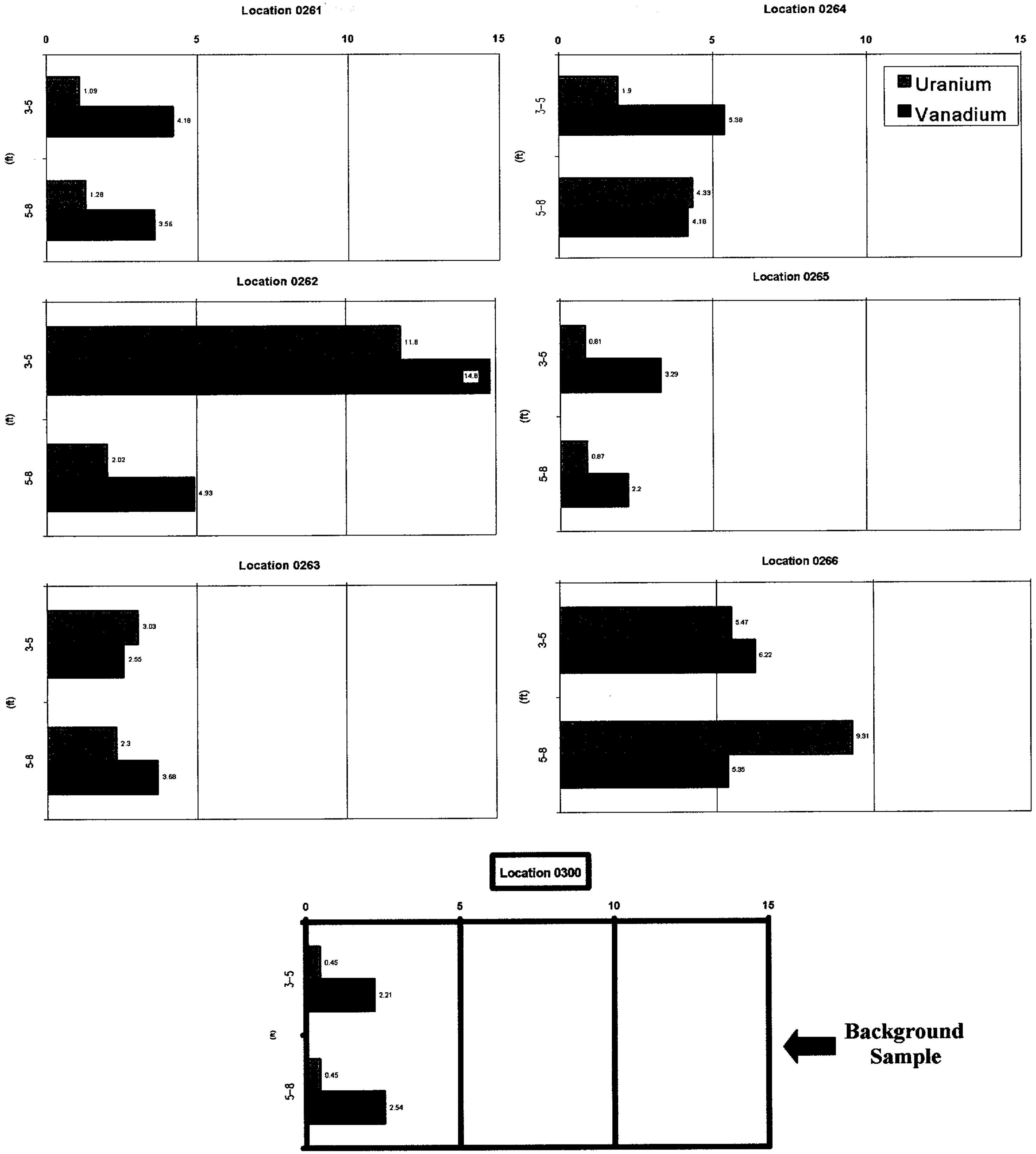
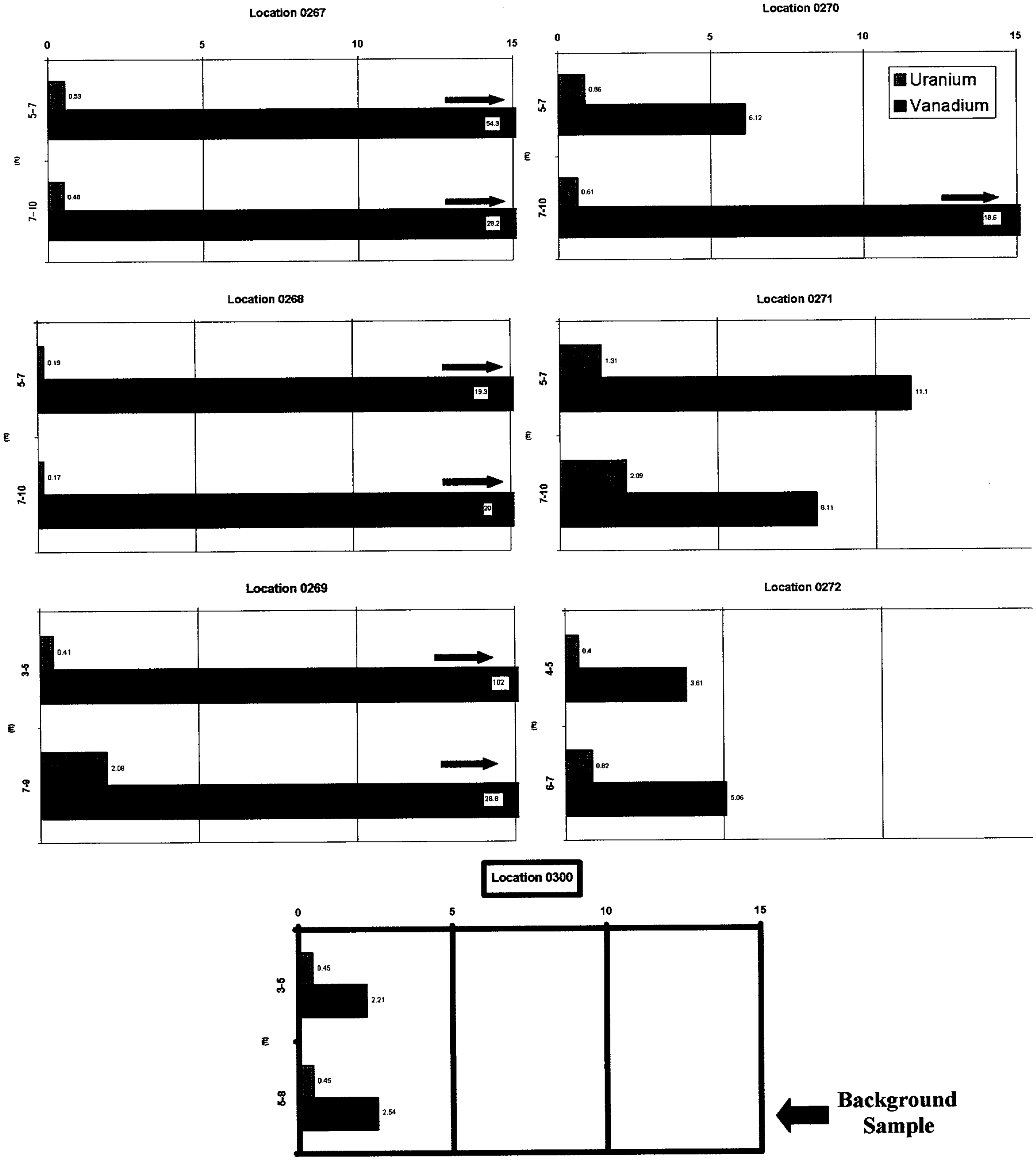


Figure 4–5. Vertical Distribution of Vanadium and Uranium Concentrations in Subpile Soil from the NC Site



Background Sample

Figure 4–6. Vertical Distribution of Vanadium and Uranium Concentrations in Subpile Soil from the UC Site

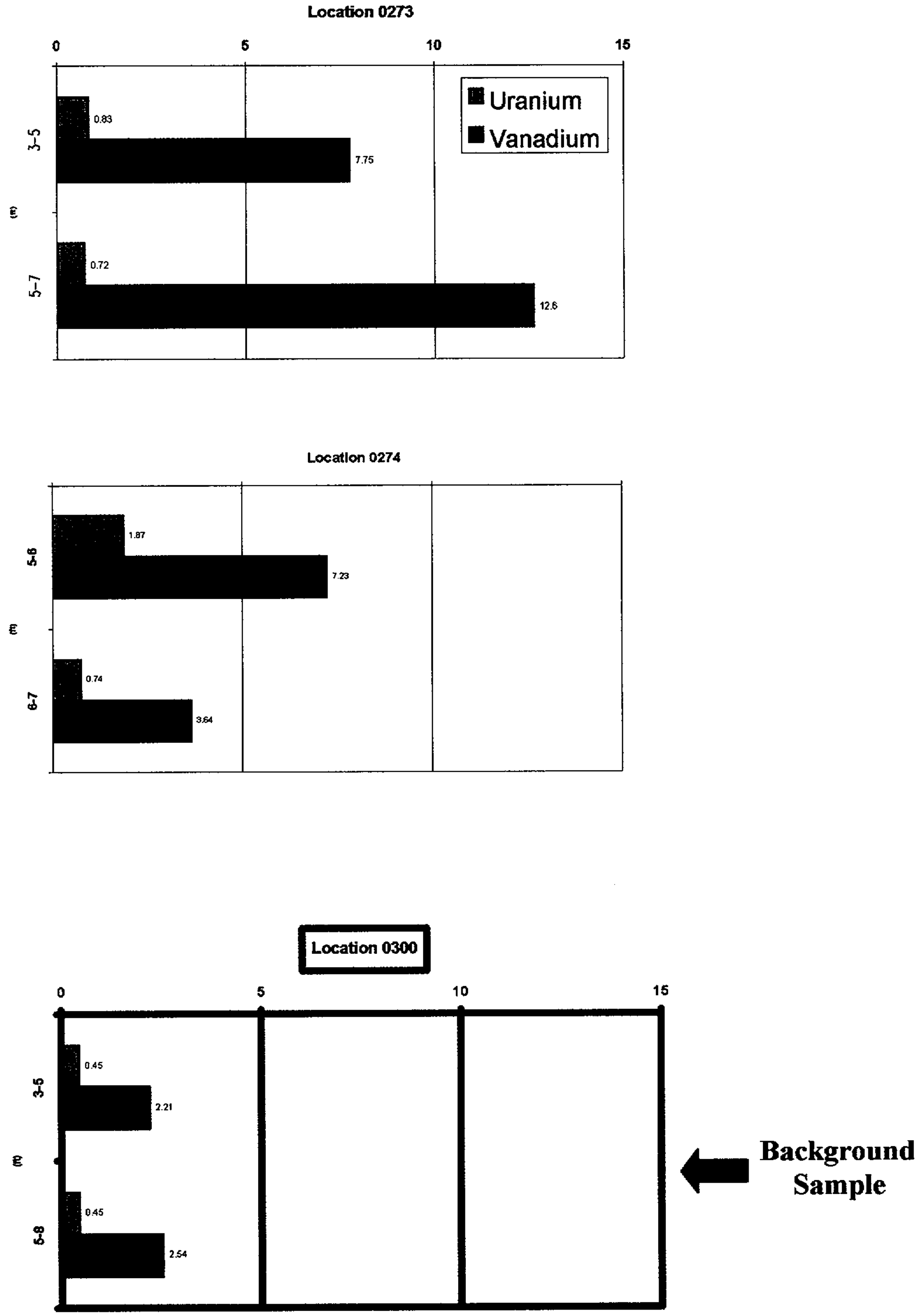


Figure 4–6 (continued). Distribution of Vanadium and Uranium Concentrations in Subpile Soil from the UC Site

Vanadium: Vanadium concentrations have more contrast. The 7 to 9 ft sample collected at location 0269 had a vanadium concentration of 102 mg/kg, which is approximately 40 times the background and, therefore, was clearly affected by site operations. The next highest concentration was 54.3 mg/kg from location 0267 at 5 to 7 ft, or approximately 20 times background. Locations 0267 and 0269 are adjacent and near locations 0268 and 0270. Seven of the eight highest vanadium concentrations are associated with the eight samples from this cluster. In general, vanadium concentrations in samples collected at the other locations decrease to the northwest in the direction of ground water flow.

4.4 Distribution Coefficients

As contaminated ground water migrates through soils and rocks, the contamination is distributed between the solid and the liquid phases. This phenomenon causes the contamination to travel at a slower rate than the average ground water velocity. Chemical processes that retard the contaminant plume can include adsorption, absorption, mineral precipitation, diffusion into immobile porosity, attachment to microbes, and transfer to vapor phases. It is generally not possible to differentiate among these processes. However, a bulk parameter (K_d) can be used to model the retardation of contamination for many aquifer systems. Most numerical ground water models use the K_d concept in simulations of contaminant transport. Site-specific K_d values are approximated from distribution ratios or R_d values that are empirically determined. Hence, a laboratory study was conducted to determine R_d values for uranium and vanadium in the alluvial system at the Slick Rock site. A separate report on this work was completed in February 2001 (DOE 2001b). Subsequent to that report, distribution ratios (R_ds) for molybdenum and selenium were measured on the same samples used for uranium and vanadium. These data were reported in an addendum provided during May 2001.

4.4.1 Definitions and Calculations

R_d is defined as the concentration of a constituent in the solid fraction divided by the concentration in the aqueous phase:

$$R_d = \frac{\text{mass of solute sorbed per unit mass of solids}}{\text{mass of solute per volume of solution}}$$

R_d values are calculated from experimental data as

$$Rd = \frac{(A - B)V}{M_s B}$$

where

A = initial concentration of the constituent in mg/L,
B = final concentration of the constituent in mg/L,
V = volume of solution [100 mL in all cases],
M_s = mass of soil used in grams, and
R_d = distribution ratio in milliliters per gram (mL/g).

K_d is numerically equivalent to R_d if the system is at equilibrium and R_d is constant over the range of conditions being considered. If R_d is constant over a large range of contaminant concentrations, it is said to be "linear" because a plot of aqueous concentration against solid-phase concentration data forms a straight line on an arithmetic plot. R_d data are often displayed on log-log concentration plots. A linear plot of R_d (referred to as a linear isotherm because temperature is held constant) is a straight line with a slope of 1 on a log-log plot.

At elevated concentrations of a constituent, R_d often varies with the aqueous concentration. In this case, the isotherm is said to be nonlinear and cannot be accurately represented by K_d. The grain-size distribution influences the effect that sediment has on retarding migration of contaminants by sorption. For example, sediment that has a high proportion of fines will usually have a high R_d value compared with mineralogically similar but coarser-grained sediment. The increase in sorption is due to a high proportion of sorbent phases, such as clay minerals and iron oxyhydroxides, and a large surface area.

Fine-grained splits are commonly used in the laboratory to determine R_d values. The finer grain sizes are easier to work with and require less equipment. Because more contaminant is sorbed to finer-grained sediment, the analysis is more sensitive and has lower detection limits than would be possible using the coarser-grained fractions. However, the results are biased toward elevated values of R_d. The laboratory-derived R_d values should be adjusted to account for actual grain-size distributions in the aquifer.

Grain-size distribution data can be used to adjust the laboratory-derived values of R_d to the coarse-grained alluvial aquifer (DOE 2001b). Values of R_d can be adjusted according to

$$R_{dadj} = R_{d(<2\,mm)} \times f$$

where

$R_{d\,adj}$ = adjusted R_d values,
$R_{d\,(<2\,mm)}$ = laboratory R_d measured on the < 2-mm fraction, and
f = weight fraction of sediment < 2 mm (from sieve analysis).

Use of this method assumes that there is no sorption on the >2-mm fraction. This is a reasonable method for estimating R_d for input into contaminant transport models. For example, a recent study examined the utility of this approach. The study concluded that assuming that the >2-mm fraction had no sorptive capacity and only served to dilute sorption from the < 2-mm fraction "may be a reasonable alternative" to explicit measurement of the sorptive capacity of the larger fraction (Kaplan et al. 2000).

4.4.2 Methods

Core from the alluvial aquifer was sampled during rotosonic drilling at locations 0300, 0301, and 0323 (Figure 4–7). Locations 0300 and 0301 are 3,000 and 4,000 ft upgradient, respectively, of the NC site. Location 0323 is approximately 1,500 ft downgradient of the UC area. Ground water analyses from wells at all three locations indicate that the ground water at these locations has not been contaminated by former uranium-ore-processing operations. Background locations were used to avoid the complication of addressing existing contamination. If there is pre-existing contamination, measurement of the R_d would require quantifying the element of interest in both the solid and liquid phases. If contamination is not present, only analysis of the aqueous phase is required. The well logs (Appendix B) indicate that the lithologies at R_d sample locations are representative of the contaminated portion of the alluvial aquifer.

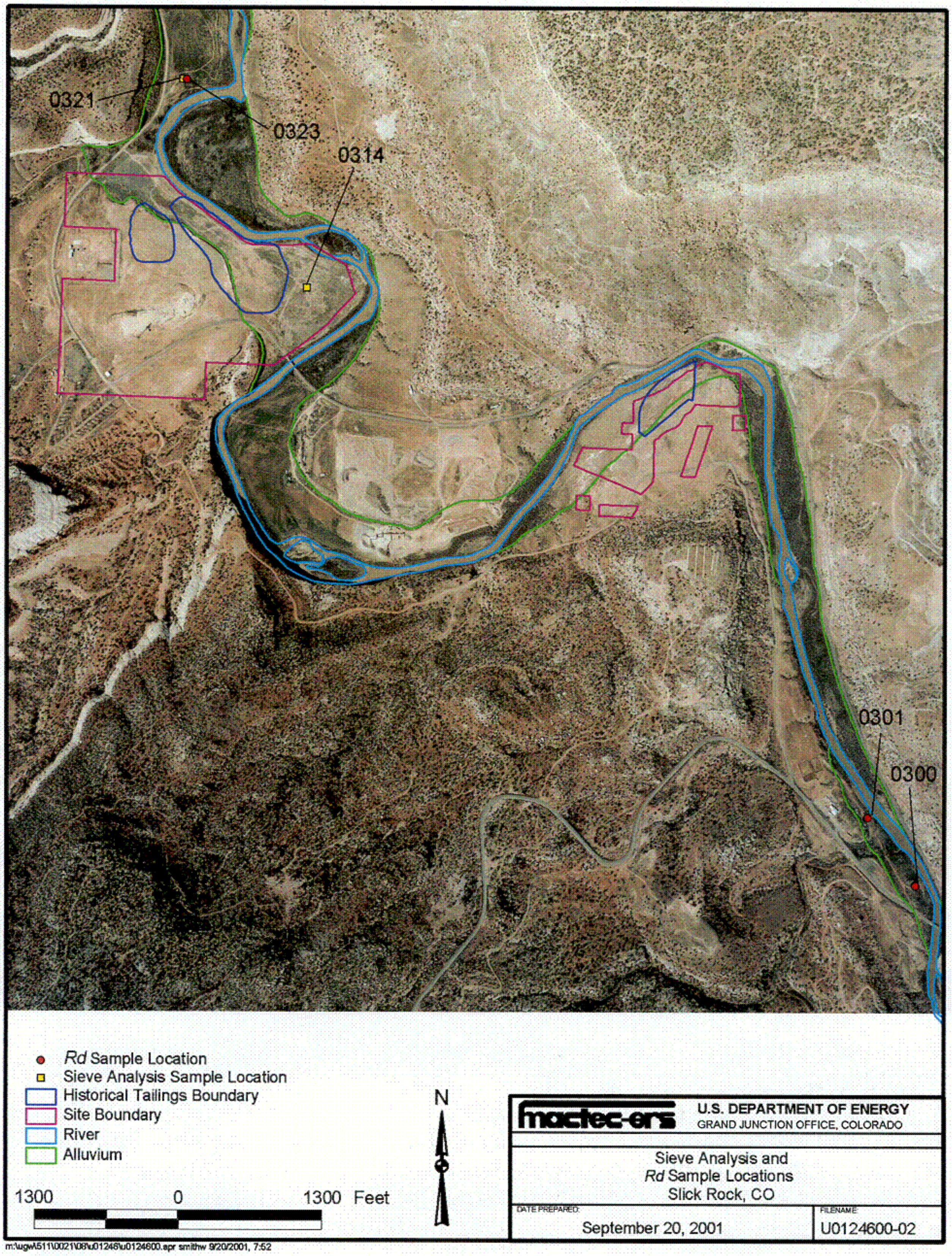


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Figure 4–7. R_d *Sample Location Map*

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The samples were prepared at the ESL. R_d data were obtained using ESL Procedure CB(Rd–1) (MACTEC–ERS 1999), which follows an American Society for Testing and Materials (ASTM) procedure for batch-type experiments (ASTM 1993).

A representative portion of each sample was air dried at room temperature. The samples were sieved to less than 10 mesh (< 2 mm). Past experience has demonstrated that the difference between air-dried and oven-dried weights is less than 2 percent and usually less than 1 percent. Therefore, no correction was made for the water content of the air-dried samples. Ground water samples from well 0301 were spiked with approximately 1,000 micrograms per liter (µg/L) of uranium or vanadium for use in the uranium and vanadium R_d determinations. Synthetic ground water (Table 4–7) was used for selenium and molybdenum instead of actual ground water to eliminate the need for another trip to the site. Controls were analyzed to confirm the stability of the spikes. Water from well 0301 was transported to the ESL where it was filtered before use. Table 4–8 presents field measurements for well 0301. The December 2000 measurements were made when the water was collected for the R_d determinations.

Table 4–7. Composition of Synthetic Ground Water Modeled After Well 0301 Water Sampled on February 28, 2001

Analyte	Value
Na	318 mg/L
Ca	140 mg/L
Mg	75 mg/L
NH_4	0.39 mg/L
SO_4	727 mg/L
Cl	140 mg/L
Mo	1.117 mg/L
Se	1.327 mg/L
pH	7.44
Alkalinity	280 mg/L $CaCO_3$

Table 4–8. Ground Water Quality for Well 0301

Sample Date	pH	Temperature (°C)	Eh (mV)	Turbidity (NTUs)
09/00	7.22	15.2	–75	212
12/00	7.10	11.7	–62	6.51

A six-point isotherm was determined for each uranium and vanadium sample. For selenium and molybdenum, distribution ratios were determined at two solids-to-water ratios instead of the six-point isotherms conducted for uranium and vanadium. The appropriate mass of soil sample (1, 2.5, 5, 10, 15, or 20 g for six-point isotherms or 2.5 and 15 g for the two-point isotherms) was placed in a 125-mL Nalgene bottle with 100 mL of the ground water. Samples were rotated end-over-end at 8 revolutions per minute for 24 hours, then centrifuged at 3,000 revolutions per minute, and vacuum filtered through a 0.45-micrometer (µm) filter. The samples were divided into two groups and processed on consecutive days. Two blanks were run each day. Samples were analyzed in the GJO Analytical Chemistry Laboratory. Procedure AS–5 Rev. 06 was used for vanadium and selenium and procedure AS–6 Rev. 06 was used for uranium and molybdenum. Both procedures employ ICP for an excitation source. The vanadium and selenium were quantified by AES and the uranium and molybdenum by MS.

4.4.3 Results and Discussion

The results of the R_d measurements on the < 2-mm fraction are presented in Table 4–9 through Table 4–12 and on Figure 4–8 and Figure 4–9. The colored lines on the figures show the position of theoretical isotherm R_d values of 1, 10, 20, and 30 mL/g for comparison. Isotherms behave ideally only if chemical conditions such as pH, alkalinity, conductivity, temperature, and oxidation-reduction potential (ORP) remain relatively constant in all experiments. Previous experiments conducted by ESL personnel have documented that these parameters often remain constant during the course of an R_d determination.

Table 4–9. Uranium Distribution Ratios Measured for Slick Rock (<2-mm fraction)

Location	Depth (ft)	Sample Weight (g)	Uranium (mg/L)	R_d[a] (mL/g)	Mean R_d (mL/g)
0300	12.5	1	0.924	4.33	1.64
		2.5	0.946	0.76	
		5	0.887	1.74	
		10	0.865	1.14	
		15	0.844	0.95	
		20	0.811	0.94	
0300	17	1	0.961	0.31	1.22
		2.5	0.905	2.61	
		5	0.895	1.54	
		10	0.866	1.13	
		15	0.847	0.92	
		20	0.830	0.81	
0301	13.5	1	0.951	1.37	1.08
		2.5	0.948	0.68	
		5	0.928	0.78	
		10	0.847	1.38	
		15	0.820	1.17	
		20	0.790	1.1	
0301	17.5	1	0.956	0.84	0.69
		2.5	0.953	0.46	
		5	0.934	0.64	
		10	0.910	0.59	
		15	0.868	0.74	
		20	0.822	0.86	
0323	14	1	0.950	1.47	0.76
		2.5	0.958	0.25	
		5	0.934	0.64	
		10	0.894	0.78	
		15	0.867	0.75	
		20	0.852	0.66	
0323	16.8	1	0.967	0[b]	0.3
		2.5	0.964	0	
		5	0.943	0.45	
		10	0.915	0.54	
		15	0.909	0.4	
		20	0.888	0.43	

[a] Each of the six individual R_d measurements is presented. The measurements correspond to sample weights of 1, 2.5, 5, 10, 15, and 20 grams.

[b] The measured concentration was within experimental error but slightly greater than the initial concentration. Because a negative R_d has no meaning, the result is represented as a zero.

Table 4–10. Vanadium Distribution Ratios Measured for Slick Rock (<2-mm fraction)

Location	Depth (ft)	Sample Weight (g)	Vanadium (mg/L)	R_d[a] (mL/g)	Mean R_d (mL/g)
0300	12.5	1	0.753	30.88	67.86
		2.5	0.525	35.09	
		5	0.293	47.27	
		10	0.110	79.59	
		15	0.064	95.83	
		20	0.039	118.5	
0300	17	1	0.778	26.67	59.58
		2.5	0.538	33.27	
		5	0.318	41.98	
		10	0.133	64.1	
		15	0.069	88.41	
		20	0.045	103.06	
0301	13.5	1	0.736	33.9	76.27
		2.5	0.475	42.99	
		5	0.256	56.99	
		10	0.098	90.36	
		15	0.059	103.38	
		20	0.036	130	
0301	17.5	1	0.729	35.19	72.8
		2.5	0.536	33.54	
		5	0.280	50.39	
		10	0.103	85.68	
		15	0.058	105.64	
		20	0.037	126.4	
0323	14	1	0.784	25.7	48.3
		2.5	0.564	29.89	
		5	0.352	35.99	
		10	0.158	52.37	
		15	0.089	66.74	
		20	0.058	79.09	
0323	16.8	1	0.880	11.99	23.06
		2.5	0.724	14.45	
		5	0.540	16.5	
		10	0.298	23.07	
		15	0.171	31.75	
		20	0.108	40.63	

[a] Each of the six individual R_d measurements is presented. The measurements correspond to sample weights of 1, 2.5, 5, 10, 15, and 20 grams.

Table 4–11. Selenium Distribution Ratios Measured for Slick Rock (<2-mm fraction)

Location	Depth (ft)	Sample Weight (g)	Selenium (mg/L)	R_d (mL/g)	Mean R_d (mL/g)
0300	12.5	2.5	1.01	12.5	15.2
		15	0.362	17.8	
	17	2.5	1.02	12.0	14.0
		15	0.39	16.0	
0301	13.5	2.5	0.939	13.7	16.4
		15	0.343	19.1	
	17.5	2.5	1.03	11.5	14.6
		15	0.363	17.7	
0323	14	2.5	1.06	10.1	12.0
		15	0.431	13.9	
	16.8	2.5	1.15	6.2	6.6
		15	0.648	7.0	

Table 4–12. Molybdenum Distribution Ratios Measured for Slick Rock (<2-mm fraction)

Location	Depth (ft)	Sample Weight (g)	Molybdenum (mg/L)	R_d (mL/g)	Mean R_d (mL/g)
0300	12.5	2.5	1.10	0.62	0.56
		15	1.04	0.49	
	17	2.5	1.09	0.99	0.71
		15	1.05	0.43	
0301	13.5	2.5	1.10	0.62	0.49
		15	1.06	0.36	
	17.5	2.5	1.10	0.62	0.49
		15	1.06	0.36	
0323	14	2.5	1.10	0.62	0.53
		15	1.05	0.43	
	16.8	2.5	1.11	0.25	0.15
		15	1.11	0.04	

As Figure 4–8 and Table 4–9 demonstrate, there is little difference in the uranium values, indicating that there is little tendency for the Slick Rock soils to remove uranium spiked into water from well 0301. The moderately alkaline pH (about 7.2) and moderate alkalinity (about 350 mg/L) were apparently sufficient for the uranium to form carbonate complexes. These complexes are large, neutral, or anionic species that sorb weakly to soil materials. The low R_d for uranium is also consistent with the well logs (Appendix B) and sieve analyses (Table 4–14) that demonstrate the aquifer material tested is low in clay. Thus, much of the < 2-mm material used for the R_d determinations was sand grains that have relatively little surface area and little propensity for removal of dissolved species. Molybdenum is similar to uranium, having a very low R_d, indicating little tendency for sorption in the aquifer matrix. Vanadium and selenium, in contrast to uranium and molybdenum, form less soluble compounds and are more easily taken up by soil materials (Table 4–10 and Table 4–11). The uranium R_d values (Table 4–13) are similar to those measured at the Shiprock, New Rifle, Old Rifle, and Grand Junction UMTRA Project sites.

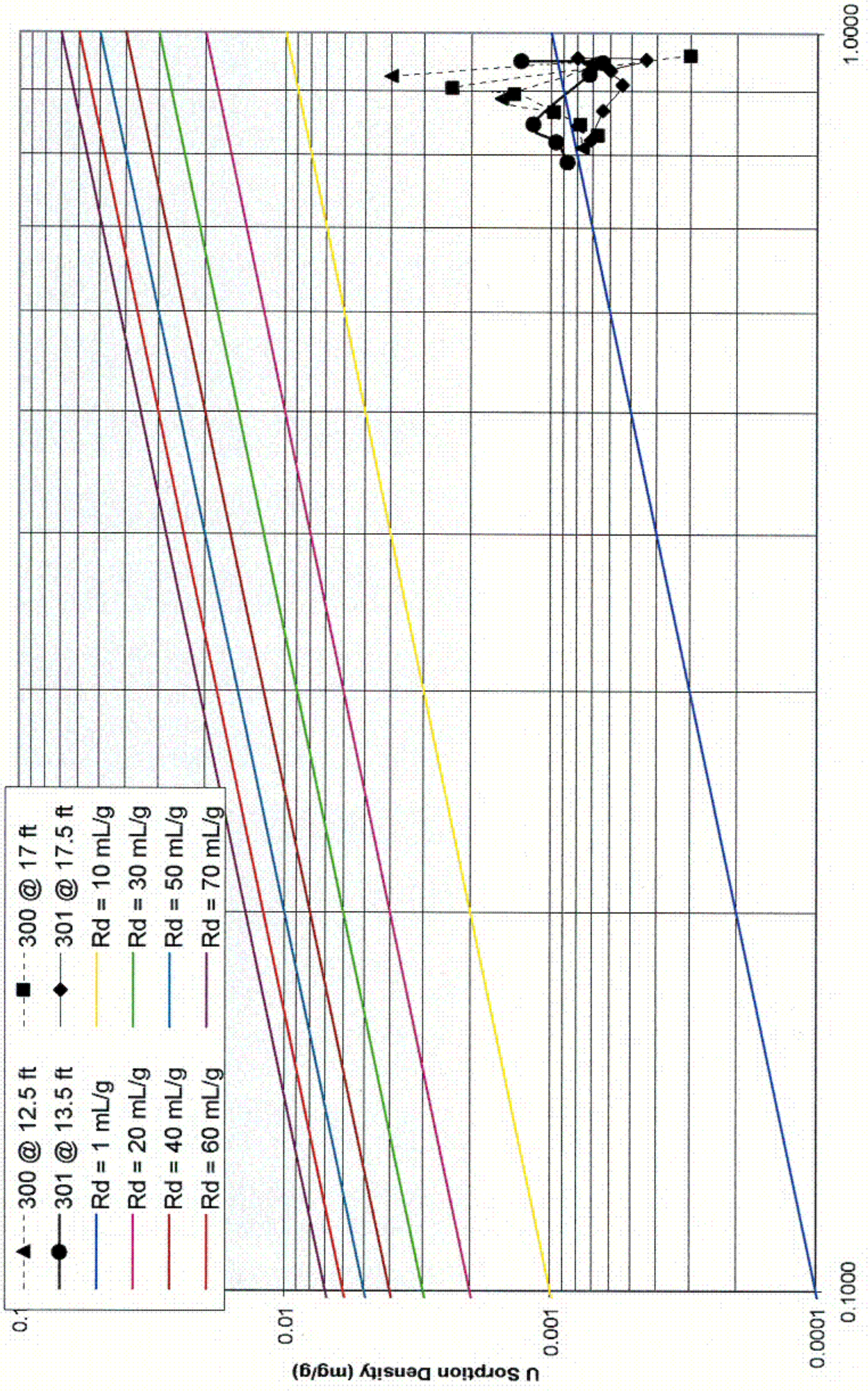

Figure 4–8. Measured Isotherms for the Slick Rock Samples Compared With Theoretical Isotherms—Uranium

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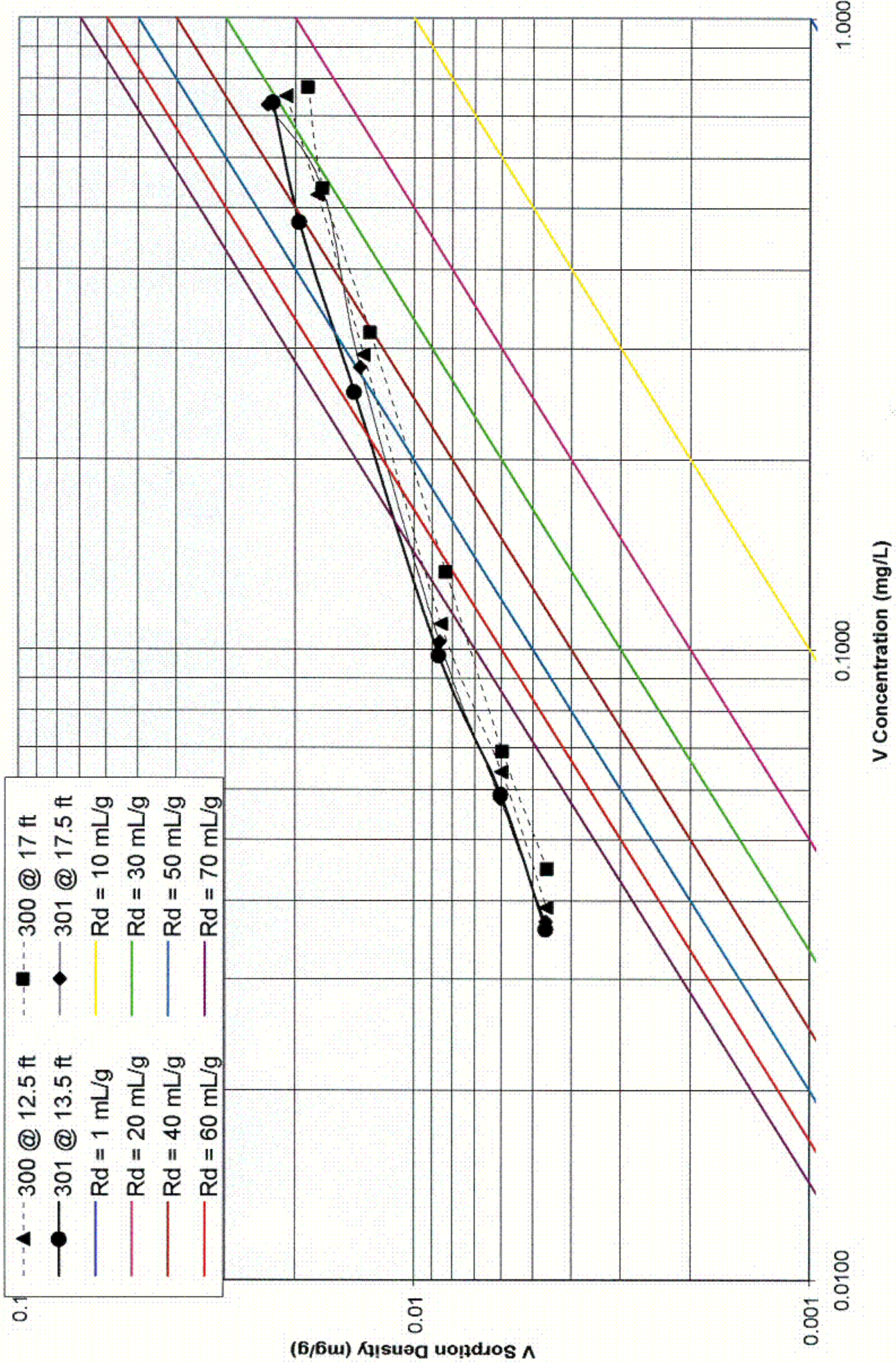

Figure 4–9. Measured Isotherms for the Slick Rock Samples Compared With Theoretical Isotherms—Vanadium

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Table 4–13. Mean Distribution Ratios for Uranium From Slick Rock Compared With Selected Other UMTRA Project Sites

Site	Location or Formation[a]	R_d (mL/g)[b]
Slick Rock–well 0300–12.5 ft	Qal	1.64
Slick Rock–well 0300–17 ft	Qal	1.22
Slick Rock–well 0301–13.5 ft	Qal	1.08
Slick Rock–well 0301–17.5 ft	Qal	0.69
Slick Rock–well 0323–14 ft	Qal	0.76
Slick Rock–well 0323–16.8 ft	Qal	0.30
Shiprock	Weathered Km	1.59[c]
Shiprock	Unweathered Km	2.13[c]
Shiprock	Qal (floodplain)	0.54[c]
New Rifle	Qal	0.7[d]
Old Rifle	Qal	0.5[e]
Old Rifle	Wasatch claystone	1.3[e]
Grand Junction	Qal	2.15[f]

[a] Qal = Quaternary alluvium; Km = Mancos Shale Formation.
[b] All samples were sieved to less than 2 mm.
[c] DOE (1999c)
[d] DOE (1999d)
[e] DOE (1999e)
[f] DOE (1999f)

There is a small difference in R_d among the three Slick Rock locations. Those locations south (0300 and 0301) and upgradient of the uranium-processing areas have similar results. Location 0323, which is downgradient of the site, has somewhat lower values, although all are within a factor of two or three. In terms of precision for this type of measurement, the values can be considered to be in relatively good agreement.

The samples used for the R_d measurements were from the < 2-mm fraction. The smaller grain-size fraction is more convenient because smaller-sized equipment can be used for the experiments. However, the R_d values for the < 2-mm fraction are usually biased toward high values compared with the bulk sediment in the aquifer. More sorption typically occurs in finer-grained portions of soils because more highly sorptive minerals are present and the surface area is greater.

The R_d value for the aquifer can be estimated from the < 2-mm fraction by normalizing it to the grain-size distribution in the aquifer and assuming that the larger fractions are nonadsorptive (DOE 2001b). Grain-size distributions were performed on two samples from the alluvial aquifer. The samples used for grain-size analyses were taken during drilling at locations 0314 and 0321 (Figure 4–7). Location 0314 is on the UC site, and 0321 is hydraulically downgradient of the UC site. The relevant grain-size results are presented in Table 4–14 and demonstrate that the < 2-mm fraction constitutes 51 and 55 percent of the two samples. The sieve analyses also demonstrated that the mass of material passing a 200-mesh sieve (less than 0.074 mm), or the silt/clay fraction, was less than 1 percent.

Table 4–14. Grain-Size Distribution of Slick Rock Aquifer Solids

Sample Location	Size Fraction	Weight (g)	Weight Fraction
Well 0314 at 15 to 18 ft	≥ 2 mm	201.9	0.49
	≤ 2 mm	212.9	0.51
Well 0321 at 13 to 15 ft	≥ 2 mm	205	0.45
	≤ 2 mm	251.7	0.55

The chemical and physical properties of alluvial aquifers may vary substantially both vertically and horizontally. The distribution of the properties is rarely known because of the high cost of completely characterizing the aquifer. For this reason, it is common to apply parameters such as K_d uniformly for the entire aquifer to make estimates of contaminant transport. Although this approach is not likely to predict accurately all details of contaminant migration, it provides a useful estimate for the trends in the aquifer.

The uranium, molybdenum, and selenium R_d values that are most representative for Slick Rock are averages of the adjusted values (Table 4–15). Circumstances are more complex for vanadium. As shown in Figure 4–9, the isotherms are linear but the curves are not parallel to the theoretical plots, indicating that the simple linear R_d described in Section 4.4.1 does not apply. However, the maximum vanadium concentrations identified in samples from the Slick Rock aquifer are approximately 0.5 mg/L. Data in Figure 4–9 and the vanadium concentration of 0.5 mg/L indicate that the appropriate R_d value is 30 to 40 mL/g and that the value increases as concentrations decrease. Hence, after adjustment for grain size, the appropriate R_d value for vanadium at Slick Rock, based on the measured value of 40 mL/g, is 21 mL/g (Table 4–15).

Table 4–15. Mean Distribution Ratios (R_d) for Selected COPCs From Slick Rock Adjusted for Grain Size

Sample Location	Depth (ft)	Uranium Mean R_d (mL/g)	Vanadium Mean R_d (mL/g)	Molybdenum Mean R_d (mL/g)	Selenium Mean R_d (mL/g)
0300	12.5	0.87	67.86	0.30	8.1
0300	17	0.65	59.59	0.38	7.4
0301	13.5	0.57	76.27	0.26	8.7
0301	17.5	0.37	72.8	0.26	7.7
0323	14	0.4	48.3	0.28	6.4
0323	16.8	0.16	23.06	0.08	3.5
Representative Value		0.5 mL/g[a]	21 mL/g[b]	0.26[a]	7.0[a]

[a] The representative uranium, molybdenum, and selenium R_d s are averages of the values listed above.
[b] The representative vanadium R_d *is* not an average but was selected based on the maximum concentrations observed in the Slick Rock aquifer. See text for explanation.

4.5 Dolores River Elevations

To define the relationship between the river and the alluvial aquifer, river stage (elevation) was determined by using data from the U.S. Geological Survey (USGS) gaging station adjacent to the UC site. The discharge curve was obtained from USGS to convert discharge back to river elevation. River elevations were compared to ground water elevations in the alluvial aquifer to determine interaction between the river and the alluvial aquifer; these data were used for input into the ground water flow model. In addition, selected locations along the Dolores River were surveyed at a point where the depth to the water surface could be measured. This provided additional river elevation data along the length of the Dolores River. River elevation measurement locations are shown in Figure 4–10 and Figure 4–11. River elevation data are

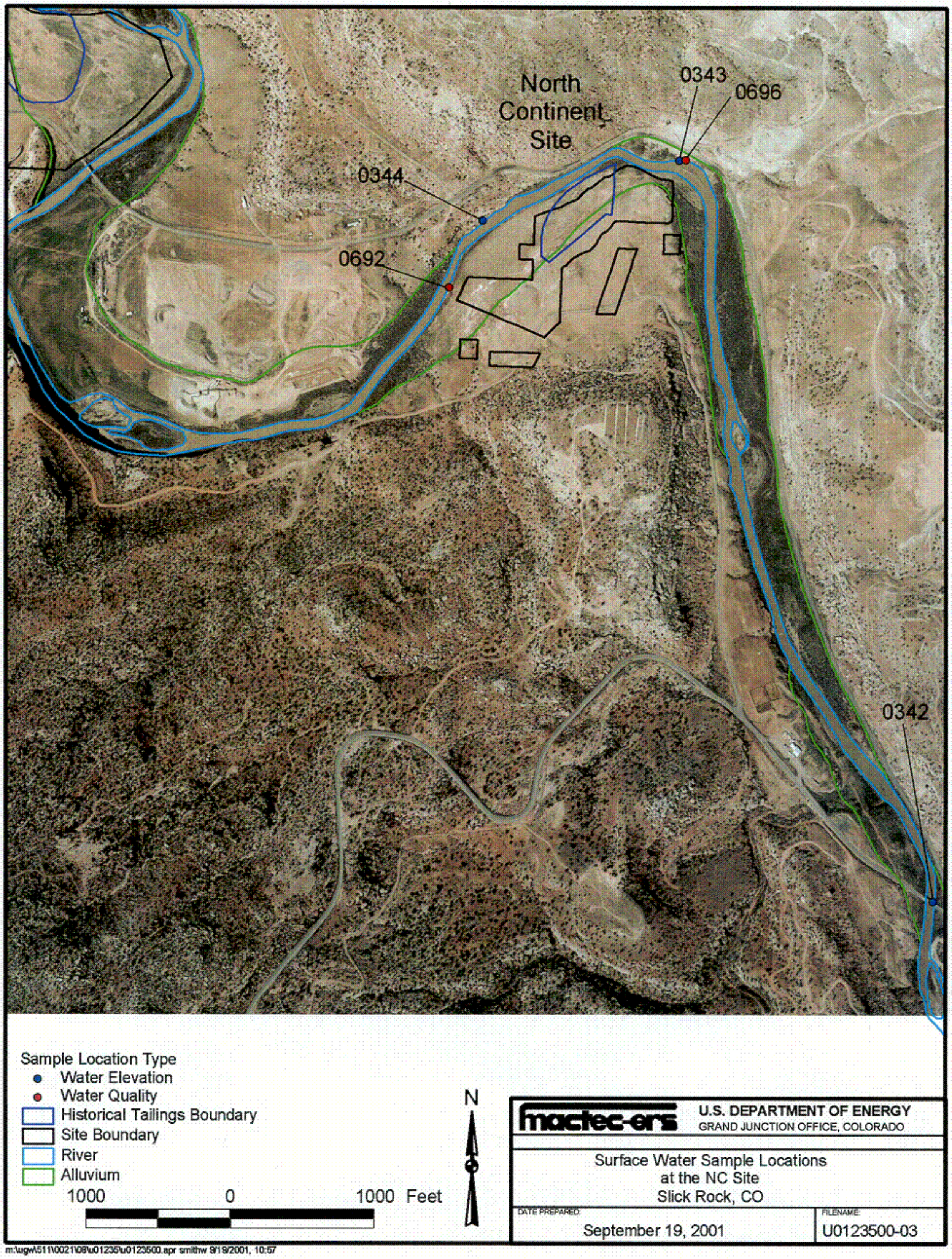

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Figure 4–10. Surface Water Sampling Locations at the NC Site

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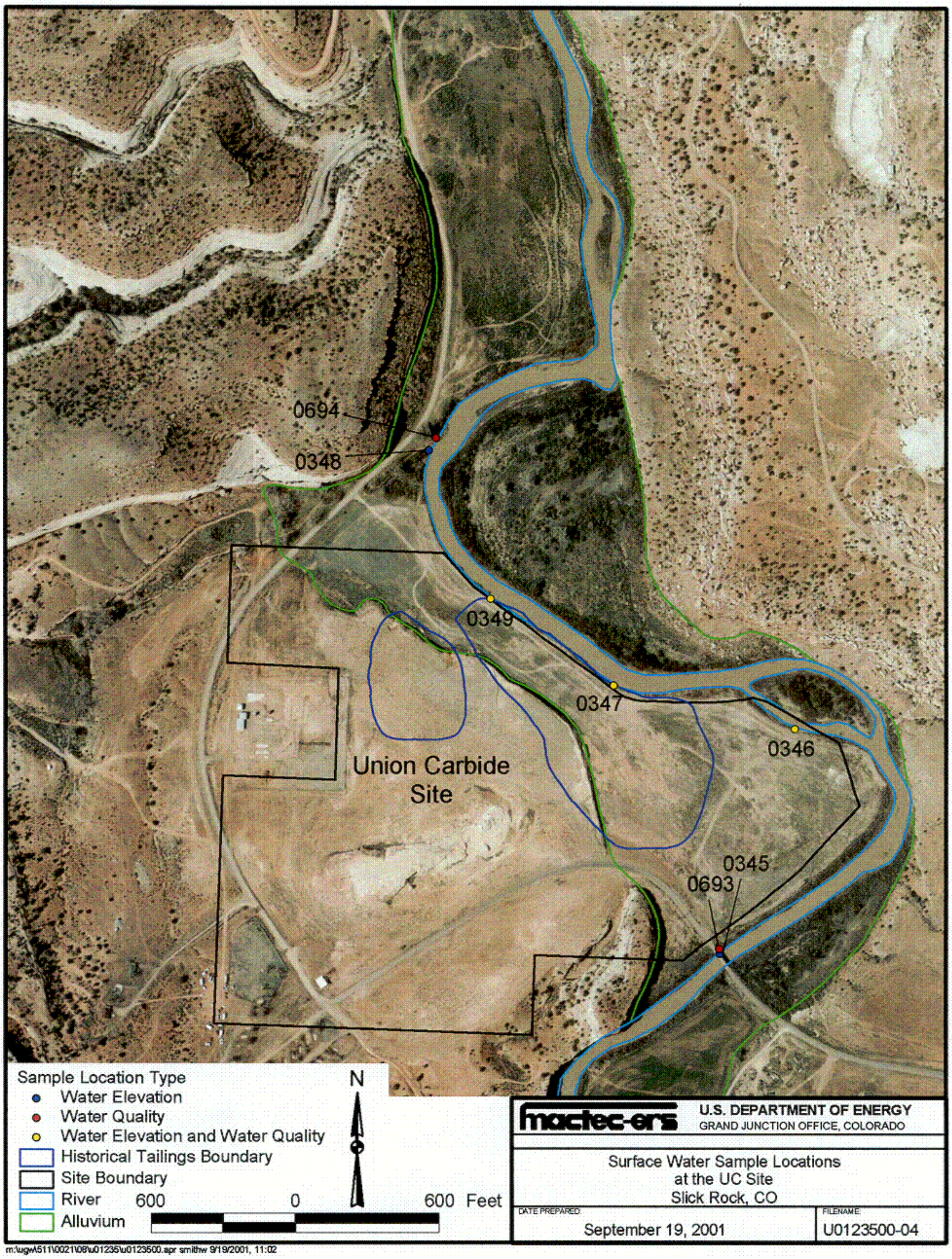

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Figure 4–11. Surface Water Sampling Locations at the UC Site

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included as Tables C–2, C–3, and C–4 (CD-ROM format) in Appendix C. The surface water and ground water interaction is described in Section 5.1.

4.6 Water Quality Sampling

Quarterly water quality sampling has been conducted since February 1999. Wells installed in August/September 2000 have been sampled four times. All sampling and water level measurements were conducted according to the standard operating procedures in the *Sampling and Analysis Plan for the UMTRA Ground Water Project* (DOE 1999g). Validated results were entered in the SEE-Pro database at DOE–GJO, and recent results are provided in Appendix D. Complete water quality data are on compact disks (CDs) provided in Appendices E and F. A discussion of the results of water quality sampling is included in Section 5.2.

4.7 Geologic Investigation

Historical documentation contains conflicting information regarding the geology beneath the NC site; therefore, a borehole was drilled and sampled at location 0275 (Figure 4–2) to identify the subsurface geology at the NC site. A rotosonic drill rig was used to collect continuous core. The core from location 0275 consisted of a sequence of sandstones and mudstones down to 120 ft below ground surface, which is consistent with the Jurassic Summerville Formation. At 120 ft, the white/buff sandstone of the Jurassic Entrada Sandstone appeared. The borehole log and lithologic description for borehole 0275 is included in Appendix B.

On the basis of the geology, bedrock wells were not installed at the NC site. A study of ground water resources in the Grand Junction area entitled *Geology and Artesian Water Supply, Grand Junction Area, Colorado* (Lohman 1965) provides information that can be applied to the same formations present in the Slick Rock area. The study concluded that the relatively impermeable Summerville and Morrison Formations effectively keep the artesian water in the Entrada and underlying aquifers under considerable pressure and probably permit only very slow upward leakage. Because these formations have an abundance of fine-grained, low-permeability units and are considered regional aquitards, voluminous downward migration of contaminated alluvial ground water is unlikely. In addition, if a water-yielding zone could be found in the Salt Wash Member of the Morrison Formation beneath the NC site, and a well was installed, determination of effects to water quality could be complicated by naturally occurring uranium in the member. Because of the bedrock conditions that exist at the NC site, the uppermost aquifer is considered to be the alluvial aquifer.

4.8 Surveying

Surveying was conducted in September 2000 to obtain horizontal and vertical control of site features to build accurate site maps, develop ground water models and geologic cross sections, and determine ground water flow direction. All new and existing monitor wells were surveyed for horizontal coordinates and elevation. Horizontal coordinates were surveyed to the nearest 0.1 ft, and the elevation was surveyed to the nearest 0.01 ft. Several benchmarks and known features in the area were also surveyed to correct historical maps to actual conditions.

An aerial photographic survey of the Slick Rock area was conducted in April 2000 to develop a higher quality base map of the Slick Rock site.

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